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A wetland framework for impact assessment at statutory sites in England and Wales

Integrated Catchment science programme
Science report: SC030232

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This report is the result of research commissioned and funded by the Environment Agency's Science Programme.

Published by:
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 978-1-84911-003-7

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Dissemination Status:
Publicly available / Released to all regions

Keywords:
Wetland, ecohydrology, ecology, hydrology, fen, bog, vegetation, WETMECs, hydrogeology

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Science Project Number:
SC030232/SR1

Product Code:
SCHO0309BPOE-E-P

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Steve Killeen

Steve Killeen

Head of Science

Executive Summary

The *Wetland Framework* project was set up as a partnership between the Wetland Research Group at the University of Sheffield, the Environment Agency, English Nature (now Natural England) and Countryside Council for Wales. It was initiated in response to the Environment Agency's need to interpret international conservation objectives whilst carrying out a review of consents for the EC Habitats Directive. This work required an understanding of hydrological and vegetation processes within wetlands and how these relate to the response and tolerance of different wetland types to external influences, such as changes in groundwater pumping and water quality. The project aimed to complement work by Natural England (then English Nature) and the Countryside Council for Wales in establishing detailed conservation objectives for designated sites by: (i) identifying environmental features critical for their maintenance or enhancement; (ii) distinguishing these from less critical features; and (iii) providing a basis for assessing whether these objectives could be sustained or enhanced in specific wetland sites. The work originally focussed on the Anglian Region, but was expanded to include other sites, mainly in the South, South West, West Midlands, Cumbria and Wales.

The essence of this project was to combine and review ecological and hydrogeological data sources for about 200 wetland sites (including over 1,500 stand samples). At the core of the Framework was the identification of the main distinctive wetland habitats. A bottom-up approach, based on an analysis of field data from wetlands, was used to detect the recurrence of sets of conditions and species and to use these as the foundation for a classification. The main procedures used for data analysis were multivariate classification and cluster analysis, in particular canonical correspondence analysis (CCA) and Ward's method.

An ecohydrological framework was developed in which habitats were defined according to a combination of three base-richness (pH) categories, three fertility categories and twenty wetland water supply mechanisms (WETMECs), plus sub-types. WETMECs were one of the most important outcomes of the study, in essence offering a summary of how wetlands work hydrologically. Certain WETMECs are associated with specific hydrogeological and landscape contexts. Analysis of these relationships showed why some habitats and vegetation types are intrinsically rare and confined to specific locations. A key finding of the study was the importance of top-layer conditions (the wetland substratum itself) in regulating the water environment and character of the habitat.

The different sets of Framework units developed provide both a vocabulary and basis for descriptions of wetlands, help to develop a holistic understanding of the requirements of different vegetation types, and provide a basis for assessing the likely outcome of conservation activities. In addition, framework categories help to establish appropriate conservation objectives for individual sites. Developing conservation objectives that are in keeping with the ecohydrological character of particular WETMECs mean that conservation objectives work with the ecohydrological 'grain' rather than against it.

This report has been written for hydrologists and ecologists, to boost cooperation and integration between the two disciplines. The report is concerned primarily with European designated conservation sites, together with other statutory (and non-statutory) sites. The approach used can be extended to cover additional international designations.

Part 1 introduces aspects of the ecohydrology and classification of wetlands, outlining the report's main concepts. It describes the complex relationships between wetland vegetation and environmental conditions, hydrodynamics, succession and development.

Part 2 outlines the main approaches to the project and data analysis procedures, and describes a typology which forms the core of the Wetland Framework. This typology relates primarily to types *within* wetlands rather than types *of* wetlands. Two main sets of units are used: 'wetland water supply mechanisms' (WETMECs) and 'ecological types' (permutations of water base-richness (pH) and soil fertility categories). The twenty WETMECS identified are:

1. Domed Ombrogenous Surfaces ('raised bog' sensu stricto);
2. Buoyant Ombrogenous Surfaces (quag bogs);
3. Buoyant, Weakly Minerotrophic Surfaces ('transition bogs');
4. Drained Ombrotrophic Surfaces (in bogs and fens);
5. Summer-Dry Floodplains;
6. Surface Water Percolation Floodplains;
7. Groundwater Floodplains;
8. Groundwater-Fed Bottoms with Aquitard;
9. Groundwater-Fed Bottoms;
10. Permanent Seepage Slopes;
11. Intermittent and Part-Drained Seepages;
12. Fluctuating Seepage Basins;
13. Seepage Percolation Basins;
14. Seepage Percolation Troughs;
15. Seepage Flow Tracks;
16. Groundwater-Flushed Bottoms;
17. Groundwater-Flushed Slopes;
18. Percolation Troughs;
19. Flow Tracks;
20. Percolation Basins.

The WETMECs, in combination with the ecological types, effectively identify the main wetland habitats that occur in lowland herbaceous wetlands in England and Wales.

Part 3 examines the relationships between the occurrence and composition of selected wetland plant communities in relation to hydrological, ecological and management variables. Particular reference is made to water sources and conditions and to the wetland types (Part 2) in which communities occur. Communities selected include those that are most critically water-dependent (NVC types M4, M5, M10, M13, M14, M18, M21, M22, M24, M29, S1, S2, S24, S27; NVC community M9 is also considered, but as three new segregates (M9-1, M9-2 and M9-3: the latter is effectively unclassified by NVC (*Peucedano-Phragmitetum caricetosum*)). These communities include those considered particularly important under EC Habitats Directive. The main environmental conditions under which they occur are described, with comments on their perceived vulnerability to dehydration, eutrophication and management practices.

A glossary of terms is provided in **Appendix 1**, while **Appendix 2** lists data sources, details of the main data types and categories used, and analytical methods and results. **Appendix 3** (ecohydrological site accounts) is available on a separate CD, briefly describing each site that was included in the data analysis with reference to its hydrogeological context, apparent main water sources and supply mechanisms, and vegetation types. WETMECs sampled at each site are also shown. Commissioned hydrogeological site accounts are given in **Appendix 4** (available on CD).

A supplement to the main report provides a synopsis of details and diagrams for each WETMEC.

Crynodeb Gweithredol

Sefydlwyd y prosiect ‘Fframwaith Gwlyptiroedd’ fel prosiect mewn partneriaeth rhwng y Grŵp Ymchwil i Wlyptiroedd ym Mhrifysgol Sheffield, Asiantaeth yr Amgylchedd, English Nature (Natural England erbyn hyn) a Chyngor Cefn Gwlad Cymru. Rhoddwyd ef ar waith i ddechrau fel ymateb i angen yr Asiantaeth i ddehongli amcanion cadwraeth rhyngwladol tra’n cynnal arolwg o ganiatadau ar gyfer Cyfarwyddeb Cynefinoedd y GE. Er mwyn hwyluso’r arolwg hwn, sylweddolwyd bod angen gwaith er mwyn ceisio cyfuno dealltwriaeth o brosesau hydrolegol a llystyfiant o fewn gwlyptiroedd a chysylltu’r rhain i ymateb, a gallu, mathau gwahanol o wlyptir i oddef dylanwadau allanol, e.e. newidiadau o safbwynt pwmpio dŵr daear ac ansawdd dŵr. Ystyriwyd y prosiect fel un a fyddai’n cyfannu gwaith gan English Nature a Chyngor Cefn Gwlad Cymru o ran nod-adnabod amcanion cadwraeth manwl ar gyfer safleoedd wedi’u dynodi, trwy (i) nodi nodweddion amgylcheddol sy’n hanfodol ar gyfer eu cynnal (neu eu gwella), (ii) gwahaniaethu rhwng y rhain a nodweddion nad ydynt mor hollbwysig a (iii) darparu sylfaen ar gyfer asesu’r potensial i’r amcanion hyn gael eu cynnal neu eu gwella mewn safleoedd gwlyptir penodedig. Canolbwyntiodd y gwaith yn wreiddiol ar Ranbarth Anglia, ond ehangwyd ef i gynnwys safleoedd eraill, yn bennaf yn y de, y de orllewin, Gorllewin y Canolbarth, Cumbria a Chymru.

Hanfod y prosiect fu cyfuno ac adolygu ffynonellau data ecolegol a hydro-daearegol sy’n bodoli eisoes o oddeutu 200 o safleoedd gwlyptir (gan gynnwys dros 1500 o samplau sefyllfan). Craidd y Fframwaith yw nodi’r prif ‘gynefinoedd’ gwlyptir gwahaniaethol. Mae hyn wedi defnyddio dull ‘o’r gwaelod’ o fynd ati, wedi’i seilio ar ddadansoddiad o ddata maes o samplau o fewn gwlyptiroedd, er mwyn darganfod pa mor fynych y mae setiau o gyflyrau a rhywogaethau yn ymddangos dro ar ôl tro ac er mwyn defnyddio’r cyd-drawiadau hyn fel sylfaen ar gyfer dosbarthu. Y prif weithdrefnau a ddefnyddiwyd ar gyfer dehongli data oedd dosbarthu amlamrywedd a dadansoddi clwstwr, yn arbennig Dadansoddiad Cyfatebiaeth Ganonaidd (CCA) a Dull Ward. Mae’r setiau gwahanol o unedau Fframwaith yn darparu geirfa a hefyd sail disgrifio ar gyfer gwlyptiroedd; maent yn helpu i ddatblygu dealltwriaeth holistaidd o ofynion mathau penodol o lystyfiant; ac maent yn darparu sylfaen ar gyfer asesu canlyniad tebygol gweithgareddau rheoli cadwraeth penodol. Ar ben hyn, mae’r Categorïau Fframwaith yn helpu i nodi amcanion cadwraeth addas ar gyfer safleoedd unigol, yn arbennig, amcanion sy’n cyd fynd â chymeriad ecohydrolegol WETMECs penodol, fel bod amcanion cadwraeth yn gweithio gyda’r ‘graen’ ecohydrolegol yn lle mynd yn groes iddo.

Yn arbennig, cafodd fframwaith ecohydrolegol ei ddatblygu lle caiff cynefinoedd eu diffinio trwy gyfeirio at gyfuniad o dri categori cyfoeth-sylfaen (pH), tri categori ffrwythlondeb, ac ugain o Fathau o Fecanweithiau ar gyfer Cyflenwi Dŵr i Wlyptiroedd (WETMECs), plws is-fathau. (Mae’r rhain yn un o ganlyniadau pwysicaf yr astudiaeth; yn eu hanfod, maent yn grynodeb o sut bydd gwlyptiroedd yn gweithio, o safbwynt hydrolegol). Mae rhai WETMECs yn gysylltiedig â chyd-destunau hydro-daearegol a thirwedd penodol. Dangosodd dadansoddiad o’r cydberthnasau hyn pam fod rhai mathau o ‘gynefinoedd’ a mathau o lystyfiant yn brin yn gynhenid ac wedi’u cyfyngu i fannau penodol, ac un o ganfyddiadau allweddol yr astudiaeth yw nod-adnabyddiaeth glir o bwysigrwydd ‘cyflyrau haen uchaf’ (h.y. is haen y gwlyptir ei hun) yn y gwaith o reoleiddio’r amgylchedd dŵr a chymeriad y cynefin mewn amgylchiadau penodol.

Ysgrifennwyd yr adroddiad hwn gyda’r bwriad iddo fod yn hygyrch i, ac yn hawdd ei ddeall gan, hydrolegwyr ac ecolegwyr, fel cyfraniad tuag at fwy o gydweithio ac integreiddio rhwng y ddwy ddisgyblaeth. Mae’n ymwneud yn bennaf â safleoedd cadwraeth dynodedig Ewropeaidd, ynghyd â safleoedd statudol (a rhai sy’n anstatudol)

cysylltiedig eraill; gellir ehangu'r dull o fynd ati a ddefnyddiwyd er mwyn cymryd dynodiadau rhyngwladol ychwanegol sydd ar y gweill i ystyriaeth.

Mae Rhan 1 yn darparu deunydd rhagarweiniol ynghylch agweddau gwahanol ar ecohydroleg a dosbarthiad gwlyptiroedd, gyda braslun a thrafodaeth o'r prif gysyniadau y cyfeirir atynt yn yr Adroddiad. Mae'n cynnwys adrannau sy'n disgrifio'r cydberthnasau cymhleth rhwng llystyfiant gwlyptir ac chyflyrau amgylcheddol, hydrodynameg, dilyniant a datblygiad.

Mae Rhan 2 yn cynnig braslun o'r prif ddulliau a ddefnyddiwyd ar gyfer y prosiect a'r gweithdrefnau dadansoddi data, ac yn nodi a disgrifio teipoleg sy'n ffurfio craidd y Fframwaith Gwlyptiroedd. Mae'r 'mathau' o wlyptir a adnabyddir gan mwyaf yn fathau o fewn gwlyptiroedd yn hytrach na'n fathau o wlyptiroedd. Defnyddiwyd dau brif fath o unedau: 'Mecanweithiau ar gyfer Cyflenwi Dŵr i Wlyptiroedd' (WETMECs), a 'Mathau Ecolegol' (trynewidiadau o gyfoeth-sail dŵr (pH) a chategorïau ffrwythlondeb pridd). Mae'r prif ffocws ar yr ugain o WETMECS a nod-adnabuwyd: 1, Wynebau Cromennog Wedi'u Ffurfio gan Ddŵr Glaw ('corsydd dyrchafedig' yng ngwir ystyr y geiriau); 2, Wynebau Nofiadwy Wedi'u Ffurfio gan Ddŵr Glaw ('cors siglennog'); 3, Wynebau Nofiadwy Sy'n Defnyddio Ychydig o Ddŵr o Nentydd neu Darddiannau ('Corsydd Rhyngbarthol'); 4, Wynebau A Fwydir gan Ddŵr Glaw Wedi'u Draenio (mewn Corsydd a Ffeniau); 5, Gorlifdiroedd sy'n 'Sych' yn yr Haf; 6, Gorlifdiroedd Trylifiad Dŵr Wyneb; 7, Gorlifdiroedd Dŵr Daear; 8, Gwaelodion a Fwydir gan Ddŵr Daear gyda Haen Hydreiddedd Isel; 9, Gwaelodion a Fwydir gan Ddŵr Daear; 10, Llethrau Tryddiferiad Di baid; 11, Tryddiferiadau Cyfnodol ac Wedi'u Draenio'n Rhannol; 12, Basnau Tryddiferiad Cyfnewidiol; 13, Basnau Tryddiferiad sy'n Trylifo;14, Pantiau Tryddiferiad sy'n Trylifo; 15, Traciau Llif Tryddiferiad; 16, Gwaelodion a Lifolchir gan Ddŵr Daear; 17, Llethrau a Lifolchir gan Ddŵr Daear; 18, Pantiau Trylifiad; 19, Traciau Llif; 20, Basnau Trylifiad. Mae'r WETMECs ar y cyd â'r Mathau Ecolegol yn effeithiol o ran nodi'r prif 'gynefinoedd' gwlyptir a geir mewn gwlyptiroedd llysieuol ar dir isel yng Nghymru a Lloegr.

Caiff y cydberthnasau rhwng mynychder a chyfansoddiad cymunedau o blanhigion gwlyptir dethol mewn perthynas â newidion hydrolegol, ecolegol a rheolaeth eu harchwilio yn Rhan 3. Cyfeirir yn arbennig at ffynonellau a chyflyrau dŵr ac i'r Mathau o Wlyptir (Rhan 2) lle ceir y cymunedau. Mae cymunedau a ddetholwyd yn cynnwys mathau sy'n dibynnu ar ddŵr i'r graddau mwyaf critigol (mathau NVC M4, M5, M10, M13, M14, M18, M21, M22, M24, M29, S1, S2, S24, S27; caiff cymuned NVC M9 ei ystyried yn ogystal ond ar ffurf tri ymwahaniad newydd (M9-1, M9-2 a M9-3: mae'r olaf yn cwmpasu math sydd mewn gwirionedd heb ei ddosbarthu gan NVC (Peucedano-Phragmitetum caricetosum)). Mae'r cymunedau hyn yn cynnwys y rheini a gânt eu hystyried yn rhai arbennig o bwysig o dan Gyfarwyddeb Cynefinoedd y GE. Disgrifir y prif sefyllfaoedd a'r cyflyrau amgylcheddol lle'u ceir, a darparir sylwadau ynghylch eu bregusrwydd canfyddedig yn wyneb dysychiad, ewtroffeiddio ac arferion rheoli.

Darparir Rhestr Termau yn Atodiad 1. Mae Atodiad 2 yn darparu datganiad o'r ffynonellau data, manylion y prif fathau o ddata a chategorïau a ddefnyddiwyd, a'r prif ddulliau a chanlyniadau dadansoddol. Caiff Atodiad 3 (Adroddiadau safle hydro-ecolegol) ei ddarparu fel cyfrol ar wahân, gan roi disgrifiad cryno o bob safle a gafodd ei gynnwys yn y dadansoddiad data, a chan gyfeirio'n arbennig at ei gyd-destun hydro-daearegol, prif ffynonellau dŵr a mecanweithiau cyflenwi ymddangosiadol, a mathau o lystyfiant. Caiff y WETMEC's a samplwyd ym mhob safle eu dangos yn ogystal. Darparir yr adroddiadau safle hydro-daearegol a gomisiynwyd yn Atodiad 4 (ar gael ar ffurf electronig yn unig). Mae map o bob safle ar gael ar ffurf electronig yn ogystal.

Mae atodlen i'r prif adroddiad yn darparu manylion mewn crynodeb a diagramau ar gyfer pob WETMEC.

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Acknowledgements

The project was guided by a Steering Group with representatives from the Environment Agency (Kathryn Tanner, Mark Whiteman, Paul José), Natural England (Roger Meade, Hans Schutten) and Countryside Council for Wales (Peter Jones, Rhian Thomas).

We would particularly like to thank the sub-contractors for this project, Andreas Charalambous and Sarah Horrocks (*Hydrogeological Sciences International*), Ron Allen (*Environmental Project Consulting Group*) and Jill Labadz (*Nottingham Trent University*), for providing the invaluable hydrogeological site accounts presented in Appendix 4, and for fielding numerous questions about the sites.

Andrew Baird (University of Sheffield/QMC, London) and Kevin Gilman (Llangurig) provided many valued discussions and information.

We thank all of them for their help, and their forbearance in answering naïve questions.

We also thank landowners for providing access to sites and to site managers, and other individuals and organisations who – sometimes unwittingly – provided many useful insights into, and information about, the ecohydrological 'workings' of particular sites. We particularly thank the Environment Agency, Natural England and Countryside Council for Wales for permitting free use of their site data.

Finally, especial thanks are due to Prof. David Bellamy who, in his seminal studies on mires in the 1960s, recognised the importance of contrasting water supply and flow to their characteristics and vegetation. And who, exactly forty years ago, first introduced one of the present authors to British mires and their ecology, and stimulated his curiosity to find out how they 'work', resulting in a series of subsequent studies that have culminated in the present publication.

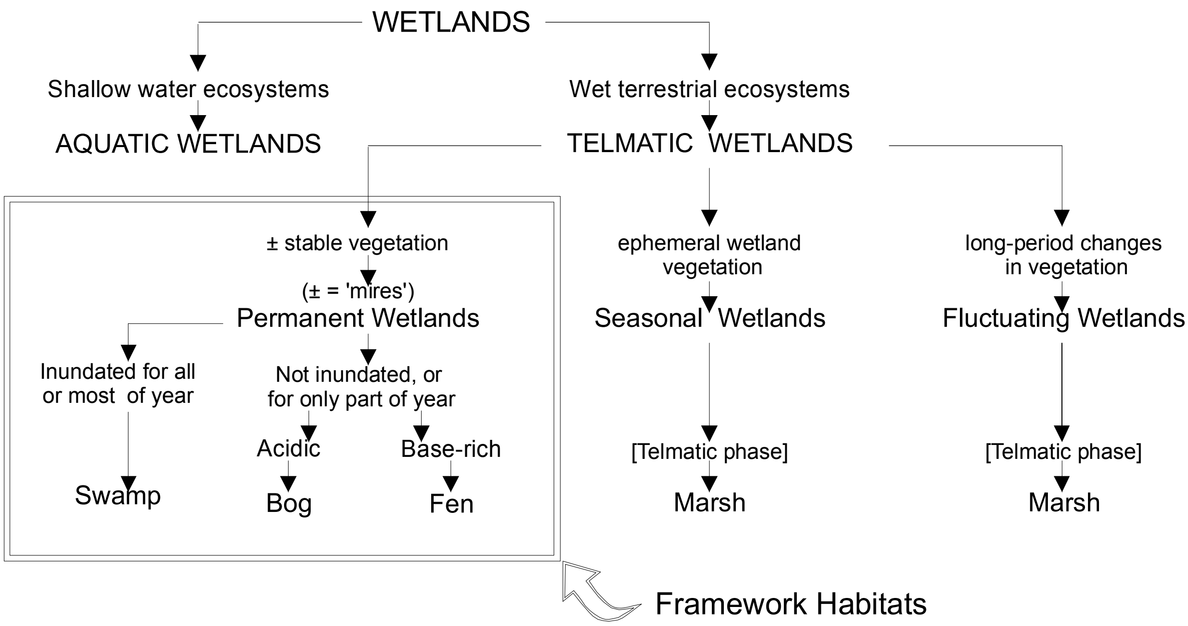
Frequently-used terms

The following terms are used frequently in this report. A more detailed glossary is provided in Appendix 1. Terms marked with an asterisk are explained in more detail in Chapter 2.

Telmatic wetland	Wet, semi-terrestrial wetlands (not aquatic wetlands). Subdivided into *permanent*, *seasonal* and *fluctuating* types.
Mire	Unconverted permanent telmatic wetlands. Includes wet sites on both peat and mineral soils, but excludes former wetlands which have been badly damaged or converted into another habitat.
Peatland	All areas with peat, including sites with natural or semi-natural vegetation and areas converted to agriculture or forestry or used for peat extraction.
Bog[1]	Acidic (pH < *c.* 5.5) mires (mainly on peat, but some mineral soils).
Fen[1]	Base-rich (pH > *c.* 5.5) mires (peat and normally wet mineral soils).
Marsh	Seasonally dry wetlands on mineral soils.
Swamp	Wetlands with summer water table typically > c. 25 cm above ground level.
Carr	Tree-covered fen.
Topogenous*	Wetness induced by topography and poor drainage (such as hollows).
Soligenous*	Wetness induced by water supply (such as seepage slopes).
Ombrogenous*	Wetness induced by precipitation.
Ombrotrophic	Surface fed directly and exclusively by precipitation.
Minerotrophic	Surface fed in part by telluric water.
Eutrophic	High fertility conditions, rich in nutrients.
Mesotrophic	Moderately fertile conditions.
Oligotrophic	Low fertility conditions, nutrient poor.
Meteoric water	Precipitation.
Telluric water*	Water that has had some contact with the mineral ground
Water table	Below-ground free water surface
Water surface	Surface of standing water
Water level	Used generically to include water table and water surface
Stand	A relatively uniform patch of vegetation of distinctive species composition and appearance. Can vary in size from very small (in m^2) to very large (in ha).

[1]. This definition of 'bog' and 'fen' differs from its common usage. Many workers follow Du Rietz (1949) and equate 'bog' with ombrotrophic peatlands and 'fen' with minerotrophic sites. However, Du Rietz's distinction, based mainly on water source, does not relate well to hydrochemical or vegetational differences between the habitats. The new definition suggested here follows the proposals of Damman (1995) and Wheeler and Proctor (2000) and comes very close to the original meaning of the terms as used by Tansley (1939).

Major wetland habitat categories and terms



1 Introduction

1.1 Concept and outline

The *Wetland Framework* project initially began in 1998 as a partnership project between the Wetland Research Group at the University of Sheffield, the Environment Agency and English Nature (now Natural England), subsequently involving the Countryside Council for Wales. It attempts to link together different features of wetlands, focussing primarily on mires (fens, bogs and swamps); and, in particular, to identify relationships between wetland topography, hydrology, hydrogeology and hydrochemistry and the ecological and biological characteristics of sites; and to develop a framework of understanding about how wetlands work. It pays particular regard to the occurrence of specific water supply mechanisms and environmental conditions and their relationship to vegetation and other features of conservation interest.

1.1.1 Objectives

The main objectives of this project were to:

- link wetland vegetation types to environmental conditions;
- link wetland vegetation types to water supply;
- link water supply mechanisms to the hydrogeological, topographical and landscape circumstances that produce these;
- use this understanding to assess and predict the impact of specific environmental changes (water level drawdown, nutrient enrichment).

1.1.2 Outputs

The main outcomes of the project were the:

- identification of generic **wet**land water supply **mec**hanisms (WETMECs);
- identification of primary wetland hydrochemical 'habitats' (particularly base-richness and fertility categories);
- assessment of water supply and habitat conditions needed by selected vegetation types;
- assessment of how selected wetland sites 'work', ecohydrologically, with particular reference to their conservation interest.

These results were used to construct the *Wetland Framework*.

This report provides a detailed account of the main wetland water supply mechanisms (WETMECs). These are perhaps best seen as conceptual units which take account of the impact of top-layer effects [1] (see Chapter 5) in the supply and distribution of water

1 The 'top-layer' effect includes well-known features such as lithological variation within drift deposits coupled with features more localised to the wetland, such as induration layers below the site, organic 'seals' lining the site, and variation in the character of the peat infill (from forming an effective aquitard to highly transmissive horizons).

within wetlands and which can form an add-on to wider conceptual hydrogeological models. They can help identify the components of water supply that sustain habitat features of conservation importance in wetlands. The report also identifies other habitat and topographical subdivisions that help describe the variation encountered in wetlands and which provide a basis for understanding how wetlands work.

1.2 Wetland Framework

The *Wetland Framework* should not be seen as a classification of wetlands as such, but rather as a series of generic units which can, in combination, be used to categorise wetland sites or parts of sites for various purposes. The units are arranged in independent layers (Table 1.1), so that individual sites or samples can be defined by their combination of layers. Whilst the layers are nominally independent, in practice not all permutations of units occur. 'Landscape type' units are rather crude, informal categories and, except in the case of very large or complex examples, many wetland 'sites' belong to only one landscape type. By contrast, except for very small or simple examples, wetland 'sites' will contain more than one of the other categories. In any one site, a combination of WETMEC, base-richness, fertility and management units is likely to correspond to a distinctive patch (or stand) of vegetation and to a specific plant community (Table 1.2).

With the exception of landscape types and management units, the framework approach has essentially been bottom-up, in that units and their limits have been derived from an analysis of data collected from individual stands of vegetation. This differs from some existing wetland categorisations which are essentially top-down in character, based on subdivisions usually imposed by expert judgement via an intuitive appraisal of the main units.

Table 1.1 Layers of the Wetland Framework

Landscape type	Hillslope	Valleyhead	Valleyhead trough/ basin	Basin	Lakeside	Trough (valley - bottom)	Floodplain	Coastal plain	Plateau–plain

WETMEC	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20

Base richness	Highly acidic (<4.0)	Acidic (4.0 – 5.5)	Sub neutral (5.5 – 6.5)	Base rich (>6.5)

Fertility	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic

Management	Unmanaged	Winter grazed	Winter mown	Summer grazed	Summer mown	Burnt

Table 1.2 Illustration of the use of categories of the *Wetland Framework*

Landscape type	Hillslope	Valleyhead	Valleyhead trough/ basin	Basin	Lakeside	Trough (valley-bottom)	Floodplain	Coastal plain	Plateau–plain

WETMEC										
	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16	17	18	19	20

Base richness	Highly acidic (<4.0)	Acidic (4.0 – 5.5)	Sub neutral (5.5 – 6.5)	Base rich (>6.5)

Fertility	Oligotrophic	Mesotrophic	Eutrophic	Hypertrophic

Management	Unmanaged	Winter grazed	Winter mown	Summer grazed	Summer mown	Burnt

The category combination shown by red cells is widespread and supports M21 vegetation (*Narthecium ossifragum–Sphagnum papillosum* mire).

We consider the *Wetland Framework* to have considerable relevance to the study and conservation of wetlands. Given their often complex character, a tool which can categorise parts of wetlands to reflect their function and dependence on specific environmental factors is of obvious benefit in assessing impacts and developing conservation and restoration programmes. Wetlands are not only important for wildlife conservation, but often play a significant role in flood mitigation and in regulating water quality.

1.3 Background to building the Wetland Framework

This project is a partnership between the Wetland Research Group University of Sheffield, the Environment Agency, English Nature (now Natural England) and the Countryside Council for Wales. The impetus for the project arose from the need to carry out detailed assessments of the impacts of consented and unconsented activities on conservation features (habitats and species) of European importance. The project complements work by Natural England and the Countryside Council for Wales to set conservation objectives for designated sites and their features. This was by identifying environmental factors critical for the maintenance or enhancement of conservation features and distinguishing these from less critical factors and providing a basis for assessing whether these objectives could be sustained or enhanced in specific wetland sites.

The project started as a pilot conceived jointly by the University of Sheffield and Environment Agency Anglian Region which covered sites in Eastern England (Wheeler and Shaw, 2000a). The pilot set out to answer the question: Why do groundwater-fed fens, all apparently irrigated primarily from a chalk aquifer, support such different types of vegetation? This raised a number of sub-questions, for example: How does the position of the groundwater table relative to the surface vary amongst sites? What controls such variation? Are there major differences in the quality of the discharging water, or in the substratum onto which it discharges? And how does this relate to variation in vegetation composition? The outcome of this pilot proved to be critical in aiding the assessment of impacts on groundwater-dependent wetlands, and a much wider project was initiated.

The second phase of work extended the Framework to include other regions of England and Wales with markedly different rocks, topographies and climates. This phase consisted of two parts, the first encompassing sites and site types in southern England (including Surrey, the New Forest, Dorset and Devon), and the second looking at wetlands in Wales, North-western and North-eastern England, and the West Midlands. In total, about 200 sites across England and Wales were included.

The pilot project and subsequent work did not set out to collect large quantities of new data; the main rationale was to collate and analyse *existing* information, to determine what use could be made of it and to identify important deficiencies. It was possible that the limitations of existing data might prevent a coherent framework from emerging, but the fact that it has proved possible to extract a fairly clear framework from the available material is itself of considerable interest. Nonetheless, it is important to appreciate the limitations of some of the data on which the framework is based; it should not be seen as an *ex cathedra* statement but rather as a hypothesis which can be tested, modified and developed as further data become available.

The *Wetland Framework* is exclusively concerned with *mires* (bogs, fens and some swamps). Even within this category, the geographical limits of the study mean that other wetland categories in the UK may not yet have been identified, especially in parts of Scotland. A series of smaller scale desktop studies have tried to identify a similar functionally driven classification in wet woodlands (Barsoum *et al*., 2005), wet heath (Mountford, Rose and Bromley, 2005) wet dunes (Davy *et al*., 2006), swamps and ditches (Mountford in Wheeler *et al.,* 2004) and wet grasslands (Gowing in Wheeler *et al.,* 2004). The ecohydrology of mires, ditches, swamps and wet grasslands are summarised in a user-friendly format in the publication *Ecohydrological guidelines for lowland wetland plant communities* by Wheeler *et al.* (2004). These studies have not yet been fully integrated with the results reported here.

1.4 Application

1.4.1 General applications

Generically, the *Wetland Framework* has a number of applications:

i. It can support Environment Agency assessments of the impact of consented and unconsented activities on the environment and wetland conservation features in particular. A better understanding of how wetlands work is particularly important in supporting regulatory decisions and water resource planning.

ii. It provides conservation bodies with a better understanding of how wetlands, and categories of wetlands, function. Understanding the water supply to a wetland site and how changes may affect the ecological character of the site is essential to protect and restore sites and determine what activities may enhance or diminish their condition. A functional understanding of our wetlands can help to scope responses to climatic change and guide the debate about adaptive management.

iii. It could be used to develop or underpin conservation strategies for wetland sites, by identifying hydrological and environmental features critical for the maintenance (or enhancement) of wetland habitats; by distinguishing these from less critical features; and by providing a basis for assessing the potential for these strategies to be sustained or enhanced in specific wetland sites.

iv. The Framework is specifically relevant to the Water Framework Directive, the Birds and Habitats Directives, and targets established in England and Wales for favourable condition on statutory sites.

v. It is also hoped that the Framework will help to bridge academic understanding of wetland ecology with the interests of conservationists and water resource managers and engineers, and between ecologists and hydrologists. All of these groups need to establish a common platform on which to base and agree decisions relating to the assessment of impacts on particular features. Without this, uncertainties can result in misunderstandings and unrealistic expectations. Bridging this gap should enable ecologically and hydrologically sustainable targets to be set for individual sites.

vi. The Framework proposes a consistent terminology (Chapter 2) for describing wetlands and their features. Whilst this sometimes represents a compromise between conflicting usages, and may cause some dissent, the development of an agreed terminology should help communication between different groups with an interest in wetlands. The *Wetland Framework* represents a step towards the development of this.

1.4.2 Thinking like a WETMEC

The identification of a series of generic water supply mechanisms (WETMECs) is a major component of the *Wetland Framework*. A WETMEC-based approach can influence the way in which wetlands are perceived and investigated. The following applications, both conceptual and practical, could arise as a consequence of 'thinking like a WETMEC'.

i. **Ecohydrological units**: WETMECs can be regarded as basic ecohydrological units within wetlands. In some respects, they are fundamental units comparable to species in taxonomy (though they are more variable and show more intergradation). As a fundamental unit they appear to be broadly equivalent to the *mesotope* of some peatland scientists (Ivanov, 1981). As units, WETMECs have obvious potential for the purposes of description, communication, mapping and so on (Figure 1.1).

ii. **Conceptual units**: Conceptual hydrogeological models are frequently developed for wetland sites, particularly in the early stages of impact assessments. WETMECs can function as add-ons by extending such models to take better account of the properties of the wetland and its infill, although they are generic rather than site specific. WETMECs can thus form part of the conceptual model, representing the conservation interest of wetlands, used as the basis to prepare a numerical groundwater model. Since groundwater models, particularly regional ones, can only represent conceptual detail for the scale at which they are constructed, WETMECs are likely to be represented when they occupy relatively large areas. It may be difficult to accommodate the hydraulic detail and patchiness of more localised WETMECs (which may occupy some tens of square metres) within the grid sizes typically used in current models. Nonetheless, small patches of WETMECs often correspond to particular features of conservation interest (such as vegetation types). Coarser-grained groundwater models may be inappropriate to adequately represent the hydrological characteristics of small WETMECs and conservation features.

iii. **Top-layer units**: WETMECs are partly based on the potential importance of top-layer conditions to the water supply of wetlands. The top layer (Chapter 5) is the uppermost substratum, including the wetland infill, which is sometime disregarded by hydrogeologists, either because it is poorly characterised, poorly documented or deemed unimportant. [The disposition and character of top layers varies horizontally as well as vertically and some layers are not laterally persistent. This creates a patchiness beneath or within the wetland deposit and is often one of the reasons for the occurrence of different WETMECs within a single wetland site.]

iv. **Investigative units**: Although within a wetland site adjoining WETMECs are likely to have some hydraulic connection, because they represent distinct water supply mechanisms WETMECs can provide the basis for hydrological investigations within wetlands. Hydrological monitoring could be stratified to ensure that different WETMECs are represented. As top-layer units WETMECs also emphasise the need for measurements within the wetland itself, as well as in its surroundings.

v. **Conservation units**: WETMECs provide a potential basis for the subdivision of sites for conservation activities, assessments and monitoring. Different WETMECs may have different water supply, and water and vegetation management requirements. Moreover, superficially similar WETMECs may have strikingly different vulnerabilities.

vi. **Vegetation-related units**: WETMECs form part of the conditions that influence the distribution of plant communities in wetland sites (Table 1.2). In some instances, a single WETMEC may be co-extensive with an individual plant community, but at some sites a WETMEC may support several communities (because they depend on other habitat conditions in addition to water supply (Table 1.1). Some plant communities are strongly associated with a particular WETMEC in almost all of the sites where they occur, though none of those considered (Part 3) are completely confined to a single WETMEC. Overall, 'thinking like a WETMEC' means shifting investigative focus away from, for example, *single* target water levels to a holistic consideration of water supply mechanisms and delivery, that is, to entire wetland regimes including hydrological (groundwater level, groundwater flow, seepage, surface water flow), hydrochemical and site management.

vii. **Impact assessment and management**: All of the applications identified above feed directly into the process of assessing the likely consequences of impacts on habitat quality. Knowledge of the key WETMECs sustaining features of interest can, for example, help determine their sensitivity to abstraction and surface drainage within various physical contexts in the wetland. Equally important, WETMECs can guide conservation and restoration management decisions by helping site managers understand the suitability of different water management options.

1.4.3 Limitations of WETMECs

WETMECs have some intrinsic limitations. In particular:

i. WETMECs are generic conceptual units whose characteristics are related to the frequency of recurrent conditions within the dataset, and subject to its limitations.

ii. The existing series of WETMECs is not comprehensive. Wetlands fed primarily by surface run-off may be under-represented and some wetland types, such as the blanket mires of the uplands, have not been considered.

iii. It is likely that some sites with unusual water supply mechanisms may not easily relate to existing WETMECs.

iv. WETMECs are variable and show intergradation.

Hence WETMECs should be seen not as inviolate units, but as hypotheses which can be tested, modified and developed further as data become available.

Figure 1.1 Distribution of different WETMEC types at Smallburgh Fen (Norfolk)

1.5 Content and structure of report

This report presents the results of investigations into the relationships between water source, quantity and quality and vegetation type in sites supporting herbaceous wetland vegetation in lowland England and Wales.

To reduce the complexity of this report, some detailed material (mainly relating to the methods and results of data analysis) is placed in appendices.

VOLUME 1

Part 1 Scope, purpose and context.

The introduction includes an outline and discussion of the main terms and concepts referred to in the report, and an appraisal of the limitations of some existing information and approaches. Particular consideration is given to topics where misconceptions seem to arise.

Part 2 Wetland Framework

This section outlines the main approaches to the project, its rationale, data analysis procedures, and the typology which forms the core of the *Wetland Framework*. The wetland types recognised are primarily types *within* wetlands rather than types *of* wetlands. Chapter 5 discusses the importance of the wetland infill and immediate underlying material in helping to regulate water supply (top-layer control). Chapter 6 provides the core of the *Wetland Framework* – a typology of the main ecohydrological units that occur within lowland herbaceous wetlands in England and Wales, based on a synthesis of available data and analysis results. Twenty WETMECs are identified and described in detail, along with the ecological types associated with them. Together, the WETMECs and ecological types define ecohydrological habitats.

Part 3 Ecohydrology of wetland plant communities

Variations in plant communities are considered in relation to environmental variation, with particular reference to water sources and conditions and the ecohydrological habitats (Part 2) in which they occur. Some communities are largely specific to particular WETMECs, where an awareness of water supply mechanisms is as important for their conservation (or re-creation) as is an understanding of their relationship with water levels. Some accounts of communities covered in Phase 1 which have had only few extra data added have been updated with the new WETMEC specifications and changes to data tables.

Part 4 Conclusions and reference material

Conclusions and suggestions for future work are given, along with a list of references.

Appendices

Appendix 1 provides a glossary of terms and lists of plant species, plant communities and abbreviations used in the text.

Appendix 2 provides a statement on the data sources, details of the main data types and categories used, and main analytical methods and results.

VOLUME 2

Appendix 3 Ecohydrological site accounts

A brief description of each site in the data analysis is given in terms of its hydrogeological context, apparent main water sources and supply mechanisms, and vegetation types. The WETMECs sampled at each site are also indicated. Accounts are not intended to be comprehensive and primarily cover site characteristics relevant to the data and samples included in the analysis. Accounts prepared for the first *Wetland Framework* report (Wheeler and Shaw, 2000a) are included and updated with the new WETMEC numbers.

SUPPLEMENT:

Wetland functional mechanisms: a synopsis of WETMECS

The supplement provides summary details and schematic diagrams for each WETMEC.

Additional material available electronically:

Appendix 4 Hydrogeological site accounts

Hydrogeological accounts were commissioned for most of the sites in the project. These were based primarily on a desk study of maps and published and unpublished material. Only a few of the sites were visited by hydrogeologists. Accounts prepared for the first *Wetland Framework* report (see Wheeler and Shaw, 2000a) are also included.

2 Wetland terms and concepts

2.1 Introduction

Wetland terminology[1] is notoriously complex and confusing, partly because of the wide variability of the wetland condition, which demands a rich diversity of descriptive terms, coupled with a sparsity of appropriate commonplace words. The response of wetland workers has been to generate new, and essentially idiosyncratic, terms or to hijack idiomatic words and give them a specific meaning or connotation that in normal vernacular use they do not posses. In consequence there has been a proliferation of specialist wetland-specific terms, often with a clear and precise meaning, but also a tendency for workers to give specific – though not always clearly specified – meanings to some vernacular words. Different disciplines have their particular terminological traditions and there are not only disagreements within these but also between them, so that ecologists, hydrologists and conservationists with their own perspectives and requirements may be unaware of the nuances of meaning attached to specific terms when used in other disciplines. The word 'groundwater' provides a good example of this. This state of affairs is unfortunate, not least because terminology should assist communication, rather than form a barrier to it.

Issues of terminology run deeper than just considerations of semantics. A term represents the label for the concept underlying some type of category, and the concepts themselves may differ amongst workers, especially when the categorised entities are not very discrete. Wetland terms frequently represent arbitrary or bespoke subdivisions of variable items and processes that show few, if any, natural splits (see Wheeler and Proctor, 2000). Thus, the problem of terminology is not just to what category a particular term should be applied, but also the conceptual validity of the category itself, which is an altogether more fundamental consideration.

A further difficulty is that some terms and categorisations are based on multiple features which may nonetheless vary independently of each other. A good example is the quite well-established usage (see Ratcliffe, 1977) of 'oligotrophic' and 'eutrophic' to refer both to base status and fertility (base-poor–infertile and base-rich–fertile, respectively). This creates obvious difficulties, such as the absence of a category for base-rich–infertile habitats (which do occur). Various work-arounds are possible, but we strongly advocate, as a matter of classificatory principle, that composite categories should be disambiguated into single elements (or at least groups of elements that *always* vary concurrently). However, long-established usages can be deeply entrenched and difficult to change.

For some purposes (such as general descriptions), terms do not necessarily need crisp definitions, nor are these always possible. But for other requirements (such as terms in equations, units of resource assessment or fields in a database), categories and terms require definitions that are both clear and non-overlapping. The current *Wetland Framework* project is database-centred, and has required the identification of a series of clear, consistent and meaningful wetland categories, whatever they may be called.

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1 A more comprehensive list of terms is provided in the glossary. Here, attention is given to the specific usage and explanation of a number of terms that are used widely in this report.

Inquiry into the *desiridata* for the development of a terminology for some categories required for the Framework led to the advice that, because of the expected broad user-base of ecologists, hydrologists and conservationists, it would be unhelpful (a) to use too many technical terms, however well established; (b) to redefine some existing widely used terms from a paludocentric perspective for the specific purposes of the project; or (c) to generate new terms. These proscriptions created an impasse which could be resolved only by the generation of descriptive phrases rather than terms, an approach which is acceptable in many contexts, but not all (such as where labels require succinct descriptors). As a result, it has proved necessary to develop a terminology for the project. In doing this we have (a) attempted to keep technical terms to a minimum and (b) taken account, as far as possible, of comments from the Steering Group and other workers (particularly Ursula Buss and Donal Daly) on the acceptable use of various terms. The usage adopted is outlined below and has been designed to minimise confusion and modification of established definitions. In some instances, it represents a compromise between conflicting opinions.

2.2 Topographic terms

Topographic terms are used as loose descriptors of the situations in which wetlands occur, especially in relation to their water supply. The categories they represent often intergrade and are not crisply defined.

2.2.1 Soligenous, topogenous, ombrogenous

These terms, which originate in part from the ideas of von Post and Granlund (1926), are widely used by mire ecologists, but not always in exactly the same way. The following compasses of the terms are used here.

Soligenous

Soligenous wetlands are kept wet primarily by a supply of TELLURIC water with little impedance to outflow, and are most typical of slopes where groundwater outflow or run-off input produces surface wet conditions. Such wetlands frequently have thin deposits of peat and water movement is often apparently more by surface flow than percolation through the peat. This is a generic category for both groundwater and surface water-fed mires in appropriate topographical contexts and includes both FLUSHES and SEEPAGE slopes. GROUNDWATER-fed peatlands on flat or near-flat surfaces or wetlands in troughs with significant horizontal water flow are not generally classified as being soligenous unless they have a fairly skeletal substratum, are usually small, and effectively form a flat version of a soligenous slope. Instead, they are considered to be rheo-TOPOGENOUS wetlands. The scope of ‘soligenous’ as used in this report is thus considerably narrower than that apparently adopted by some workers (such as Rodwell, 1991b, 1995), but is perhaps more in keeping with the original concept of von Post and Granlund (1926) with its etymological basis of being ‘soil made’ (formed by the immediate influence of water sourced from the mineral soil).

Topogenous

Topogenous wetlands are considered here to be TELLURIC wetlands in which high water levels are maintained primarily by topographical constraints upon the drainage of water inputs (which may include precipitation, land drainage, river flooding, run-off and groundwater). Thus, whilst SOLIGENOUS surfaces are kept wet mainly by high rates of TELLURIC water supply, topogenous wetlands are kept wet more by impeded drainage. Examples of topogenous wetlands include open water fringes, basins, floodplains and troughs. Impeded drainage is typically a product of landscape configuration, but it may also be induced by the topography of the wetland itself or, for example, by river water levels. Some topogenous wetlands may experience high rates of telluric water supply; those subject to significant water throughflow are considered to be *rheo-topogenous*, whereas those with little or insignificant water throughflow are *stagno-topogenous*. Surfaces in topogenous locations fed exclusively by precipitation are regarded as OMBROGENOUS.

Ombrogenous

Ombrogenous wetland surfaces are those which have formed under the exclusive influence of precipitation. The ombrogenous peat surface is raised above the level of any TELLURIC water, fen peat or mineral soil, often to produce a dome of peat that can be independent of sub-surface topography. In the examples considered here, ombrogenous surfaces have developed serally within TOPOGENOUS mires. *Ombrogenous* is sometimes used as a synonym for *ombrotrophic* (more or less exclusively and directly rain-nourished), but whilst ombrogenous surfaces are always ombrotrophic, some (usually drained) fen (once minerotrophic) surfaces may also now be fed exclusively by precipitation. [These are distinguished here as 'ombrotrophic legacy TELLURIC'.]

2.2.2 Landscape terms

Bottoms

Bottom is used mainly as a generic term for a range of TOPOGENOUS situations (basins, flats, floodplains and troughs) (being more or less synonymous with TOPOGENOUS). It is sometimes used as a catch-all term for topogenous settings that are not readily allocated to a better-defined landscape category.

Basins

Basins are quite difficult to define. Ostensibly they are bowl-like depressions, but they differ considerably in shape, size, openess and topographical irregularity. Wetland sites considered to be basin mires are typically small (< 10 ha), possibly because basins appear to be discrete only when it is possible to see the entire site; conversely, tiny hollows (such as individual pingo depressions) are sometimes, for reasons that are not very clear, not regarded as basin mires. The classic concept of a basin mire is that of a roughly isodiametric unit, but elongate depressions and irregular shapes also occur.

Basins are essentially TOPOGENOUS units, but some examples, especially those fed by groundwater outflow, may have SOLIGENOUS slopes around their margins. A few examples are apparently closed, without any significant surface inflow or outflow (such as Lin Can Moss, Shropshire), but the majority have at least an obvious surface outflow, though this is sometimes artificial and not always active (such as Abbots Moss, Cheshire). Some throughflow basins have a strong throughflowing stream (such as Biglands Bog, Cumbria). Where there is an inflow or outflow, to qualify as a basin the hollow must be a constriction of the margin associated with it, which helps to define a fairly discrete, visibly basin-like structure. Where this is not the case, the unit is considered to form a TROUGH. Elongate hollows that look like troughs but which are actually elongate basins are referred to as trough-like basins.

Basins frequently occur as isolated units (kettle holes and so on) but can be embedded within other topographical types. Where there are just small depressions within another topographical unit these are referred to as SUMPS, but sometimes basins can occupy much or all of another unit. Where, as is sometimes the case, a VALLEYHEAD is configured mostly as a basin or series of basin units, it is referred to as a valleyhead basin. A complicating consideration is that some sites, which in terms of their sub-surface topography were at one time valleyhead basins, now appear as valleyhead troughs because their original basins have become largely filled with peat, for example, and are obscured by this (such as Great Cressingham Fen, Norfolk; Stable Harvey Moss, Cumbria; Wybunbury Moss, Cheshire).

Floodplains

Floodplains are usually more or less flat valley-bottom surfaces alongside relatively mature watercourses which are episodically flooded by these (such as most of the Broadland mires). Floodplain surfaces which are now effectively isolated from the watercourses (by channelling or embankment) are referred to as drained floodplains, drained levels or valley bottoms, depending on their context. Narrow zones of episodic flooding alongside watercourses in other topographical situations that are not floodplains (for example, some valleyheads) are not generally considered to be floodplains at a landscape level (though in some cases, they may support the same WETMECs as floodplains). Some floodplain wetlands may have SOLIGENOUS margins, but these are small in relation to the size of the whole unit.

Valleyheads

This term is used in the sense proposed by Fojt (1990) and largely equates to the category of ‘headwater fen’ as used by Haslam (1965). It includes wetlands associated with the upper reaches of small valleys, which are often quite sharply incised into the surrounding mineral ground. In many instances, small axial streams originate within the valleyhead and help drain it, but in some cases the valleyhead, or at least the wetland area within it, is fed by small watercourses that originate upslope of the site. Valleyhead wetlands are essentially sloping systems, usually with lateral wetland slopes feeding down to the valley, as well as having down-valley flow, and are thus primarily SOLIGENOUS. Small-scale topographical variation sometimes creates SUMPS and BOTTOMS alongside the streams and these may, in some broader, flatter examples, receive episodic recharge or flooding from the stream (forming very small FLOODPLAINS). Some valleyheads are largely configured as BASINS and are referred to as valleyhead basins. Others, for example some in the New Forest, have a deep peat infill which forms a flattish surface that obliterates much of the underlying incised topography, and are referred to as valleyhead TROUGHS.

Troughs

The unqualified term ‘trough’ is used to refer to elongate, mostly valley-bottom contexts which are neither VALLEYHEADS nor FLOODPLAINS. It includes sites alongside watercourses some distance below the valleyheads, but where a floodplain is either absent or is a minor constituent of the trough (transitional between valleyheads and floodplains, such as Swangey Fen, Norfolk). Such sites often support SOLIGENOUS wetlands on the slopes of the trough, grading into more TOPOGENOUS conditions along the bottom.

Some valleyheads also contain trough-like features, where a quite deep peat infill largely obscures the valley topography, and these are considered to form valleyhead troughs. These usually differ from a normal valleyhead in being partly topogenous, often with a gentle slope. Some of the New Forest mires are valleyhead troughs (such as Cranes Moor), and in some of the larger sites (such as Denny Bog) grade downstream into true troughs.

Troughs differ from BASINS in that they normally gently slope along the drainage axis, rather than being bowl-like, and do not have a clear basin-like constriction at the outflow. However, this distinction is not always easy to apply, not least because some troughs and valleyhead troughs have developed over basins, where peat formation has obscured the former basin topography. An elongate character is also typical of troughs, but is not unknown in some basins. In some sites (such as Corsydd Erddreiniog and Nantisaf, Môn), it is a moot point whether the wetland is best called a valleyhead trough or a valleyhead basin.

Valleysides and hill slopes

Valleyside and hill slope categories here essentially represent SOLIGENOUS wetlands developed along a valley slope or as patches on a hillside. They are mostly similar to VALLEYHEAD systems, but are not organised into a valleyhead, nor do they normally have a valley-bottom component – for example, they tend to lack the soakways that occur along the drainage axis of some valleyhead systems (valleyside wetlands with a well-developed topogenous wetland bottom would generally be regarded as TROUGHS). In some locations, valleyside wetlands occur as a downstream continuation of valleyhead systems, and in this case only an arbitrary distinction may be possible between the two. The main area of wetlands at Cwm Cadlan (Brecknock) provides a good example of a valleyside system.

Hill slope wetlands here are similar to valleyside wetlands, differing mainly as small patches on a hillside rather than elongate systems along a valleyside. They sometimes occur on slopes high up on valleysides, and well above the main valley bottom. Examples include some of the soligenous mires at Banc y Mwldan (Ceredigion) and Crosby Gill (Cumbria). Hill slope wetlands are a more typical feature of uplands than of locations examined here and, in certain climatic regions, can support some of the extensive tracts of ombrogenous hill peat (blanket bog), a wetland type that was outwith the compass of the present study.

2.2.3 Valley mires

Although frequently found in the literature, this term is not used here except when referring to sources that use it. It has received wide and variable use in the past, for example referring both to VALLEYHEAD mires (such as the ‘valley bogs’ of Rose, 1953, perhaps the most common usage) and to FLOODPLAIN mires (such as the ‘valley fens’ of Haslam, 1965).

2.3 Wetland topography terms

2.3.1 Sumps

Sumps are small, shallow depressions within mire systems. They may reflect small-scale topographical variation in the underlying mineral material, such as can be created by small or coalesced ground ice hollows, or by peat excavations. PEAT PITS and TURF PONDS are usually a type of sump, but are distinguished separately.

2.3.2 Peat pits

Peat pits are excavated hollows within wetlands. Their bottoms may be wetter than adjoining uncut (or less cut) surfaces, but unlike TURF PONDS they are not significantly flooded (except perhaps during particularly wet periods) and their revegetation has occurred by direct colonisation of the exposed peat surface.

2.3.3 Turf ponds

Turf ponds are more or less sealed excavated hollows within wetlands which have reflooded since abandonment, so that recolonisation has often been by terrestrialisation of shallow open water or swamp, rather than by colonisation of the peat bottom (as is the case in a PEAT PIT). Note that the term 'turf pond' is used for all artificial hollows corresponding to this description, whether excavated for peat, another product (such as marl) or for fish ponds.

2.3.4 Tumps

Tumps are the opposite of SUMPS: small elevations within wetlands. These may reflect irregularities in the underlying mineral ground, or locally elevated peat surfaces and platforms. Definitions given by the *Oxford English Dictionary* include: "a hillock, mound … a clump of trees or shrubs; a clump of grass, esp. one forming a dry spot in a bog or fen".

2.3.5 Tussocks

Elevated mounds created by the growth of caespitose vascular plants. Tussocks usually occur individually, but can sometimes coalesce to create elevated platforms.

2.3.6 Hummocks

Elevated mounds created by the growth of bryophytes, especially *Sphagnum* species. Hummocks may sometimes develop over TUSSOCKS.

2.3.7 Lawns

Noticeably even (level) surfaces on flat or sloping ground, usually with low-growing vegetation which may be dominated by bryophytes (such as *Sphagnum* lawns) or vascular plants. Generally not, or only little, punctured by mounds, depressions, runnels and so on.

2.4 Water supply terms

Wetlands receive varying amounts of water from aquifers, surface drainage and precipitation. However, the terminology associated with water supply is not always clear and would benefit from clarification. A particular problem is that the same word can be used to refer both to the *state* of water *within* a wetland and for a *source* of water *to* the wetland. Thus, 'groundwater' can refer both to the water within a wetland aquifer, and to the water in a mineral aquifer which flows into the wetland. This can result in considerable confusion. For example, the water in the peat of an OMBROGENOUS bog is strictly 'groundwater', but it may have been sourced exclusively and directly from precipitation, thereby differing considerably in its water supply mechanism and hydrochemical character from wetlands fed by water from mineral aquifers, though this is also ultimately precipitation-sourced. In ombrogenous bogs, particular confusion is possible because the peat *body* (as distinct from the peat *surface*) of some ostensibly ombrogenous peatlands may receive some groundwater flow from proximate mineral aquifers. There is a real need for terms that distinguish between water source and water state, but these do not yet exist.

2.4.1 Meteoric water

Water of recent atmospheric origin, that is, direct precipitation (rain, snow, mist, frost, condensation and so on).

2.4.2 Telluric water

This term refers to water that has been in contact with the mineral ground as opposed to direct precipitation (METEORIC WATER). It is thus a useful generic term which encompasses (most) GROUNDWATER and SURFACE WATER. TELLURIC WATER is typically more rich in bases, often much more so, than METEORIC WATER, though in some instances TELLURIC WATER sourced from unreactive rocks, or with a short residence time within these, may have a chemical fingerprint that is little different to that of rainwater.

2.4.3 Groundwater

Groundwater here primarily refers to water in, or sourced from, a bedrock or drift aquifer. Water within a peat aquifer is not explicitly described as groundwater unless it is thought to be sourced primarily from such an outflow. Instead, it is referred to generically (and noncommittally) as 'mire water'. Moreover, where wetland sites receive groundwater flow from an adjoining aquifer, this is usually referred to as 'groundwater outflow from a mineral aquifer', except where the context is sufficiently obvious as to not need clarification. Thus, the mire water in the peat of an ombrogenous bog is *not* generally referred to as groundwater, though its status may be amplified by specification of some groundwater outflow from a mineral aquifer where this appears to occur.

Where groundwater outflows directly onto a wetland surface, the water in pools, streams and runnels primarily sourced thereby is either not specifically named or is described as groundwater-sourced; it is not referred to as SURFACE WATER. [In the database on which the WETMECs are based, such water was categorised as ‘groundwater’.] However, where streams and other bodies feeding the wetland originate from well outside the site, their water is described as SURFACE WATER, even though it may be principally sourced by groundwater outflow. Within a site, if water in groundwater-fed streams is clearly supplemented by other sources (including rainfall), the water is described as surface water.

2.4.4 Surface water

Surface water is a generic term for TELLURIC water that is not GROUNDWATER (though some SURFACE WATERS may be substantially sourced by GROUNDWATER outflows). In this report, surface water sources are usually described by their commonly used names. However, ‘surface run-off’ is used as a generic term to include rain-generated run-off, tile drainage, and stream and ditch flow into a mire. Some of these may also be sourced by groundwater. ‘Surface water body’ is a generic term for watercourses, pools, lakes and so on.

For the database categories used for WETMEC analyses, surface water systems proximate to individual stands were divided into the two main categories of ‘upslope’ and ‘downslope’:

Upslope surface water sources

These include sources of surface water that enter a wetland stand or site from the upland margin, usually as surface (or near-surface) rain-generated run-off, or as drain, ditch or stream inflow into the stand. Where ditches run through a stand and serve to drain it rather than provide a water supply, they are not considered to form a surface water *source*.

Downslope surface water sources and sinks

These include bodies of surface water alongside or within stands on the downslope (drainage) side or, in the case of more or less flat sites, in a location that is not obviously upslope. They thus include rivers, streams, lakes, dykes and ditches. Depending on their water regime and the topography of the site, some surface water bodies have both water drainage and supply functions at different times, reflecting changes in the direction of the hydraulic gradient. Supply episodes are often associated with flooding events, but in flat sites, especially those with a network of dykes, the surface water body may sometimes act as a source of water recharge to the adjoining mire for much, or all, of the year.

In most sites, DYKE systems are considered downslope water bodies. Exceptions are sites where there is a land-spring dyke or ditch along the upland margin which is obviously above, or not connected to, any other dykes and which receives most or all of its water from drainage of the adjoining upland.

Groundwater outflows

Where water sourced from groundwater outflow runs down, say, a seepage slope as runnels and so on to feed into a stand downstream, this supply to the downslope stand is referred to as GROUNDWATER rather than surface water. Where clarification appears necessary, it is referred to as ‘groundwater-sourced’.

2.5 Groundwater outflow processes and features

2.5.1 Spring

A spring refers to a discrete focus of groundwater outflow from a mineral aquifer onto the ground surface, usually with visible water flow into a stream, runnel(s) or soakway. It may occur as an area of preferential outflow within a SEEPAGE system.

2.5.2 Spring mound

Usually fairly small, convex mounds developed over springs. They may be stabilised by precipitated calcite (tufa mounds) or inwashed mineral material (sands and silts), but the surface may also be buoyed-up by the pressure of groundwater outflow and some unstabilised mounds can collapse during droughts. Often on slopes, spring mounds may themselves be sloping and asymmetric. They vary in topography from small, discrete mounds to shallow bulges (with a diameter of 10–20 m) and to large, tufa-based deposits.

2.5.3 Seepage

Groundwater seepage is considered to be groundwater outflow from a mineral aquifer to the surface of a wetland. Seepages can be subdivided based on the seasonal persistence of groundwater outflow into PERMANENT and INTERMITTENT seepages, and on the basis of topography into *seepage slopes* and *seepage basins* or *troughs.* The term 'seepage' is also sometimes used as a generic term to encompass some other types of groundwater outflow (most notably SPRINGS), but not for FLUSHES*.* This is because, whilst the flushes considered here are often fed by groundwater outflow, this is by superficial, downslope flow of seepage-sourced water over an aquitard. Thus, whilst there may be a distinct seepage face along the top edge of a flush, the main area of flush below this is not considered to be a seepage. The term seepage is also not used for wetland surfaces where surface water sources make a significant contribution to summer wetness, even when they may also experience groundwater outflow.

Permanent and intermittent seepages

Permanent seepage strictly refers to circumstances in which groundwater outflow is at or near the wetland surface year round, and differs from intermittent seepage where surface outflow only occurs episodically (usually seasonally). For the purposes of this project, an empirical and practical distinction is made: permanent seepages are those areas of wetland where groundwater outflow to the surface occurs year round *and* those where the groundwater-sourced water table is sufficiently close to the surface for free water to ooze out underfoot during a normal (non-drought) summer. An intermittent seepage is one in which free water does not ooze underfoot in normal summer conditions, but is wet in winter. Although somewhat arbitrary, experience suggests that this pragmatic definition can be applied fairly easily and consistently.

Whereas technically the term 'seepage' requires some period of groundwater outflow to the surface, in some wetland locations the aquifer head is consistently sub-surface year round, sometimes in response to drainage*.* In the WETMEC analyses such samples have mostly clustered with true intermittent seepages, and are therefore also included within this category.

2.5.4 Flushes, flushed surfaces

Groundwater flushes and flushed surfaces are surfaces located below a SPRING or SEEPAGE line, but which are situated over an aquitard and which are irrigated primarily by surface or near-surface water derived from groundwater outflow upslope of them. Surface water flushes are similar in character, but are fed primarily by upslope surface water sources.

2.5.5 Groundwater percolation (seepage percolation)

Groundwater percolation is a feature of PERCOLATION mires that have GROUNDWATER as their principal TELLURIC water source.

2.5.6 Percolation

The concept of 'percolating fen' was introduced by Succow and Lange (1984) as a translation of *durchströmungsmoor* (throughflowing mire) and 'percolation' has been retained here in a similar sense to refer to water flow through a (usually topogenous) wetland deposit. Topogenous surfaces with significant percolation are *rheo-topogenous* (as opposed to *stagno-topogenous* locations which have little percolation). Percolating systems can be fed both by groundwater and surface water (this usage differs from Succow and Lange (1984) who used the term just for what are here called *groundwater percolation mires*). Flow patterns depend upon the water source and peat permeability and can, in principle, be vertically up and down or lateral. However, it is likely that in most systems where percolation is a significant process, lateral flow through upper, transmissive peat layers may be particularly important; a feature of the surfaces of many percolating mires is that the peat is loose, quaking or buoyant. Examples that have GROUNDWATER as their main TELLURIC water source are referred to as *groundwater percolation* (or *seepage percolation*) systems. Examples which receive significant inputs of both GROUNDWATER and SURFACE RUN-OFF are referred to just as *percolation systems*.

2.5.7 Groundwater

Unqualified, 'groundwater' is used adjectivally for various (mostly TOPOGENOUS) wetlands which have some hydraulic relationship to adjoining mineral aquifers, but which are not referable to the other categories of SEEPAGE, FLUSHES or GROUNDWATER PERCOLATION. This is therefore a rather non-specific, catch-all category which encompasses the following situations: (a) locations where the wetland infill is in hydraulic connection with the mineral aquifer, but where there appears to be rather limited water exchange between the two (sometimes because the wetland infill is only slowly permeable); (b) locations where the groundwater table is normally consistently below the surface of the wetland; and (c) locations (usually part-drained and often with a fairly low-permeability infill) where groundwater outflow at the margins is largely captured by drains or dykes and makes limited ingress into the wetland deposit.

2.6 Water flow tracks and channels

2.6.1 Runnels

Runnels are small lines of water flow on fairly steep slopes, often on a skeletal substratum. They typically form narrow channels winding amongst small TUMPS and TUSSOCKS and can be distinguished from SOAKWAYS and WATER TRACKS by their smaller size and, usually, by being less sluggish. They also normally just form an element within a mosaiciform mire community, whereas soakways and water tracks normally support a vegetation type different to that of the main area of wetland through which they flow.

2.6.2 Soakways

Soakways are water FLOW TRACKS within wetlands which can be detected by the contrast in their vegetation and wetness relative to the flanking mire. They are distinguished here from WATER TRACKS by being almost completely vegetated and having little surface water, except in times of flood and so on. They can intergrade into, and may flank, water tracks. This compass of 'soakway' is narrower than that implied by Rodwell's (1991b) use of the term as a community suffix (for example, for M29)[1].

2.6.3 Water tracks

Water tracks are particularly wet FLOW TRACKS within wetlands, and can be regarded as proto-streams. They can be distinguished from soakways under most conditions by a high proportion of surface water, sometimes with visible flow, and from streams by having patches or tussocks of mire vegetation or species across most or all of their width. They sometimes consist of an anastomosing series of small water channels separated by TUMPS or TUSSOCKS of vegetation.

2.6.4 Flow tracks

This is used as a generic term for distinct, linear zones of focussed surface or near-surface water flow within wetlands, and includes RUNNELS, SOAKWAYS and WATER TRACKS.

2.6.5 Dykes

Dykes are ditches within more or less flat wetlands and generally have a consistently high water level. They may have a drainage or water supply function at different times of the year, depending on their water level. This may be below the mire surface in summer, but can flood across the surface in wet conditions. Dykes are often deep (two metres is not unusual) and can be wide (up to three metres). This definition of a dyke primarily reflects usage in East Anglia and should not be confused with other definitions used elsewhere in Britain (for example, for a wall or bank).

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1 The community units of Rodwell (1991b) are based on floristic composition and in our view little is to be gained – other than confusion – by incorporating a habitat type (such as soakway) into their name.

2.6.6 Drains

Drains are usually ditches within or alongside wetlands, dug with the primary intention of drainage and in which the water level usually stays well below the surface of the adjoining mire, other than in exceptionally wet circumstances. They occur both in sloping and more or less flat sites, but are often (though not always) less substantial structures than DYKES.

3 Aspects of the ecohydrology of wetlands

3.1 Wetland vegetation and species

3.1.1 Wetland plants and water

Considered together, wetlands provide a rich habitat for plant species. About 650 plant species have been recorded from telmatic wetlands in Britain, though less than half of these (around 250 species in the UK) can be considered to be specifically characteristic of this habitat. Thus, a substantial number of plant species regularly found in wetlands also grow in dry sites. Such ‘dryland species’ are not necessarily confined to dry microsites in wetlands, nor are ‘wetland species’ always found in especially wet conditions. As a consequence, as a generic category the concept of ‘wetland plants’ can be misleading.

The primary problem to be overcome by plants that grow in waterlogged soils is anoxia and strongly reducing conditions in the substratum, induced by the low solubility and diffusion rates of oxygen in water (compared to the atmosphere). Not only are oxygen deficits a constraint upon the aerobic respiration of rooting structures, they are also often associated with an increased availability of reduced phytotoxins, especially Mn^{2+}, Fe^{2+} and S^{-}. The most important adaptations to waterlogging found amongst the plants in the wetlands considered in this report are shallow rooting and root ventilation (Wheeler, 1999a) (see Box 3.1). However, whilst it may have some substance, it is erroneous to think that all wetland plants are particularly tolerant of waterlogging. Some are as sensitive to high concentrations of reduced phytotoxins as many dryland species.

3.1.2 Plant communities of wetlands

With the publication of the National Vegetation Classification (NVC) volumes for wetlands (Rodwell, 1991a, b; 1995), plant communities (units of vegetation characterised by a distinctive species composition) have become widely accepted and used as categories of vegetation description. They have also been widely adopted as units of vegetation resource: they have been mapped and measured, used in inventories and for assessing conservation value and there is a widespread presumption that distinctive communities occur in distinctive habitats and have specifiable habitat ranges. The main NVC plant communities of the wetlands considered in this project are outlined in Table 3.1. Wheeler and Proctor (2000) have proposed an informal terminology for these (Table 3.2).

Table 3.1 Main wetland plant communities mentioned in the report

NVC[1] code	Scientific name	Common name[2]	Comments
M3	*Eriophorum angustifolium* bog pool community	Common cotton-grass community	Mainly associated with blanket mire; also widespread, but local in some lowland mires and heaths. Typically found as small stands on acid peat in depressions, erosion channels or shallow peat cuttings.
M4[n]	*Carex rostrata–Sphagnum recurvum mire*	Bottle sedge–Bog moss community.	A species-poor, poor-fen community, primarily comprising a carpet of Sphagna with a cover of sedges and impoverished herb flora. Supports a few uncommon species. Mainly a western and northern distribution in Britain. Typically found in conditions which are base-poor and generally of low to moderate fertility, with summer water levels at or near the surface. Examples are included in the SAC category "transition mire and quaking bog".
M5[n]	*Carex rostrata–Sphagnum squarrosum mire*	Bottle sedge–Bog moss community	Characterised by the dominance of sedges with scattered poor-fen herbs over a patchy carpet of moderately base-tolerant Sphagna (particularly *S. squarrosum* and *S. palustre*). Mainly a western and northern distribution in Britain. Typically found as a floating raft, with water level generally close to the surface year round, and in moderately base-poor and moderately fertile conditions. Examples are included in the SAC category "transition mire and quaking bog".
M9[eu] (M9-1 and M9-2)	*Carex rostrata–Calliergon cuspidatum* mire or *Acrocladio-Caricetum*	Bottle sedge–Brown moss community	Widespread in Britain, but rare in the South and West and can be particularly important in supporting rare fen species. Examples here are included in the SAC category "calcium-rich spring water-fed fens". Some examples have been included in the "transition mire" and "chalk-rich fen dominated by saw sedge" SAC categories. A community of low fertility, wet, topogenous situations, usually of low base status. Particularly vulnerable to lowered water tables and eutrophication, although floating raft may provide some accommodation. Note that in the accounts of the ecohydrology of wetland plant communities provided in this report, evidence is presented that 'M9' is not a very good community and it has been subdivided into M9-1 (*Carex lasiocarpa–Scorpidium* mire) and M9-2 (*Carex diandra–Calliergon* mire), which correspond broadly but by no means exactly with M9a and M9b.

[1] NVC = National Vegetation Classification (Rodwell, 1991a,b; 1995).

[2] Note that these common names are provided for guidance, and are not necessarily officially accepted.

NVC[1] code	Scientific name	Common name[2]	Comments
M9-3[u]	*Carex diandra–Peucedanum palustre* mire (*ex. Peucedano-Phragmitetum caricetosum (PPc)* [e]	Milk parsley–Slender sedge community	A fine-leaved sedge–brown moss community, of restricted distribution in the UK (recorded only from Broadland), and supporting some internationally rare species (such as *Liparis loeselii*). Typically associated with conditions of low fertility and moderate though relatively constant water tables in topogenous fens. Stands require management (usually mowing or burning), and possibly periodic excavation of peat to maintain hydroseral conditions. Particularly vulnerable to lowered water tables and eutrophication, although floating raft may provide some accommodation. Included in the SAC category "chalk-rich fen dominated by saw sedge". Note the change in name from *Peucedano-Phragmitetum caricetosum (PPc)* to *Carex diandra–Peucedanum palustre* mire (see community accounts in Part 3 of this report).
M10 [n]	*Pinguicula vulgaris –Carex dioica mire*	Butterwort–Dioecious sedge community	Generally an open sward, dominated by low-growing monocots (mainly sedges). *Molinia* and/or rushes are sometimes prominent; there is often an extensive bryophyte component and a wide range of associated short herbs. Typically found in soligenous conditions of relatively high base status but low fertility, where summer water levels are close to the surface between tussocks. Stands require management (light grazing). Examples are included in the SAC category "calcium-rich spring water-fed fens".
M13 [eu]	*Schoenus nigricans –Juncus subnodulosus* mire or *Schoeno-Juncetum*	Black bog rush–Blunt-flowered rush community	Widespread in southern Britain, but of rare occurrence and can be particularly important in supporting rare fen species. Typically associated with low fertility, very base-rich spring-fed sites, where summer water tables are usually close to the surface. Management is required (mowing or grazing). Examples are included in the SAC categories "calcium-rich spring water-fed fens" and "chalk-rich fen dominated by saw sedge".
M14 [n]	*Schoenus nigricans –Narthecium ossifragum* mire	Black bog rush–Bog asphodel community	Uncommon community, largely confined to Southern England (although a similar vegetation type occurs in Scotland). Typically found in sites where there is a strong soligenous input of water, which is of moderate base status and low fertility. Water can have a quite high pH (> 6) but is weakly buffered. Particularly vulnerable to lowered water tables and eutrophication. Requires moderate grazing pressure to maintain diversity. Examples are included in the SAC categories "chalk-rich fen dominated by saw sedge" and "transition mire and quaking bogs".
M18 [n]	*Erica tetralix–Sphagnum papillosum raised and blanket mire*	Cross-leaved heath –Bog moss community	Considered to be the natural core community type of lowland raised bogs. Vegetation generally dominated by Sphagna with a few ericaceous sub-shrubs (such as *Calluna vulgaris*), monocotyledons (such as *Eriophorum* spp) and herbs. Supports several uncommon or rare species. Solely dependent on rainfall for water supply, and thus has a mainly western and northern distribution in Britain. Particularly vulnerable to lowered water tables, eutrophication and increase in base status. Some examples are included in the SAC category "active raised bogs"
M21 [n]	*Narthecium ossifragum–Sphagnum papillosum* valley mire	Bog asphodel–Bog moss community	A local community of the southern lowlands. Characteristic of base-poor soligenous situations of low fertility. Particularly vulnerable to lowered water tables and eutrophication. Some examples are included in the SAC category "depressions on peat substrates (*Rhynchosporion*)" (though this community rarely occurs in such situations, nor is it referable to the *Rhynchosporion*).

NVC[1] code	Scientific name	Common name[2]	Comments
M22 [e]	*Juncus subnodulosus–Cirsium palustre* fen meadow	Blunt-flowered rush –Marsh thistle community.	The most widespread form of rich-fen vegetation in England and Wales, associated with a wide range of habitat conditions. The most species-rich examples are managed, usually by grazing. Low water levels tend to be associated with the loss of fen species. A few examples are included in the SAC category “chalk-rich fen dominated by saw sedge”, but this is exceptional.
M24 [e]	*Molinia caerulea–Cirsium dissectum* fen meadow or *Cirsio-Molinietum*	Purple moor grass –Meadow thistle community	Widespread through the lowland south of Britain, but becoming more localised. On the borderline between fen and wet grassland – typically associated with low fertility substrata and relatively low water levels. Lack of management can lead to loss of species. Examples are included in the SAC category “chalk-rich fen dominated by saw sedge” and (probably) “*Molinia* meadows on chalk and clay”.
M25	*Molinia caerulea–Potentilla erecta* mire	Purple moor grass –Tormentil community	Occurs throughout Western Britain, and is especially frequent in South-West England, Wales and southern Scotland. Uncommon in East Anglia. Very poorly defined. A community of moist but well-aerated acid to neutral peats and peaty mineral soils in the lowlands and upland fringes. The most species-rich examples are managed, usually by grazing. Not included within an SAC category.
M26	*Molinia caerulea–Crepis paludosa mire*	Purple moor grass–Marsh hawksbeard community	A fairly scarce community of parts of northern Britain, occurring on relatively base-rich, but relatively low fertility soils; possibly a geographical vicariant of M24. Examples included within “*Molinia* meadows on chalk and clay (Eu-MOLINION)” SAC category.
M29 [n]	*Hypericum elodes –Potamogeton polygonifolius soakway*	Marsh St John’s Wort–Bog pondweed community	Typically consists of mats of *Hypericum elodes* and *Potamogeton polygonifolius* within a submerged carpet of *Sphagnum auriculatum*, but with a limited range of vascular associates. Has an exclusively western distribution in Britain. Characteristic of base-poor oligotrophic pools and soakways, often shallowly flooded, but may occasionally dry out. Some examples are included within “transition mire and quaking bogs” SAC category
S1 [e]	*Carex elata* sedge swamp	Tufted sedge community	An uncommon community, restricted to a few localities in West Norfolk, Anglesey and Cumbria. Usually occurs as emergent vegetation in shallow pools (including pingos and peat cuttings). May form an unstable, semi-floating mat.
S2 [e]	*Cladium mariscus* sedge swamp	Saw sedge community	Generally uncommon in Britain, and many examples are fragmentary. Species-poor and of limited floristic interest. Typically found in fairly nutrient-poor, base-rich situations in wet hollows in fens and flooded peat pits. Examples are included in the SAC category “chalk-rich fen dominated by saw sedge”.
S4	*Phragmites australis* swamp and reed-beds	Common reed community	A widespread community, but frequently only as fragmentary stands, making the extensive and managed stands in Broadland of particular importance. Associated with a wide range of habitat conditions, but typically relatively fertile substrata. Not of great botanical interest (except for some of the wettest examples), but especially prized as supporting various rare birds and invertebrates.
S5	*Glyceria maxima* swamp	Reed sweet-grass community	A lowland community, commonest in the Midlands and East of England. Very species-poor and of limited floristic interest. Especially characteristic of nutrient-rich, circumneutral to basic mineral substrata (alluvia), or on fen peats irrigated by nutrient-rich waters.

NVC[1] code	Scientific name	Common name[2]	Comments
S24 [e]	*Phragmites australis–Peucedanum palustre fen*	Common reed–Milk parsley community	A very localised community in Britain, for which Broadland is particularly important. Associated with a range of habitat conditions, but typically of only moderate fertility. Low water levels tend to lead to an increase in grassland species. Vegetation management is essential to maintain species richness. The community has added importance as the main vegetation type supporting milk parsley, the food plant of the rare swallow-tail butterfly. Examples here are included in the SAC category "chalk-rich fen dominated by saw sedge" (although note that not all stands of S24 necessarily support *Cladium mariscus*).
S25	*Phragmites australis–Eupatorium cannabinum* tall-herb fen	Common reed–Hemp agrimony community	A widespread, but rather variable, mixed tall fen vegetation, often of only moderate species richness. Most characteristic of base-rich and fairly fertile conditions. Stands are normally unmanaged (or occasionally grazed or burnt), although may have been grazed or mown in the past. Some examples are included in the SAC category "chalk-rich fen dominated by saw sedge".
S27 [n]	*Carex rostrata–Potentilla palustris* fen or *Potentillo-Caricetum*	Bottle sedge–Marsh cinquefoil community.	A widespread community in Britain, but mainly in the North and West. Typically associated with wet, topogenous situations, usually as a floating raft, and thus with some accommodation of variations in water level. Examples are included in the SAC category "transition mire and quaking bog".

e: see Wheeler and Shaw (2000a) for community account.
n: new account of the community in this volume.
u: community account in Wheeler and Shaw (2000a) has been updated in this volume.

One of the main benefits of an agreed vegetation classification is the development of a taxonomy for vegetation analogous to (and as important as) the development of a taxonomy for species. Like species, *community types* are abstractions, derived by comparing 'real' individuals (patches of vegetation or *stands*). However, unlike species, communities are not produced by reproduction and the inheritance of genetically determined attributes, but by stochastic colonisation of a suitable habitat by a range of adapted species. Thus, attributes used to define communities (the species present) are much more likely to vary, or to be missing, than features used to define species. Like species, communities are expressed on the ground as real entities (stands), but these 'individuals', unlike most species, are not discrete and physically merge into one another to a greater or lesser extent. Indeed, one well-established tradition in plant ecology, associated particularly with American workers such as J.T. Curtis (Bray and Curtis, 1957), has regarded vegetation as a continuum, with continuous variation both amongst stands and amongst abstracted community types – a perspective which has called into question the very existence of plant communities as discrete, recognisable, definable entities. Many European ecologists would dissent from such an extreme viewpoint, not least because the patchwork landscape of much of Europe – where vegetation boundaries have often been sharpened by human manipulation as well as by habitat contrasts – lends itself to the discernment of discrete units of vegetation; and also because, whatever the realities of floristic variation in the field, vegetation classification is pragmatically useful (just as we categorise that most continuous of variables, colour).

However, it is one thing to identify 'community types' as nodal points within a field of semi-continuous variation (Poore, 1955) and to use them as convenient descriptive labels (as is the case with colours); it is quite another to try to specify their limits. This difficulty has long been recognised, but it has come into sharp focus now that plant communities are used as a basis for some conservation activities (such as for implementing the EC Habitat and Species Directive) and where, as part of this process, there may be a desire to identify threshold habitat conditions appropriate to sustain particular community types.

Yet plant community types are neither uniform nor absolute units. The identity and scope of a community type can vary with the method used to identify it. The range of samples allocated to it may depend on both its underlying concept (definition) and the perception of the operator as to which samples fit it most appropriately (see Box 3.2). Floristic variation within a community type often reflects environmental variation and peripheral members of the unit may be associated with rather different environmental conditions (such as water levels) than core members. Hence, any attempt to specify the habitat range of a community depends critically upon the precise compass of the unit and the range of samples that are considered to be appropriate members of it.

Box 3.1: Adaptation of plants to waterlogging

WATERLOGGING AVOIDANCE

Shallow rooting

One apparently widespread strategy for avoiding excessive waterlogging is shallow rooting, by which plants – including some species confined to wetlands – root in the uppermost, better-aerated layers of wetland soils. The formation of 'plate roots' by many tree species growing in wetlands provides a good illustration of this trait, but many of the rarer herbaceous species show a similar response (such as Orchidaceae, *Drosera anglica, Parnassia palustris, Viola palustris*) (Metsävainio, 1931; Schat, 1984). Ironically, this adaptation to waterlogging may mean that some of these species are especially sensitive to a prolonged reduction in water tables, when these fall well below the shallow rooting layers.

WATERLOGGING TOLERANCE

Anaerobic metabolism

The roots of some wetland plants can endure periods of anoxia, and various suggestions have been made that they may be well adapted to forms of anaerobic respiration. However, whilst anaerobic metabolism may provide some plants with tolerance to waterlogging episodes, in general it seems to provide a mechanism by which they endure short unfavourable periods rather than conferring long-term tolerance.

Root ventilation and radial oxygen loss

Oxygen transfer from shoots to roots is almost certainly critical for the survival of many vascular plant species in waterlogged conditions. Shoot and root porosity is positively correlated with tolerance both to waterlogging and to reduced toxins, and it appears that the shoots of many wetland plants act as "snorkels". Not only does such root ventilation help maintain oxic conditions within the root, it can also provide for outwards diffusion of O_2 from the root surface (or enzymic oxidation upon this) to create a thin, oxidised rhizosphere which may help to immobilise potential plant toxins (for example, by precipitation of reduced iron as hydrated iron oxides on the root surface). The importance of this mechanism can be demonstrated empirically by cutting the shoots of some wetland species (such as *Cladium mariscus, Typha angustifolia*) beneath the water level in winter. This can cause their death or debilitation – effectively drowning them.

WATERLOGGING ESCAPE

Dormancy

Some dryland plants are able to grow in seasonal wetlands by becoming dormant (mainly as seeds) during the wet period, but this mechanism is generally of little importance for plant species of the permanent wetland habitats considered in this report. However, whilst plants of seasonal wetlands sometimes have well-developed seedbanks, and regenerate readily from seed, many of the plants of more stable wetlands – especially some of the rarer dicotyledonous species – do not have persistent seedbanks. This has considerable relevance *inter alia* to attempts to restore dry wetlands.

3.1.3 Conservation value of wetlands in England and Wales

Wetlands are valued highly by conservationists for their diversity of habitats and species, as well their range of often distinctive and localised plant communities. There are many sites of important wetland interest included within designated Sites of Special Scientific Interest (SSSIs), based around individual wetland sites or clusters of sites. The international importance of some of them has been recognised by their designation under the European Habitats and Species Directive as candidate Special Areas of Conservation (SACs), containing features of interest that appear to be distinguished primarily by their plant communities. SAC features included within the sites examined for this project are shown in Table 3.3, with examples given of some of the NVC community types considered to be included within them[1]. Some sites are also given international protection as Ramsar sites[2] and/or Special Protection Areas[3]. The conservation status of sites examined in this project is given in the corresponding site accounts in Appendix 3.

The importance of the conservation value of bog and fen habitat has been recognised in the identification of "fens" and "lowland raised bog" (as well as blanket bog and wet woodland) as priority habitats under the UK Biodiversity Action Plan (HMSO, 1995)[4]. In addition, the habitats support rare species such as the fen orchid *Liparis loeselii* – an endangered species listed on the BAP shortlist of globally threatened/declining species and as a key BAP species. The narrow-mouth whorl snail (*Vertigo angustior*) and Desmoulin's snail (*Vertigo moulinsiana*) are also BAP shortlist and key species, with RDB1 and RDB3 status respectively.

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1 Some *NVC* community types may be included in more than one SAC habitat type. However, we consider that any one stand should only be referred to one habitat type, although we understand that this may not be the approach adopted by English Nature.

2 Sites internationally important for their bird interest, and designated under the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat (1971). [See http://www.jncc.gov.uk/page-1389 for the list of UK Ramsar sites].

3 Sites internationally important for their bird interest, and designated under Article 4 of the European Council Directive 79/409 on the Conservation of Wild Birds. [See http://www.jncc.gov.uk/page-162 for more details]

4 Details of the Habitat Action Plans can be found at http://www.ukbap.org.uk/habitats.aspx

Table 3.2 Informal nomenclature and categorisation of some types of mire vegetation and habitat widespread in Britain and North-West Europe, in relation to NVC units and phytosociological higher units

(Modified from Wheeler and Proctor (2000))

Major mire type	Vegetation or habitat type	Trophic status*	NVC type (Rodwell 1991a, 1991b, 1995, 2000)	Phytosociological class, order or alliance
BOG	Bog pool	Oligo	M1, M2, M3	Scheuchzerio-Caricetea: Rhynchosporion
	Ombrotrophic bog: raised and blanket bog	Oligo	M17, M18, M19, M20	Oxycocco-Sphagnetea: Erico-Sphagnion
	Oligotrophic bog: groundwater influenced	Oligo	M21 [also often M17, M18]	Oxycocco-Sphagnetea: Erico-Sphagnion
	Birch (or pine) bog woodland	Oligo	W4	Erico-Pinetea: Betulion pubescentis
	Mesotrophic bog [poor fen]	Meso	M4–M7	Scheuchzerio-Caricetea: Caricion nigrae
	Molinia bog	Meso	M25	Molinietalia: Molinion
	Acid rushy pasture	Meso	M23	Molinietalia: Junco-Molinion
FEN	Small-sedge fen	Oligo/ Meso	M10, M13, M14	Scheuchzerio-Caricetea: Caricion davallianae
	Slender-sedge fen	Oligo/ Meso	M8, M9, PPC	Scheuchzerio-Caricetea: Caricion lasiocarpae
	Fen meadow	Oligo/ Meso	M22, M24, M26	Molinietalia: Calthion, Molinion
	Tall herb fen, Reed fen**	Meso/ Eu	M27, S4, S24–S26, S28, OV26 (some in part only)	Molinietalia: Filipendulion Phragmitetea: Phragmition, Magnocaricion, Galio-Urticetea: Convolvulion
	Tall sedge fen	Meso/ Eu	S1, S3, S7, S11	Phragmitetea: Magnocaricion
	Fen woodland (fen carr)	Meso/ Eu	W1–3, W5	Alnetea glutinosae: Alnion glutinosae; Salicion cinereae,
	Wet woodland	Eu	W6, W7	Salicetea purpureae: Salicion albae; Querco-Fagetea: Alno Ulmion
SWAMP	Named after dominant species (e.g. reed swamp**, Cladium swamp)	(Various)	S1–S23, S27, S28 (some in part only)	Phragmitetea: Phragmition, Magnocaricion

* Oligo = oligotrophic; Meso = mesotrophic; Eu = eutrophic
** Reedbed = reed swamp + reed fen

Box 3.2: Identification of plant communities

Any attempt at classification consists of two linked processes: (i) 'class creation', the identification of categories (classes) that are in some sense meaningful, based on selected features (attributes) of the individuals (samples) that are the subject of the classification; and (ii) 'allocation', the assignment of individuals to the class to which they best belong. The samples to be allocated include those used in the initial identification of the classes, plus any new samples which have become available subsequently. If the existing classification is comprehensive and robust, most new samples should fit into it fairly well (though there are always likely to be some deviants); if this is not the case some new samples may be difficult to allocate, and their incorporation may require the redefinition of existing units or the creation of new ones. Ideally, the classification process is iterative, and a classification scheme evolves to take account of new information until it becomes comprehensive and robust. However, the extent to which such iterative development occurs is, in practice, largely determined by the degree of investment in the existing classification: it may be considered undesirable or impractical to change a well-established classification even though the acquisition of new samples may suggest that this would be beneficial. Thus, there is often a tendency for classifications to become static and prescriptive rather than dynamic and responsive to new information. Hence, two major areas of classifications can be defective: (i) the extent to which the classes themselves are valid (how well they represent the samples on which they are based and especially, the extent to which they are valid for new samples); and (ii) the accuracy of allocation of samples to classes (this relates to the validity of the classes themselves but also, in the case of informal allocation procedures, to the degree to which the allocator understands the basis of the classes in relation to the properties of samples to be allocated).

Various approaches and features have been used to identify plant communities. The two main approaches in Europe have been the use of species dominance and of species composition. There is now fair agreement that the best approach, given abundant computational power, is to use full floristic composition (species present plus an estimate of their abundance). A range of numerical classification procedures is available to help generate floristic classifications, though it is important to recognise that numerical procedures have different propensities and may generate rather different classifications of the same dataset. As the correct classification of vegetation samples is not known in advance, it is often difficult to decide objectively which procedure – and which set of derived vegetation units – can be considered best!

In Britain, the National Vegetation Classification (NVC), which is ostensibly a floristically-based approach, has become the *de facto* standard for the classification of plant communities and is very widely used. However, its co-ordinator observed that "*we never thought of this work as providing the last word on the classification of British plant communities; indeed, with the limited resources at our disposal, we knew it could offer no more than a first approximation*" (Rodwell, 1991a). There is undoubtedly scope for questioning and revising parts of the NVC classification (as has been recognised by the original authors (Rodwell *et al.,* 2000). Some units were created on the basis of a very small number of samples. Another limitation, perhaps less obvious, is that parts of the classification do not reflect the true floristic relationships between different units. In part, this is due to the inevitable difficulties of condensing multidimensional floristic variation into a small number of comprehensible units, but some of the major NVC subdivisions are also more physiognomic than floristic in character. For example, in the fens of Broadland it is possible to collect samples of vegetation with *identical* species composition (though with differing abundances), from herbaceous fen (classified as a type *of Peucedano-Phragmitetum* (S24)) and from fen woodland (a form of *Salix–Betula–Phragmites* woodland (W2)), in a quite different part of the classification scheme (Volume 4 *versus* Volume 1)). Of course, workers may regard vegetation with many trees as being quite different to that with few trees so that, whatever its violations of actual floristic relationships, the NVC approach may be considered intuitively appropriate. However, in identifying relationships between floristic composition and environmental regimes, *NVC* categories can sometimes confound the identification of floristic trends and links, rather than providing a basis for their assessment.

Allocating individual stands recorded in new surveys to predefined NVC communities can also be problematic. This task is often performed by workers with no part in the original identification of NVC communities, but there is no standard or mechanism for determining the correct community (the published accounts do not always provide guidance on the precise diagnostic features of communities). Accordingly, different workers may allocate the same stand to different communities. Problems arise with samples that fit none of the NVC units well. Surveyors may be reluctant, or unable, to modify NVC categories or create new ones and, rather than leave samples unclassified, they may squeeze them into an existing unit. Multivariate classifications can also be unhelpful when classifying deviant stands – these may be forced into the class with which they are least dissimilar, even though they may have no real affinities to it. Apart from being inaccurate, mis-allocation of samples can have detrimental repercussions when assessing the conditions required to maintain or restore particular stands or communities.

These problems are common to most vegetation classifications and not a specific criticism of the NVC or of any workers concerned, who are well aware of the pitfalls involved. However, as a *de facto* standard NVC is widely used, sometimes for purposes for which it was not designed and by workers who may not fully appreciate its limitations. The comments made here are intended to emphasise that community types are rather uncertain units, which lack an objective reality, and that considerable care should be taken in the use made of them.

Table 3.3 Wetland EC Habitats Directive features (SAC habitats and species) of interest in the study sites

Name of feature in Habitats Directive§	UK name for feature	cSACs included for which the feature is designated**	Examples of NVC types which have been included within the feature***
Active raised bogs	Active raised bogs	Craven Limestone Complex; Fenn's, Whixall, Bettisfield, Wem and Cadney Mosses; Rhos Goch; South Solway Mosses ; Walton Moss; Witherslack Mosses	*Sphagnum auriculatum* bog pool community (M1); *Sphagnum cuspidatum/recurvum* bog pool community (M2); *Eriophorum angustifolium* bog pool community (M3); *Erica tetralix–Sphagnum papillosum* raised and blanket mire (M18); *Calluna vulgaris–Eriophorum vaginatum* blanket mire (M19); *Eriophorum vaginatum* blanket and raised mire (M20).
Alkaline fens	Calcium-rich spring water-fed fens	Asby Complex; Corsydd Llyn / Lleyn fens; Corsydd Môn/ Anglesey Fens; Cothill Fen; Craven limestone complex; Cwm Cadlan; Dorset Heaths[Q]; Norfolk Valley Fens; Newham Fen; The Broads; The New Forest[Q]	Mainly represented by *Schoenus nigricans–Juncus subnodulosus* mire (M13), but sometimes by *Carex rostrata–Calliergon cuspidatum* mire (M9) and *Pinguicula vulgaris–Carex dioica* mire (M10).
Calcareous fen with *Cladium mariscus* and species of the CARICION DAVALLIANAE*	Chalk-rich fen dominated by saw sedge (great fen sedge).	Asby Complex[Q]; Corsydd Llyn / Lleyn fens[Q]; Corsydd Môn/ Anglesey Fens; Dorset Heaths[Q]; Fenland; Norfolk Valley Fens[Q]; The Broads; Waveney/ Little Ouse Valley Fens;	*Cladium mariscus* sedge swamp (S2), *Phragmites australis–Peucedanum palustre* fen (S24) [*Juncus subnodulosus–Cirsium palustre* fen meadow (M22)]. May also include *Phragmites australis–Eupatorium cannabinum* tall-herb fen (S25), *Carex rostrata–Calliergon cuspidatum/giganteum* mire (M9), *Schoenus nigricans–Juncus subnodulosus* mire (M13), *Schoenus nigricans–Narthecium ossifragum* mire (M14), *Molinia caerulea–Cirsium dissectum* fen meadow (M24)
Depressions on peat substrates (RHYNCHOSPORION)	Depressions on peat substrates	Dorset Heaths; Roydon Common and Dersingham Bog; Subberthwaite, Blawith and Torver Low Commons[Q]; The New Forest; Thursley, Ash, Pirbright and Chobham	In southern localities, often associated with *Narthecium ossifragum –Sphagnum papillosum* valley mire (M21); in the North and West, may be found on raised mires and blanket bogs.

Name of feature in Habitats Directive§	UK name for feature	cSACs included for which the feature is designated**	Examples of NVC types which have been included within the feature***
Molinia meadows on chalk and clay (Eu-MOLINION).	Purple moor grass meadows	Asby Complex, Craven Limestone Complex; Dorset Heaths[Q]; Fenland; Norfolk Valley Fens[Q]; The Broads[Q]; The New Forest; Waveney/ Little Ouse Valley Fens; Corsydd Môn/ Anglesey Fens[Q]; NW Pembs Commons, Cwm Cadlan; Rhos Goch[Q];	*Molinia caerulea–Cirsium dissectum* fen meadow (M24); *Molinia caerulea–Crepis paludosa* mire (M26)
Transition mire and quaking bogs	Very wet mires often identified by an unstable 'quaking' surface	Emer Bog; Shortheath Common; Subberthwaite; The New Forest[Q]; Tarn Moss; The Broads; West Midlands Mosses; Corsydd Eifionydd; NW Pembs Commons, Rhos Goch	*Carex rostrata–Calliergon cuspidatum* mire (M9); *Carex rostrata–Potentilla palustris* fen (S27); *Carex rostrata–Sphagnum recurvum* mire (M4); *Carex rostrata–Sphagnum squarrosum* mire (M5); *Carex rostrata–Sphagnum warnstorfii* mire (M8). (This category may also include forms of M2, M14 and M29. M21 *Narthecium ossifragum–Sphagnum papillosum* valley mire is excluded as it is not transitional in a successional sense or in terms of its soil chemistry. Not all examples of M9 *Carex–Calliergon* mire belong to this Annex I type; where it occurs in more base-rich conditions or in association with other rich fen communities, it may be referable to alkaline fens; or in stands where great fen-sedge *Cladium mariscus* is dominant, to calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*.)

* = Priority natural habitat types: those in danger of disappearance; and for which the EU has particular responsibility in view of the proportion of their natural range which falls within the EU territory
** Details of cSAC sites, Annex 1 habitats (SAC "interest features") and species can be found on the JNCC websites:
http://www.jncc.gov.uk/page-1458; http://www.jncc.gov.uk/ProtectedSites/SACselection/SAC_habitats.asp;
http://www.jncc.gov.uk/ProtectedSites/SACselection/SAC_species.asp
*** Details based on the "Interpretation Manual of European Union Habitats" (EUR-25), and from JNCC website (http://www.jncc.gov.uk/)
Q = Annex I habitats present as a qualifying feature, but not a primary reason for selection of the site

3.1.4 Environmental gradients and controls upon wetland vegetation

Wheeler and Shaw (1995b), using a canonical correspondence analysis (CCA) of floristic and environmental data from British fens, showed that the three main gradients in the species composition of British fen vegetation corresponded respectively to variation in base richness, fertility and water level (Figure 3.1). These same main gradients persist when data from ombrogenous bog vegetation is included in the analysis (Wheeler and Proctor, 2000), with a small increase in emphasis of the importance of the base-richness gradient.

Base richness

Variation in base-richness terms (pH, alkalinity and so on) constitutes the primary environmental gradient accounting for differences in vegetation composition within British bogs and fens. As in dryland systems, pH ([H^+] activity) has little direct impact upon plant species except at extreme values. pH values do, however, indicate or influence a variety of other hydrochemical properties of wetlands, including concentrations of phytotoxic metals with pH-related solubilities. pH shows a degree of discontinuity between samples buffered by humic acids, with pH generally below 5.5, and neutral to weakly alkaline sites buffered by the bicarbonate system (Wheeler and Proctor, 2000). The acidity of wetlands depends on the balance of metallic cations and strong-acid anions, which in turn depends upon the composition of their water sources and the capacity of these to buffer acidity produced endogenously by plants (especially *Sphagnum* species – Clymo, 1984), imported in acid rain, or arising in other ways (Urban, Eisenreich and Gorham 1986; Proctor 1992, 1995; Proctor and Maltby 1998). Base richness can be materially modified by changes in water source, or in the proportions of contrasting water sources, such as a proportionate increase in rainwater, reduction of river flooding and so on. Drying of wetlands can also sometimes lead to an increase in acidity, for example by the release of oxidised forms of sulphur. Acid rain is another potential influence, and may reinforce other changes (such as an increased proportion of rainwater). It may have greatest impact upon weakly buffered, high pH waters, such as those typically associated with *Schoenus nigricans–Narthecium ossifragum* mire (M14) vegetation.

Phytotoxic metals

Changing concentrations of certain metals (Al, Fe, Mn) form part of a composite base-richness gradient within fens (Wheeler and Shaw, 1995b), partly because their solubilities are strongly controlled by pH. However, solubilities of Fe and Mn are also strongly related to oxidation–reduction potentials and, despite the overall trend of increasing availability with decreasing pH, some water and soil samples from base-rich sites contain high concentrations of these metals. High concentrations of Fe are not only toxic to some wetland plant species, but also appear to help regulate the species composition of wetland vegetation in some field situations (Wheeler, Al-Farraj and Cook, 1985; Snowden and Wheeler, 1993).

Fertility

The fertility of wetlands (their capacity to support plant growth) is particularly determined by the availability of potentially growth-limiting nutrients, especially nitrogen, phosphorus and potassium (N, P and K). Wheeler and Shaw (1995b) found that the second main floristic gradient in fens corresponded to changes in nutrient availability and fertility. The fertility gradient was almost orthogonal to (largely independent of) variation in base richness. Acidic peats are usually among the least fertile substrata, but higher pH values do not necessarily coincide with greater nutrient availability – some highly calcareous fens have extremely low fertilities (Boyer and Wheeler 1989). This argues against the use by some authors (such as Ratcliffe, 1977) of fertility terms (oligo-, meso-, eutrophic) for pH categories.

Fertility can be difficult to assess. Various workers have found that simple measurements of N, P and K in mire waters or soil extracts may bear no relationship to fertility as assessed by the productivity of the vegetation measured *in situ* (for example Wheeler *et al*., 1992). It is not uncommon to find that concentrations of N and, particularly, P in the interstitial mire water are below detection limits in stands which by any other criteria (vegetation productivity, mass and composition) would be considered strongly eutrophic. By contrast, phytometric assays of soil fertility (by growth of a test species on soil samples in controlled conditions) show a strong relationship with *in situ* estimates of rates of vegetation productivity (Wheeler *et al*., 1992).

The fertility of wetlands is determined both by the chemical composition of inflowing waters and the characteristics of the substratum. In general, the most fertile examples are those subject to regular alluvial deposition whilst the least fertile are those fed by groundwater discharge from nutrient-poor aquifers. Enrichment of water sources by agricultural chemicals could be expected to have important impacts upon wetlands, but data are generally sparse and do not always allow simple interpretation. For example, Boyer and Wheeler (1989) found that spring water enriched with nitrogen from a Magnesian Limestone aquifer had little impact upon vegetation production and the composition of fen vegetation, because concentrations of phosphorus were limitingly low. Nor does the presence of tall, rank vegetation provide a clear indication of high fertility, because vegetation height and structure can be influenced by management regimes as well as by nutrient availability, and some tall slow-growing species (such as *Cladium mariscus*) can achieve near-monopolistic dominance even on infertile soils.

Water levels

In view of the undoubted importance of water to the character of wetlands, it may seem surprising that the floristic axis related to summer water levels is less important than those related to base richness or fertility. This is probably because water levels *within* the undrained wetland habitat show only rather limited point-to-point variation, and this is often equalled or exceeded by temporal variation. Water levels can affect plant growth by excess (waterlogging) (Box 3.1) or by deficiency (droughting) or by modifying other (especially hydrochemical) environmental characteristics (Box 3.3). Deficiency is probably of rather limited importance in many unmodified wetlands, but may become more significant with partial drainage – though some wetland plants can experience leaf water deficits even in waterlogged soils (Bradbury and Grace, 1983), due to high rates of water loss from the shoots and to constraints on water acquisition and transport. This may possibly explain the xerophytic character of some wetland plants (Yapp, 1912) and the ability of species such as black bog rush (*Schoenus nigricans*) to grow both in permanent seepages and in sun-baked Mediterranean *Rosmarinus* heaths (Zwillenberg and de Wit, 1951). The relationship between wetland vegetation and water levels is considered further below. Water regimes are intricately related to other environmental conditions in wetlands, especially nutrient availability, and within some (wet) systems neither deficiency nor anoxia are necessarily of great direct importance in determining species and community distribution. Wassen *et al.* (1990), investigating the Biebrza Marshes in Poland, concluded that their hydrodynamics determined vegetation composition primarily by regulating nutrient dynamics.

Water flow can also be of importance to wetland plant growth and distribution, for example through effects on oxidation–reduction potentials and nutrient availability (see Box 3.4).

Other gradients

Various other floristic–environmental gradients have been recognised in wetlands (Wheeler and Proctor, 2000), but the main gradient of consequence to the present study is that of fresh–brackish water (the 'lithotrophic–thallassotrophic' gradient of van Wirdum (1991)). This is of considerable local importance in some coastal sites (such as the Suffolk Broads) and also within some of the ostensibly freshwater wetlands of the Norfolk Broadland, where local development of more brackish conditions may be derived both from up-river tidal surges and from sub-surface layers of Romano-British estuarine clays, especially where these have been exposed by removal of the overlying peat.

Box 3.3: Wetland substrata and hydrochemical conditions

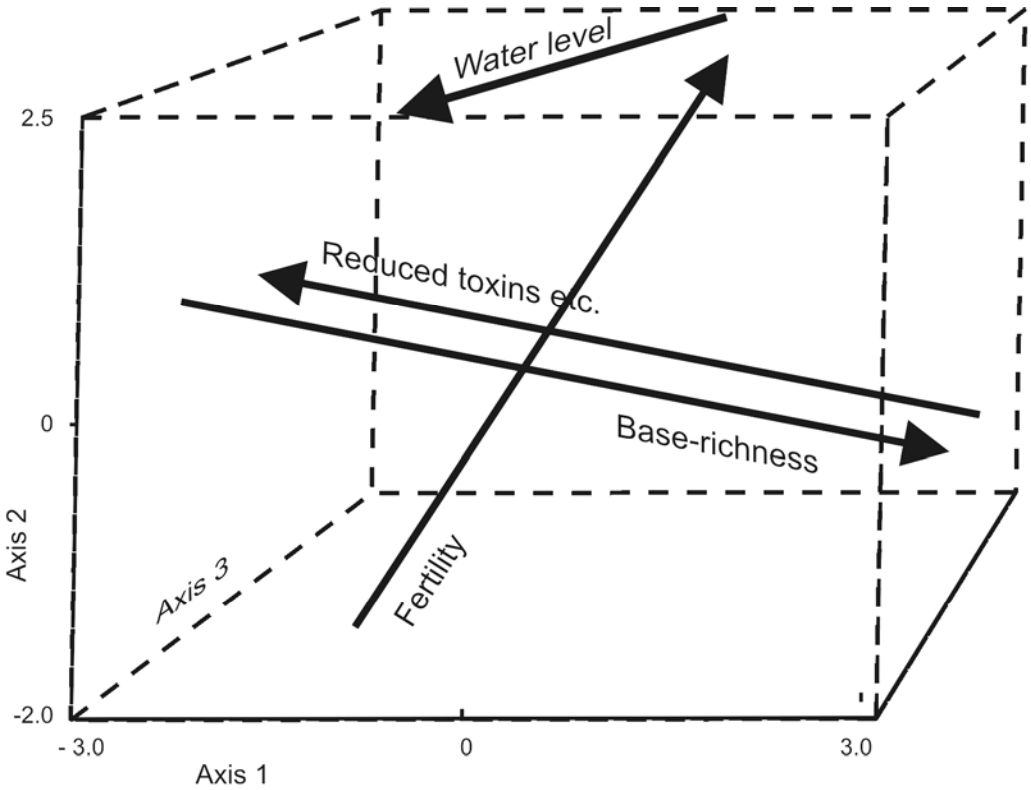
Ecohydrologists frequently consider variation in hydrochemical conditions in wetlands primarily in terms of the quality and contribution of different water sources (Wheeler, 1999a). In many situations, especially those with autochthonous substrata (such as peat) that have accumulated *in situ* under the influence of the inflowing water, this perception may be correct. However, where the substrata into which plants root are (partly) independent of the water supply (such as clays, sands), the properties of these materials may directly influence the chemical environment experienced by plant roots. Thus, Chalk water discharging onto a peat (or sand) surface often sustains a nutrient-poor wetland, but where it discharges onto alluvial silts, more fertile conditions are likely to prevail. Equally, some (drained) base-rich wetlands now appear to be irrigated exclusively by meteoric inputs, with high base richness maintained by a calcareous substratum (as occurs on, say, Chalk downlands), such as parts of Chippenham Fen (Cambridgeshire). Even in peat-based systems, the chemical environment experienced by plant roots does not necessarily correspond with the quality of the main water sources, often because of 'legacy conditions', that is, chemical conditions in the substratum established when the sites were subject to a different water supply mechanism to the current one. This is particularly likely where the contribution of groundwater supply has reduced, so that precipitation is now the main source of water to the wetland surface.

Box 3.4: Water flow in wetlands

Water flow occurs in many wetlands and its importance to plant growth and distribution has been recognised by various workers (such as Ingram, 1967; Daniels and Pearson, 1974); however, it has received rather limited study, doubtless partly because of technical difficulties in obtaining meaningful estimates of flow rates. Potentially complicating factors include those of scale and rate: slow lateral flow within wetland soils or affecting an entire wetland may have different, and probably less obvious, floristic impacts than more rapid flow concentrated into narrow flow tracks.

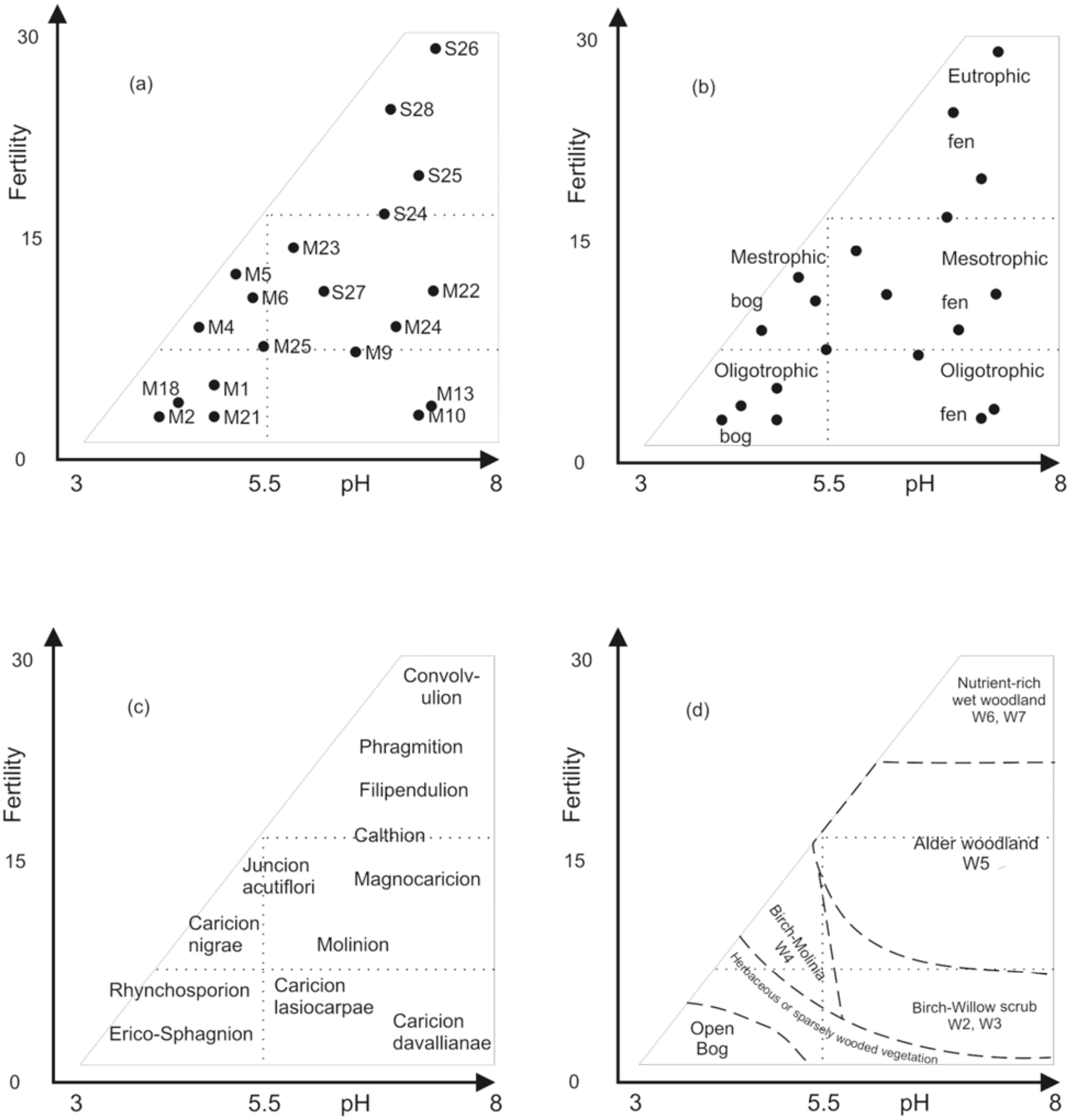
Flow can be important with respect to oxidation–reduction potentials. Several studies have shown that zones of moving water within wetlands often have higher redox potentials than more stagnant examples (Sparling, 1966; Armstrong and Boatman, 1967; Ingram, 1967, Shaw and Wheeler, 1991); that this may be associated with a lowered availability of phytotoxins with redox-related solubilities (Fe^{2+}, Mn^{2+}, S^{-}); and that some species (such as *Molinia caerulea*) can grow better in flow tracks than in stagnant, waterlogged soils (see Armstrong and Boatman, 1967). However, water flow is sometimes associated with *lower* redox potentials than in proximate more stagnant areas, such as where groundwater seepage is strongly reducing (sometimes in consequence of Fe^{2+} oxidation upon outflow).

Water movement can also increase the availability of nutrients to plant roots, both in terms of greater import of allochthonous solids (such as silt, alluvium) and increased rates of solute supply (Gorham, 1950; Chapin *et al*., 1988).



This is a conceptual diagram based on a Canonical Correspondence Analysis (see Appendix 2) of floristic and environmental data collected from fens throughout Britain. Axes 1, 2 and 3 correspond to the first, second and third most important gradients of variation in the species composition of fen vegetation. The direction of the arrows indicates the degree to which they correspond to the floristic gradients. The principal axis of vegetation variation corresponds quite closely to variation in base richness of the water (pH, alkalinity) and (inversely) to variation in the availability of phytotoxins such as Al^{+++}, Fe^{++} and Mn^{++}. The gradient of fertility (estimated phytometrically) is almost orthogonal to the base-rich gradient and corresponds well with the second main component of variation in the vegetation. The third axis of vegetation variation corresponds well to variation in summer water level, which is again almost orthogonal to both the base-richness and fertility gradients.

Figure 3.1 Main environmental gradients related to floristic composition of herbaceous vegetation in British Fens



(a) Approximate position of NVC plant community types, plotted by community mean values. (b) Subdivision of mires into broad pH and trophic status categories; category boundaries are approximate only. (c) Schematic arrangement of the main phytosociological Alliances of mires in relation to the proposed pH and trophic-status categories. (d) Schematic arrangement of the main categories of self-maintaining mire vegetation in Britain that might be expected to occur in the absence of human disturbance, plotted in relation to water pH and substratum fertility. The separating boundaries are tentative, and in general the categories will intergrade. The units shown represent the presumed climax or pro-climax state, excluding woody phases that may precede these in succession. The extent of non-wooded vegetation in this diagram will depend on factors including climate, topographical situation and water level. Fertility was estimated phytometrically by growth of *Phalaris arundinacea* seedlings on substratum samples; *y*-axis values are mg plant^{-1} from the data of Shaw & Wheeler (1991). Diagram is modified from Wheeler & Proctor (2000).

Figure 3.2 Variation of wetland vegetation in Britain relative to pH and substratum fertility

3.1.5 Water regimes and vegetation composition in wetlands

The level of water relative to the ground surface can have striking effects upon the composition of wetland vegetation, as seen in zonations around open water or along microtopographical gradients. However, it can be surprisingly difficult to relate species distributions to the height of the water table in between-site comparisons (Wheeler, 1999a). Even where there is a strong gradient of surface wetness, as around open water, individual species may occupy different positions along this gradient at different sites (Spence, 1964).

One important reason for this variability is that the water table at any one point is variable, and the amplitude and period of fluctuations can show large differences between sites and years. Even within a single wetland site, the temporal variation of water table at any one point is often equal to, or greater than, the point-to-point variation at any one time. Wheeler (1999a) reviewed evidence that, in different situations, species composition and community limits of wetland vegetation can be influenced by occasional extreme water level minima and maxima, by average minima and maxima, by average water levels, by the frequency and duration of fluctuations and by the timing of these events. In some (mainly low water table) situations, differences in soil hydrophysical properties are important in determining the relationship between water tables and soil water conditions in the main rooting zone (Von Müller, 1956; Gowing and Spoor, 1998).

In addition, the response of plants to water regimes can be strongly influenced by other environmental conditions and by the presence or absence of other species. The water level ranges occupied by plant species can be modified *inter alia* by oxidation–reduction potentials, water flow, concentrations of reduced toxins (especially Fe^{2+}, Mn^{2+} and S^{-}), availability of nutrients (NPK), competition with other plant species, and facilitative oxygenation of the rooting zone by companion species (Wheeler, 1999a; see also below).

Such considerations can help to explain why the search for an exact relationship between species distribution and water level has often proved elusive, particularly when making comparisons between sites. They also suggest that, unless these complications are taken into account, the specification of threshold values for water levels for individual species and communities can be misleading. Grootjans (1980) identified some water table limits for certain communities but, recognising the uncertainties involved, counselled against concluding that "*drainage within the indicated limits can be done without changing the floristic composition of the communities*". This may mean that the limits proposed have little practical value.

One approach to exploring species–water level relationships could be to make comparisons on a community basis, as this may help reduce the impact of extraneous variables – on the assumption that examples of communities occur in broadly comparable environmental conditions and occupy a smaller range of environmental variation than their component species. Moreover, as communities form a basis for the recognition and protection of EU habitats, there is a premium on understanding water level thresholds in relation to community limits. However, whilst there is some evidence that groups of species may show clearer relationships to water table behaviour than do individual species (Wierda *et al*., 1997), as plant communities are abstract, arbitrary and variable units, the use of syntaxa in exploring plant–water level relationships may sometimes prove more of a problem than a road to its solution (van Wirdum, 1986) (see also community accounts in Part 3 of this report).

The response of ecologists faced with the difficulties of establishing relationships between water levels and species distribution (or vegetation composition) has sometimes been to assume that more detailed hydrographic data are required, and more complex combinations of hydrographic parameters tested, to find the best fit. However, one possible explanation for some of the difficulties in identifying relationships is that no clear or simple relationships exist! A corollary of this may be that, for some species and vegetation types, precise water conditions are not as critical to their occurrence and survival as has sometimes been thought likely.

Relating water regimes to species distribution and community limits

There is an understandable desire to identify optimum water regimes and threshold values for individual wetland plants and community types, especially for conservation purposes. However, whilst water level optima and limits of various types have been published (for example, Newbould and Mountford, 1997), considerable caution is needed in the use of this approach. As this proposition may seem contentious, it is worth emphasising that a number of difficulties in relating water regimes to species distribution and community limits can arise, as outlined below.

Distributions are not necessarily in equilibrium with the water regime

Almost all attempts to relate species or community distributions to water levels are based on the correlation of field distributions of species or communities with measurements (or modelled estimates) of water regimes. Correlative approaches necessarily assume (but rarely demonstrate) an equilibrium between vegetation and water regime, but many ecohydrological studies are carried out in locations subject to considerable recent, and often ongoing, water management (drainage by water engineers or rewetting by conservation managers), in addition to climatically driven changes in water tables, and where assumptions of equilibrium may be especially questionable.

Distributions are determined by variables other than the water regime

The distribution of species and communities in the field is influenced by a number of variables other than water regimes (such as redox potential, pH, fertility, management). Unless all main variables other than water regime are constant, even at equilibrium the localisation and abundance of a particular species or community limit may not be determined primarily by water regime. Thus, unless the calibration of species and communities is comprehensive, based on measurements from a large number of contrasting sites, some apparent relationships to water tables may in fact reflect other environmental variations. For example, at Woodwalton Fen purple moor grass (*Molinia caerulea*) is restricted to patches of slightly elevated, mesotrophic and rather acidic peat (Poore, 1956), and its absence from the main areas of reed-dominated fen probably reflects the eutrophic character and rank vegetation of these stands rather than, or in addition to, particular water regimes. Even seemingly uniform sites can show considerable small-scale variation in conditions as well as in water levels (for example, zones alongside ditches and dykes often have higher fertilities and oxidation–reduction potentials than more remote locations). It can also be difficult to disentangle effects of water regimes from other environmental variables, because in some wetlands the main effect of water regimes upon vegetation distribution appears to be mediated by their impact on hydrochemical conditions (Wassen *et al*. 1990); and, conversely, because in some cases the species' tolerance to water regimes can be modified by associated environmental conditions.

Water regime tolerances can be modified by other variables

There is some evidence that the magnitude of certain environmental variables can modify species' responses to water regimes. Soil fertility has long been considered an important ameliorant of water level relationships in wet meadows and mires, particularly because various dryland species seem better able to grow in fertile wet soils than in infertile ones. For example, Ellenberg (1988) commented:

"Looking now to the wet end of our series of communities, we can add to the above saying another which at first looks equally paradoxical: 'nitrogen replaces oxygen'. Good manuring favours the species of the Arrhenatheretum in wet habitats where under less intensive methods swamp plants would get the upper hand. In parcels of land on homogeneous moist soils, it has been noticed repeatedly that those meadows which are more heavily manured carry a plant community indicating a relatively dry, better aerated soil; but these apparently fail as indicators here. In such cases, the soil may have had a dressing of compost or silt so that the level is raised and the drainage is improved, but there are also examples where no change in the soil or water levels can be detected and the manuring itself must be the deciding factor…If one wishes to use the meadow communities as indicators of dampness, then one must also take account of the fertility level."

Ivanov (1981) also considered:

"Wooded vegetation in mires serves as a good indicator of the mean long-term level of the water table. Its presence in plant associations itself indicates that the mean level is lower than where it is absent. The role of wooded vegetation as an indicator of mean levels is, however, different in oligotrophic conditions from what it is in eutrophic conditions." [Trees can generally grow in wetter locations in eutrophic conditions than in oligotrophic conditions]

Variation in oxidation–reduction potentials also affects species' response to water levels. For example, purple moor grass (*Molinia caerulea*) grows in wet conditions in water tracks, but tends to be confined to drier microsites in more stagnant parts of wetlands with lower redox potentials (Armstrong and Boatman, 1967). Phytotoxic elements can also affect distributions. Wheeler *et al*. (1985) showed that in 'normal' wetland soils (without excess Fe), greater growth of great hairy willow herb (*Epilobium hirsutum*) was measured in waterlogged conditions and at field capacity (FC) than at 80 per cent FC. But in iron-rich fen soils, growth in waterlogged and field capacity soils was smaller than that at 80 per cent FC (in the iron-rich soils, less iron was plant-available at 80 per cent FC than in wetter treatments because of lower solubility in the less strongly reducing conditions). These results were corroborated by field measurements which showed that *Epilobium hirsutum* was abundant only on iron-rich fen soils in rather dry conditions, whereas it could be dominant on permanently saturated soils when iron concentrations were low.

Such observations reinforce the need for species–water table relationships to be assessed in a large number of sites with contrasting environmental conditions, if they are to be generically valid.

Quantifying water regimes

Various approaches have been used to identify hydrological terms that can be related to species distributions in wetlands. Spieksma, Schouwenaars and Van Diggelen (1995) considered that the most discriminating variables (with regard to the occurrence of plant communities) were the mean, highest and lowest groundwater levels, together with the possibility of inundation during the growing season. Wierda *et al*. (1997) concluded that the mean highest water level was particularly important in controlling the occurrence of plant species in some types of wetland, along with amplitude of fluctuation. Scholle and Schrautzer (1993) used the combination of average water level, a Groundwater Fluctuation Index (which assessed the fluctuation pattern), and the duration of inundation to characterise six water regime types, each of which could be related quite closely to vegetation composition. Various workers have concluded that the cumulative period of time for which a particular water level is exceeded can provide a sensitive characterisation of hydrological regimes with regard to vegetation composition (see Niemann, 1963). This concept takes into account both the magnitude and duration of water level fluctuation. In Britain, Gowing and Spoor (1998) have developed a related approach and have derived 'sum exceedance values' which quantify the depth–duration the water table is above or below a specified threshold value (see Box 3.5).

Box 3.5: Sum exceedance values (SEVs)

Sum exceedance values have been developed to quantify the water regime of wet grasslands in a way which can be related meaningfully to species distributions and abundance (Gowing and Spoor, 1998; Silvertown *et al.* 1999). They have also been applied to some undrained fens in Eastern England (Adams, Gilman and Williams, 1994). The concept is based on two terms: a 'dryness SEV' (m weeks), which is the period of time for which the water table is lower than a specified threshold; and an 'aeration SEV', which is the time period for which the water table is above a specified threshold. Species distribution and frequency can be shown to be related to a particular range of SEVs and summary statistics of SEVs associated with particular species can be calculated.

'Dryness' and 'poor aeration' (waterlogging) are opposite extremes of a single variable (water level), but the partitioning adopted in the SEV concept stems from the need to identify both upper and lower wetness boundaries for wet grasslands, whilst the specification of threshold values reflects the need for SEVs to be transferable amongst soil types with different hydrophysical properties. Perhaps the main conceptual advance of SEVs has been its transferability by identifying threshold water table values (different for different soil types) which are associated with similar water conditions in the main rooting zone (the 'dryness' water table threshold is associated with a soil surface matric potential of 0.5 m and the 'aeration' water table threshold is associated with 10 per cent air-filled soil porosity at 10 cm depth) (Gowing and Spoor, 1998; Silvertown *et al*., 1999). [Adams *et al*. (1994) used an arbitrary dryness water table threshold value, applied as a standard across all soil types, thus missing the main point of the SEV method]

SEVs essentially sum 'how wet it gets' and 'how dry it gets' relative to the specified thresholds, but this broadly relates to plant responses, with threshold values corresponding to the "depth for the onset of stress" (dryness or aeration) (Gowing and Spoor, 1998). The degree of water 'stress' actually experienced by plants is species-dependent, reflecting their different adaptive traits (such as rooting depths or capacity for root aeration), and is not a generic property of any particular water level. Gowing (personal communication) has suggested that the thresholds should be seen as applying to "a somewhat hypothetical mesophyte". Thus, in wetlands where water tables are permanently above the aeration stress threshold, none of the species present need be subject to actual poor aeration-induced biological stress because of their adaptations. The specification of threshold values that can be applied to all soil types is a necessary feature for the transferability of SEVs across soil types, but a consequence is that the more the water table optima of individual species differ from the specified thresholds, the less sensitive SEVs may be in characterising their relationship to water conditions.

This is particularly the case for wetlands which are wet for most of the year, and it is not yet clear to what extent SEVs can be applied to these. The SEV concept was developed at sites where water tables are typically drawn down to a depth of 0.7 m at some point in most years. If the water table at a site is normally within about 0.3 m of the surface, then it will always be above both the dryness and aeration thresholds. Thus, all variation in growth performance of the species takes place within the water table range summed for the aeration SEV. In this instance, only one SEV can be used meaningfully to describe the variation and this may become increasingly insensitive to variations in species response to water level as the soil nears permanent saturation. Moreover, in wetlands with consistently high water tables, a main conceptual benefit of SEVs (the use of thresholds which permit cross-soil type comparisons) is

[continued over …]

Box 3.5 (continued). Sum exceedance values (SEVs)

probably considerably less important than in wet meadows, as at high water tables water conditions in the rooting zone may be little influenced by differences in the hydrophysical properties of different soil types. In this circumstance, a simple unpartitioned summation of the cumulative depth–duration of water table below the soil surface (or rooting zone) may provide a measure that is as sensitive, perhaps more sensitive, in accounting for species distribution than are SEVs (an approach which has obvious similarities with the 'duration lines' favoured by workers such as Klötzli (1969), Niemann (1963) and Grootjans and Ten Klooster (1980)). Ideally an index is needed which is appropriate for, and transferable amongst, wetland soils with both episodically low and consistently high water tables, but we know of no index which incorporates the advantages of SEVs for wetlands with episodically low water tables and which can also characterise sensitively species–water table relationships in soils permanently close to saturation. This is unfortunate, as some wetlands contain both types of water regimes in close juxtaposition (see Part 3).

SEVs have been developed and tested by Gowing and Spoor (1998) and Silvertown *et al*. (1999) using a large number of samples from specific research sites, in which water regimes have been estimated using three-dimensional hydrological models. This approach is appropriate where water table behaviour can be modelled accurately, but many of the wetland sites examined here show a great deal of small-scale variation in the hydraulic properties of their substrata and may have several contrasting water supply mechanisms (sometimes including springs) in close juxtaposition. Such circumstances are less amenable to accurate water table modelling, at a scale relevant to species distributions. However, the basic elements of the SEV approach are not dependent on the application of models and the index can be derived directly from measured water-table data where these are available.

A problem of all indices using depth–time summations is the period of time included. Gowing and Spoor (1998) summed all dryness SEVs, year round, but now the summation is apparently restricted to the growing season (Gowing, personal communication), which may be more appropriate. The aeration SEV has apparently always been summed only on growing season values, but this restriction appears to be less satisfactory, as there is strong reason to suppose that high winter water tables also influence the species composition and abundance of wetland and wet grassland vegetation. A complication here is that high winter water levels probably do not have the same effect (qualitatively or quantitatively) as do high summer levels (and may be different yet again from the effect of high water levels at the point when growth becomes active in spring). Because of this, winter wetness levels are probably not best simply summed with summer wetness levels, but if they are ignored completely then an important potential control on the occurrence and performance of some plant species is also ignored.

SEVs and other depth–time water table summations are subject generally to the same limitations as other indices for quantifying water regimes (discussed in the main text). The SEV approach considers soil texture, the time of year and the evaporative demand, all of which can strongly affect the water-table depth best suited to a given species or vegetation type. However, it is difficult to evaluate the SEV approach as few data showing the relationships between SEVs and species or community distributions have been published. Moreover, variation in soil hydrophysical properties, whilst important in the wet grasslands for which SEVs were devised, may be less relevant to water conditions experienced by plants in wetlands with consistently high water tables. As with all depth–time water table summations, identification of target water-table values from SEVs is not straightforward – though it is often equally inappropriate to use single target depths as a guide for management.

Some limitations of numerical indices of water regimes

Whilst numerical indices that summarise components of water regimes may have some value, particularly in the contexts for which they were derived, they can also have a number of limitations:

i. Different indices are often based on different components of water regimes. Their use can therefore obscure, or minimise the apparent importance of, hydrological terms that do not form part of the index.

ii. It is difficult to make a good comparative assessment of the value of different indices of water regimes. Evaluation is often made by determining which index gives the best fit to known species distributions. However, many indices will show a fairly clear relationship, at least for the datasets from which they have been developed. Moreover, evaluation based on goodness of fit rests on the assumption that a strong relationship exists between water regimes and species distribution and thus contains a degree of circularity – it is possible that an index which shows a relatively weak relationship may better reflect the actual importance of water regime in determining species distribution *in situ*. The essential problem here is that it can be difficult to establish the extent to which index values *reflect* the relationships of species to water regimes *in situ* or *impose* them through their own particular propensities.

iii. A significant limitation of attempts to quantify species–water regime relationships is that many of the derived measures do not take into account the importance of other environmental variables (especially hydrochemical conditions) both in determining the field species distributions that are used to calibrate the relationships and in modifying the response of species to water conditions in different environmental contexts.

iv. Many quantitative estimates of species–water regime relationships are not based on truly comprehensive datasets. To have generic value, they need to reflect the behaviour of species across their full habitat and community range. There is no reason to suppose *a priori* that the water regime occupied by a plant species in any one investigated site (or community) represents either its full range or even its optimum range, but there are obvious practical constraints in making accurate and detailed quantification of water regimes (whether measured or modelled) over a large number of sites.

v. A potential problem with all numerical estimates of species–water regime relationships is simply that they are beguiling! In particular, they may be used just because there is no obvious alternative, sometimes beyond the limits for which they were determined and by workers who do not always appreciate the nature of such limitations. Numerical indices can also possess an apparent precision which is absent from the dataset on which they are based; they can also be extrapolated readily and used in contexts from which they have not been derived or tested and for which they may be neither valid nor appropriate.

It is difficult to assess the merits of the various indices proposed for quantifying water regimes and relating species distribution to them, partly because few detailed and comparative evaluations of indices have been published and partly because authors are generally more inclined to emphasise the strengths of their methods than to publicise instances where they do not work well. Some doubt must attach to the generic applicability of *any* of the indices to different types of wetlands and wetland habitats.

Numerical estimates of species–water regime relationships are perhaps best seen as imperfect tools which, when well calibrated, can assist in the assessment of desirable, or acceptable, regimes for the maintenance of specific plant communities and species. They are not infallible guides and whilst conservation managers may seek target water-table depths to guide their water management, care is needed with this approach. Simple target water tables can be largely meaningless for sites with significant annual fluctuations in water-table depth. Equally however, for soils that are typically saturated, and for vegetation and species which are not constrained by high water tables, it is possible to identify a 'normal' water table minimum for the growing period that can be considered to form a 'safety threshold' (a threshold appropriate for the maintenance of a species or community in normal circumstances – but which may well be higher than the actual minimum that can be tolerated). It is likely to be considerably easier to specify such a threshold than to determine actual species and community limits with respect to water regimes.

3.1.6 Species richness in wetland vegetation

Ecologists and others have long been interested in the species richness of vegetation and the factors which control it. This has been partly for the development of ecological theory, but also because species-richness terms, as univariate variables, can often be more readily and intuitively related to environmental measurements than multivariate variables of vegetation composition. Moreover, recent interest in biodiversity, of which species richness and rarity are important components, provides further impetus for understanding the determinants of these.

In general, species-rich vegetation tends to be less common than species-poor vegetation, and often contains a larger number of uncommon species. For example, Wheeler (1988) reported the regression relationship for fen vegetation:

$R = 0.3 + 0.12C$ $(P < 0.0001)$ where:

R = number of rare species and C = number of common species (per unit area)

Relationship to environmental variables

Linear regression relationships between species-richness terms and selected environmental variables are shown in Table 3.4. These show that, on average, the number of plant species in wetland vegetation decreases with a decrease in pH and with an increase in soil fertility or in the concentration of potentially phytotoxic metals (Al and Fe). Interestingly, the number of wetland species and rare wetland species per unit area shows no significant trend in relation to variation in summer water level and oxidation–reduction potential (Eh), but there is significant tendency for the total number of species to be greater in the drier (lower water level, higher Eh) samples.

Table 3.4 Single linear regression relationships between three species-richness terms (y) and selected environmental variables (x) from samples of wetland vegetation

The species-richness terms refer to the total number of each category of plant species per unit area (4 m^2).

y: x:	All species	Wetland species	Rare wetland species
pH	$y = 2.9x + 4.4$ $p < 0.0001$	$y = 1.7x + 6.9$ $p < 0.0001$	$y = 0.6x - 1.7$ $p < 0.0001$
Fertility	$y = -0.2x + 23.1$ $p < 0.0001$	$y = -0.2x + 18.7$ $p < 0.0001$	$y = -0.03x + 2.0$ $p < 0.001$
Water level	$y = -0.06x + 20.9$ $p < 0.001$	not significant $(p = 0.68)$	not significant $(p = 0.22)$

Eh	y = 0.009x + 18.9 p < 0.01	not significant (p = 0.19)	not significant (p = 0.47)
Fe	y = –0.004x + 21.7 p < 0.0001	y = –0.003x + 17.0 p < 0.0001	y = –0.001x + 1.7 p < 0.0001
Al	y = –0.019x + 21.6 p < 0.0001	y = –0.013x + 16.9 p < 0.0001	y = –0.004x + 1.6 p < 0.0001

Relationship to water levels

Although the linear regression of summer water table against the total species richness of wetland vegetation (all species) shows a significant negative relationship, inspection of the water table–all species scatter plot (Figure 3.3) points to a more complex relationship. To examine this further, mean values of the three species-richness terms were calculated for each of 13 equal subdivisions of the water level range and used as the dependent variables in regressions against the mean water level in each subdivision (Figure 3.4). Using this approach, which reduces the importance in the regression of the most frequent water level conditions, species richness was significantly ($p < 0.001$) related to water level in polynomial regressions for all species and wetland species; the plots point to a maximum species richness at a water level of about 25 cm bgl for all species and about 10 cm bgl for wetland species, though in both cases the curve is shallow around the maximum. The number of rare wetland species showed a significant positive linear relationship with the mean water table of each category.

Relationship to crop mass

It has long been recognised empirically that in herbaceous vegetation, species richness is inversely related to the amount of above-ground plant material; the greater the mass of vegetation, the fewer plant species it tends to contain, so that coarse, rank vegetation is invariably species poor. In wetland vegetation, this relationship can be expressed by linear regression. For example, Wheeler and Shaw (1991) derived the regression equation:

$S = 5.9 - 0.43M$ ($P < 0.0001$) where:

S = number of species and M = September crop mass (biomass + litter)

However, such regressions are clearly over-simplifications, not least because they could be used to predict that species richness will be greatest when the amount of above-ground vegetation is zero! A more realistic relationship is expressed by the hump-backed curve proposed by Grime (1978) in which species-rich vegetation is restricted to a 'corridor' of intermediate crop mass. It is important to note that the hump-backed curve represents the maximum species richness found at any value of crop mass. Thus, even within the corridor of high species richness, species poor stands can, and do, occur (Figure 3.5). The variation of species richness with crop mass in fens conforms broadly to the hump-backed model (Figure 3.5), though the crop mass limits of the corridor are rather different to the values proposed by Grime for some other herbaceous types (Wheeler and Shaw, 1991).

Causes of species-richness variation in wetlands

The hump-backed model provides a neat basis for discussing the causes of species-richness variation in wetlands, because it helps to focus the problem into two separate components: (a) the cause of species-richness variation across the range of crop mass; and (b) the cause of species-richness variation within the high species richness–crop mass corridor. These effects are summarised in Figure 3.6

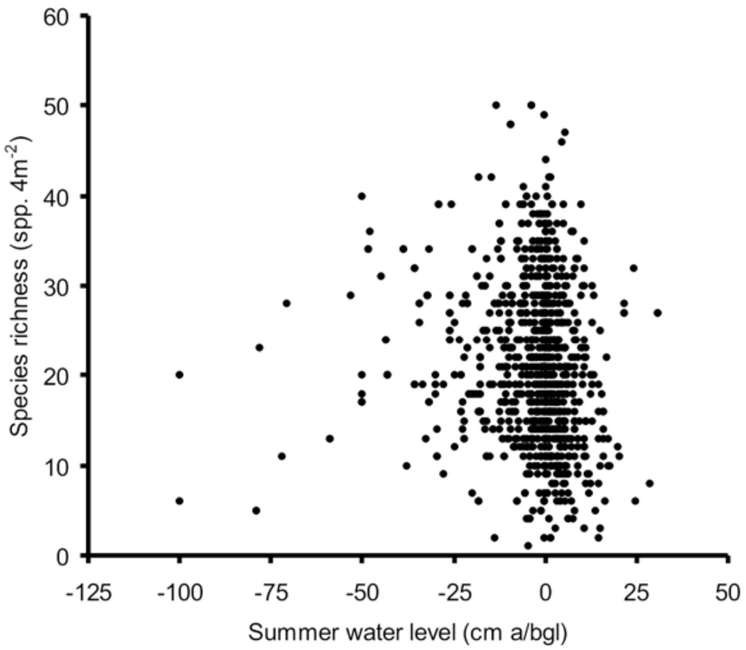


Figure 3.3 Variation in species richness of stands of fen vegetation with water level

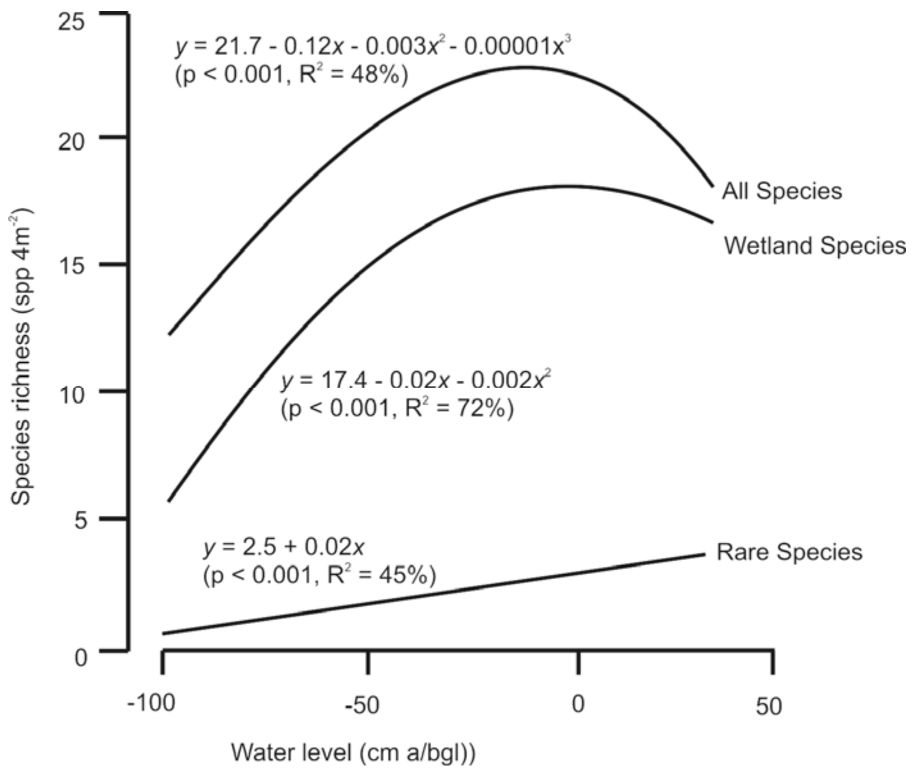


Figure 3.4 Regression relationships between three species-richness terms (all species, wetland species and rare species) and water level

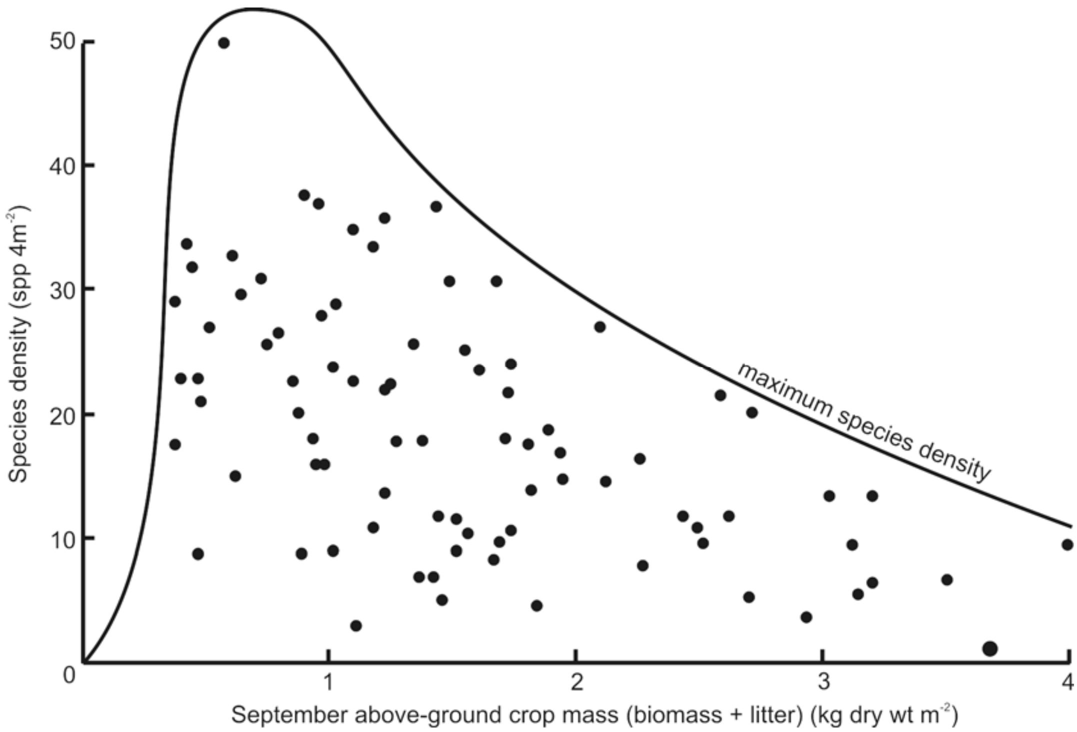


Figure 3.5 Relationship between species density and September total crop mass in samples of herbaceous fen vegetation in lowland England and Wales

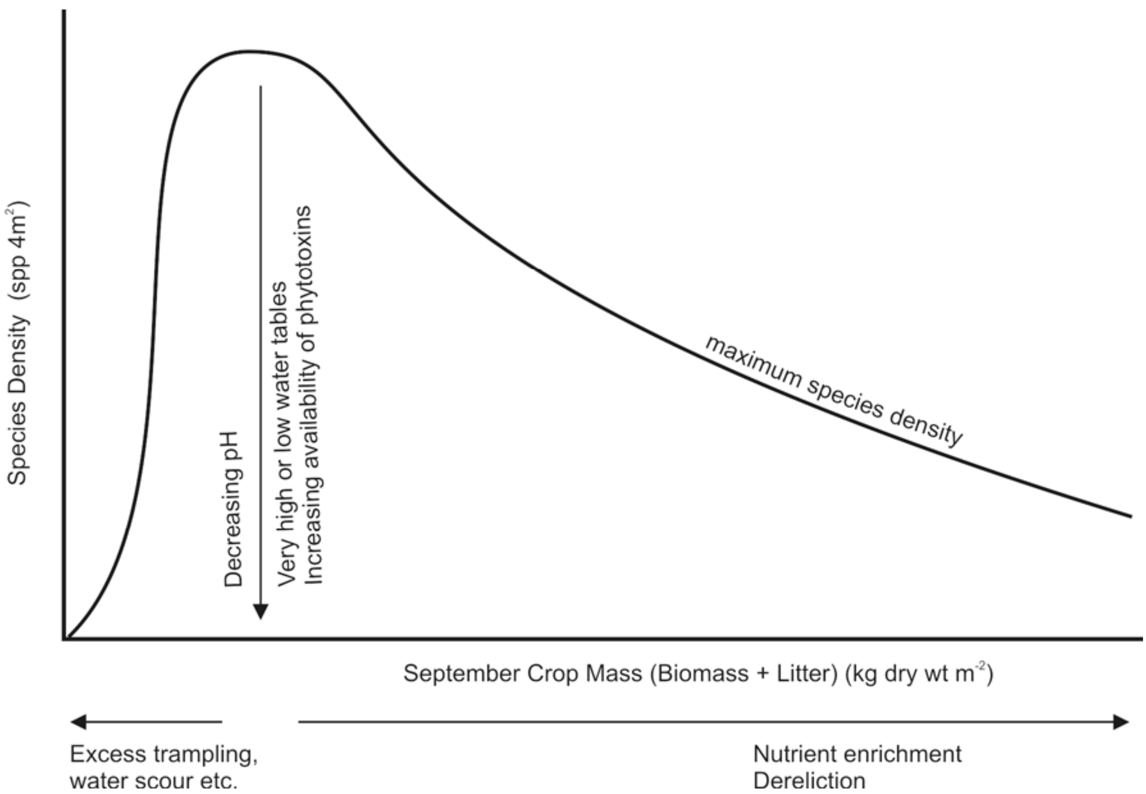


Figure 3.6 Schematic interpretation of the main controls on variation in species density in fen vegetation

Reduction of species richness at high values of crop mass

Tall, rank wetland vegetation is invariably species poor. This is most probably primarily a consequence of interactions amongst the species, and perhaps especially the interception of light, which inhibits the growth of many small, subordinate species.

The crop mass of wetland vegetation is mainly a product of three processes: (i) productivity (which, in wetlands within a particular climatic region, is primarily a function of nutrient availability); (ii) management (partial defoliation by grazing or mowing); and (iii) physical damage (including wave action, current scour, poaching).

There is generally little evidence for extensive, severe effects of physical damage in the wetlands considered here[1], so attention can be focussed on productivity and management, which can have both separate and interacting effects. In fertile environments, large biomass values and species dominance can be produced by a small number of species with the potential for rapid growth (such as *Epilobium hirsutum, Glyceria maxima, Phragmites australis*). In less productive situations growth rates are slower, but some tall-growing species can still achieve strong dominance in the absence of disturbance. For example, *Cladium mariscus* can dominate some low-productivity fens very strongly, though as much by the accumulation of thick mattresses of decay-resistant dead leaves as by the development of a dense canopy of living shoots.

High rates of production coupled with dereliction (lack of management) can lead to stands of especially high crop mass. However, management (especially summer management) can produce vegetation with low crop mass, even in very productive conditions. Wheeler and Shaw (1994) made a simple examination of the trade-off between management and soil fertility in influencing the species richness of fen vegetation. They examined the relationship between species richness and soil fertility across a large number of fens, split into subsets of summer-managed and unmanaged vegetation, using linear regressions:

	x = soil fertility	
	Unmanaged	**Managed**
y = number of species	y = 25.7 – 2.7x (p<0.005)	y = 30.1 – 2.0x (p = n.s.)
y = number of rare species	y = 7.3 – 1.9x (p<0.0001)	y = 4.7 – 1.4x (p<0.0001)

Although tentative, these results suggest that: (i) in unmanaged vegetation, species richness is negatively related to fertility; (ii) when vegetation is managed, species richness can be just as great in nutrient-rich sites as in nutrient-poor ones; and (iii) the number of rare fen species tends to be smaller in more fertile conditions, even when the vegetation is managed. In consequence, management of nutrient-rich sites can support species-rich vegetation, but this is composed mainly of common species; in low fertility systems, little or no regular management may be needed to preserve high diversity.

Species-richness variation within the corridor of low–medium crop mass

High species richness in wetland vegetation is only encountered within the corridor range of low–medium crop mass, but many stand samples within this corridor do not have high

[1] At one time, introduced coypu (*Myocastor coypus*) had a highly damaging impact on the wetland vegetation of parts of East Anglia, but this problem appears to have been eradicated.

species richness and some are as species-poor as the rankest, high crop mass vegetation. Within the corridor, other variables, including various environmental variables, appear to determine the species richness of vegetation. Stands of low species richness within the corridor tend to be those rich in Al, Fe, Mn, or of low pH and redox potential, or with particularly high or low water levels.

3.2 Succession and ontogenesis in wetlands

Wetlands are often not static entities. Many wetland sites have existed as wetlands for a very long time, in some instances throughout the post-glacial period, and have often undergone significant developmental (ontogenetic) change. Wetland vegetation is also often not intrinsically stable, but may be maintained in an unnaturally stable state by influences such as vegetation management. Spontaneous changes in the character of the vegetation in wetlands are often referred to as 'succession'. Successional processes can be similar to, and may form part of, ontogenic processes. If a distinction between the two terms can be made, it is perhaps that successional processes are those which occur, and affect the vegetation, within different parts of a wetland, whereas ontogenesis refers to the development of the wetland as a whole. Hence it is possible for the vegetation succession at any one point to have reached its perceived 'climax' state, but for the ontogenesis of the wetland to be ongoing.

Consideration of the ontogenesis of different types of wetlands is provided in the accounts of those individual WETMECs to which they most closely relate.

3.2.1 Successional processes

The concept of 'vegetation succession' is essentially that of a spontaneous, directional vegetation change from a particular starting condition towards a more stable (or climax) state. Successional change in wetlands is often referred to generically as the 'hydrosere'. This term is frequently used for almost any directional change in the composition of wetland vegetation, but such a broad compass is not particularly helpful because different types of succession occur in wetlands with different starting points and processes. A broad distinction can be made between successions that involve linked change in the environment and soil conditions and those which essentially constitute species invasion not specifically linked to environmental change. Where vegetation change is linked to environmental change, the latter can either be *autogenic* (changes made *in situ* by the vegetation, such as the accumulation of peat) or *allogenic* (changes induced by events or material external to the stand, such as inwash of silt), or a mixture of both.

In wetlands, two broad successional processes can be identified: terrestrialisation and paludification (Box 3.6), which differ in their starting conditions and environmental drivers but which share a number of common seral stages and climax states (Figure 3.7). Although the terrestrialisation process corresponds with classic descriptions of the hydrosere (Tansley, 1939), to the extent that it is sometimes considered synonymous with this, in terms of wetland area paludification has been a much more important process. Even in Broadland, which has provided some of the classic, most detailed, studies of the terrestrialisation process (Lambert, 1951), this relates just to hydroseral sequences around the margins of the reflooded turbaries (the broads). The Broadland fens proper, within which the broads were dug, are, like the once-enormous wetlands of Fenland, essentially paludification systems, with their development driven primarily by changes in sea and river water levels relative to the fen surfaces.

The successional pathways shown in Figure 3.7 are highly simplified. Other transitions, and sometimes reversals, can occur even in autogenic (self-made) successions. However, where successions are influenced or determined by allogenic processes (where external environmental changes drive the vegetation change), far more complicated sequences of events can occur, and it is often more useful to think in terms of holistic wetland development than specific successional pathways.

The climax state in wetlands

Tansley (1939) considered the development of 'dry' deciduous woodland as the culmination of the hydrosere (its climax state), at least in Eastern England. However, in general there is little evidence for the autogenic development of dry woodland in wetlands (though it certainly occurs in some marginal locations and partially drained surfaces). The two main stable climax states of the hydrosere appear to be fen woodland and ombrogenous bog. Of these, ombrogenous bog can perhaps be seen as the ultimate climax, as it can replace fen woodland and in the oceanic climates of Britain and Ireland has naturally over-run very large areas of minerotrophic mire (Goodwillie, 1980). The development of ombrogenous surfaces is undoubtedly favoured by the cool, wet climates of the North and West of Britain, but the apparent scarcity of ombrogenous surfaces in the South and East may owe less to climatic constraints than to other hydrological controls (such as regular flooding with telluric water), and probably the fact that they have been removed by drainage and peat extraction from former locations.

Ombrogenous bog still occurs in one of the drier parts of England (Thorne and Hatfield Moors) and extensive areas of raised bog were undoubtedly once associated with parts of the Fenland basin (Godwin, 1978), with Holme Fen providing the only real, and rather dry, remnant of these. Nonetheless, there is no known evidence for former ombrogenous bog in some locations where, hydrologically, it might be expected (such as in some of the mires of Ynys Môn). This may be because past ombrogenous surfaces have been completely removed by peat extraction, but this explanation is more easily invoked than demonstrated. Raised bog does not seem to have been a feature of Broadland, where fen carr is the main climax community, as demonstrated by the thick layers of brushwood peat that are a feature of the stratigraphy of most of these mires. This may be because in their natural state, the Broadland fens were too frequently flooded by river water to permit any substantial accumulation of *Sphagnum* peat. The present 'islands' of *Sphagnum* dominance which occur in some Broadland turf ponds are not raised bogs, even in miniature, and it is doubtful they will become so as it seems likely that as turf ponds fill with consolidated peat, their surfaces may lose the surface-layer characteristics that permit the prospering of *Sphagnum* species on a base-rich floodplain.

The concept of 'climax vegetation' is in some respects rather hypothetical, being the type of vegetation that will develop in a specific climatic region when other constraints (such as high water tables) have been removed. Under specific circumstances, early seral stages can be very persistent and sometimes self-maintaining, and whereas for example in some lakeside circumstances vegetation change can be readily demonstrated, as at Esthwaite North Fen (Cumbria: Pigott and Wilson, 1978), other lakeshore zonations are remarkable for their stability (see Spence, 1964). Nor is it always clear just what constitutes the climax state for some hydroseral circumstances. This is illustrated by some stratigraphical data from Great Cressingham Fen (Norfolk) (Wheeler and Money, unpublished data). The following representative core was taken near the SW corner of the mire:

Depth bgl	Characteristics
0 – 10 cm	Loose and unsampled
10 – 110 cm	Herbaceous monocot–moss peat, more humified below 45 cm
110 – 160 cm	Well humified, black, rather amorphous peat with some monocots and wood
160 – 420 cm	Khaki marl

As this site, the first two main phases of wetland development (a marl-precipitating lake colonised by swamp and then carr) can be interpreted as normal terrestrialisation, but the third phase (monocot–moss peat) is unusual, because it suggests that, far from forming a stable state, the fen carr was replaced by a herbaceous community, locally rich in mosses and with relatively few woody plants. Various explanations for this are possible, but perhaps the most likely is that it represents a development of the hydrological mechanisms in which the groundwater discharge which originally supplied the lake became more focussed into lateral near-surface flow across the mire, creating an environment suitable for the development of a largely herbaceous, moss-rich fen. This sort of sequence has been described in other parts of Europe: for example, in East Germany late glacial lakes have developed serally into ancient lake fens over which a topogenous seepage fen has developed, sometimes from an increase in groundwater tables (Succow, 1988); West (1991) has reported a post-glacial rise in water tables in central Norfolk. In parts of Eastern Europe, moss–sedge fen, with scattered scrub, appears currently to form a stable state in the absence of any explicit management. It seems very likely, from the Cressingham (and other) stratigraphical data, that this was once also the case in Britain, before circumstances changed (for example, partial drainage abetted by cultural eutrophication) and encouraged the secondary spread of woody plants across much of the site.

Box 3.6: Types of succession in wetlands

Terrestrialisation (the 'hydrosere' *sensu stricto*). This refers to the process by which open water becomes colonised by vegetation and filled in so that, for example, lakes become land. The autogenic (self-made) hydrosere is based upon the remains of plants growing and accumulating *in situ,* but this is sometimes accompanied and accelerated by the inwash of allochthonous material (silts and so on) (an allogenic process).

Paludification. This, in a sense, is the inverse of the hydrosere and refers to the process by which once-dry land becomes wet. This may be a consequence of increased precipitation, increased groundwater or sea levels and so on. In some instances, paludification can create bodies of open water within which terrestrialisation can then occur.

Secondary colonisation. The term 'hydroseral succession' is frequently used to refer to, say, the colonisation of herbaceous fen with bushes following the cessation of former management practices that kept woody vegetation at bay. However, this process does not necessarily involve any change in water level or accumulation of peat, and may be better seen as a process of secondary colonisation rather than as part of a hydroseral sequence.

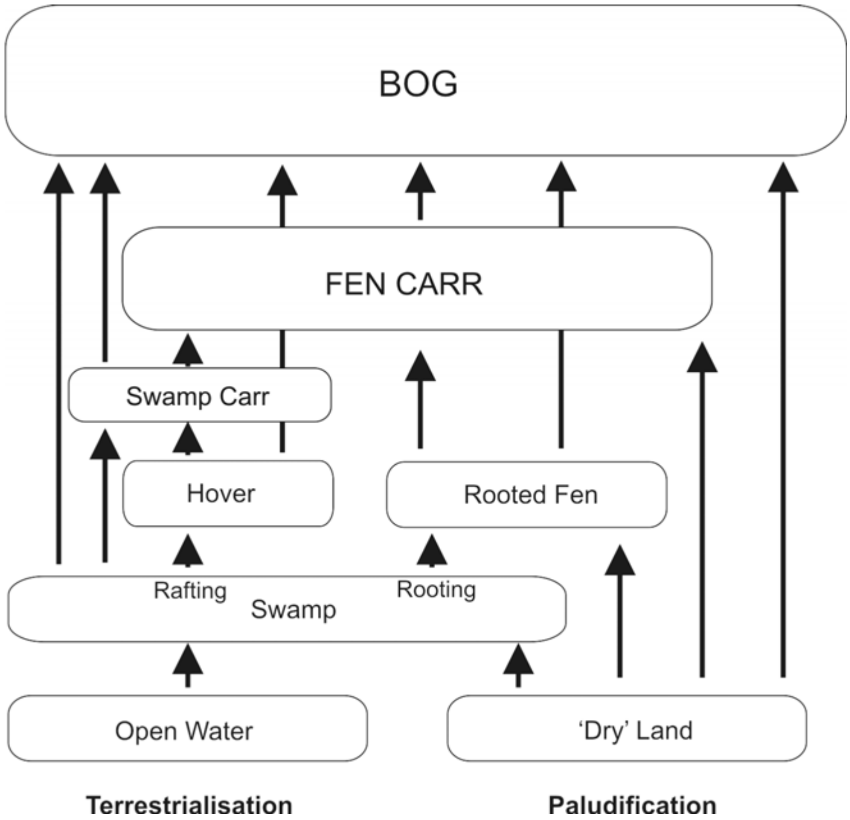


Figure 3.7 Main autogenic successional pathways in wetlands

Terrestrialisation status of wetlands

As a long-term process, terrestrialisation is effectively confined to the (former) basins of water bodies. The majority of these have little, if any, residual open water and in those where residual pools do occur, perhaps as ostensible remnants of original late-glacial lakes, the reasons for their persistence are not always obvious. In some cases they may represent the remnants of particularly deep lake basins which have not yet filled in, as may well be the case at Llyn yr wyth Eidion in Cors Eddreiniog or Llyn Cadarn in Cors Goch (both Ynys Môn). It is also sometimes suggested that groundwater outflow may occur into some residual lakes and perhaps constrain their terrestrialisation, but there seems to be little evidence either way for this proposition.

At some sites a former open water phase has been terminated prematurely by drainage, as may have been the case at Hockham Mere (Mosby, 1935), but other areas of open water may have been created or maintained artificially through peat extraction or for use as fish ponds (Clarke, 1922; Lambert, 1951). However, it is often not clear to what extent such activities have helped to retard the overgrowth of a natural water body, as may perhaps be the case at Newham Lough (Newham Fen, Northumberland), or have created a new pool on a site from which open water had long since disappeared. Such questions come into particularly sharp focus in the case of some shallow basins, for example the clusters of small, shallow, often water-filled hollows in the so-called 'pingo fields' of West Norfolk. Some of these ponds, which may be less than two metres deep, contain some of the finest examples of terrestrialisation-like vegetation zonations in Eastern England, but this raises the question as to why such small, shallow basins still have open water some 10,000 years after their formation. The most likely explanation is that a former paludogenic infill has been dug out, but there is currently no known evidence for this.

Peat cutting and the hydrosere

Although some fen-fringed lakes and pools appear to be natural, many examples of the terrestrialisation of open water and some of the wettest fens in lowland England and Wales are associated with reflooded turbaries. Moreover, revegetated peat workings can have particularly high conservation value and may sustain some of the best examples of valued vegetation types (Giller and Wheeler, 1986a; Wheeler, 1999a, b).

The extent and intensity of past peat cutting in many wetlands is not really known, but it seems likely that many, perhaps most, wetlands in lowland England and Wales have been dug to some degree, mostly for peat but sometimes for underlying clays and marls. The deep medieval excavations which formed the Norfolk Broads are particularly well known, but more recent (eighteenth and nineteenth century), shallower turf ponds are even more extensive in parts of Broadland, and can occupy as much as 90 per cent of the fen surface in some sites. Elsewhere, there is much surface evidence suggestive of past peat cutting (such as ridges and hollows) and even where such patterning is not obvious, there may be documentary evidence that digging once occurred. For example, Dernford Moor (Cambridge) apparently carried rights of turbary (peat and sedge cutting) [Sawston Court Rolls, 1351]. Fitter and Smith (1979) consider that peat has been removed from Askham Bog (York), but although this site has a quite deep infill of peat and mud, there is no visual evidence of peat removal from its apparently flat surface. Perhaps at this site peat was removed uniformly, to leave little surface evidence that digging once occurred. Rights of turbary are also known to have existed at some sites at which peat is now almost absent, pointing towards the effective skinning of the mires (such as Wendling Poor's Fen, Norfolk). The rate at which peat was removed in the past has been little documented. In some Norfolk valleyhead sites, using available information and some assumptions, Wheeler (1999b) made a conservative estimate that around one metre depth of peat may have been removed from one ha of fen in 50 years. Such rates could go a long way to explaining the shallow depth of peat remaining in many fen sites, and raises intriguing questions about the original depth of peat infill.

From the perspective of successional processes, vegetation and hydrodynamics, a broad distinction can be made between 'peat pits' and 'turf ponds'. The former are essentially depressions in the fen surface. They may be open-ended systems of ridges and trenches or discrete pits and, although they may be wetter than the uncut surface, they share the feature of being unflooded for much of the year. By contrast, turf ponds are essentially reflooded peat pits and are subject to hydroseral terrestrialisation. The difference in summer water level between the two types of excavations in sites in Eastern England is considerable (Table 3.5).

Table 3.5 is based exclusively on data from topogenous sites, where the surface topography and peat depth is such that the reflooding of peat workings could readily occur. In the contrasting topographical context of sloping spring and seepage fens, peat extraction has less often produced deep pits full of standing water, but has more typically generated a series of shallow trenches and hollows, or even a uniformly stripped surface (which may provide no visual clues for former turbary). On abandonment, such workings have usually created a wet, sometimes swampy environment within the fen, rather than a pool in which terrestrialisation processes could occur. In some sites, abandoned workings have helped focus and funnel the discharge of ground water across the peat surface; in others, the moving water has itself helped to erode and coalesce some of the irregularities produced by peat-winning.

Table 3.5 Relationship between location of past peat cutting and mean summer water tables in topogenous fens in Eastern England

Location of stand	Mean summer water table (cm bgl)
Turf pond terrestrialisation	–5.6

Other (non-turf pond) terrestrialisation	–5.1
Peat pit	–27.3
Uncut surface	–23.5

One possibly important but little considered further impact of peat removal in some groundwater-fed fens (such as Buxton Heath, Norfolk), is that removal of peat may have reduced resistance to groundwater upflow and may have helped to expose the strong springs and seepages upon which communities such as *Schoenus nigricans–Juncus subnodulosus* mire (M13) nowadays depend (Wheeler, 1999b). Thus, it is possible that these SAC habitats did not just survive peat extraction but are, at least in part, a product of it and that any ongoing accumulation of peat may help constrain groundwater outflow and gradually cause an autogenic change in the character of these stands independently of any external hydrological change.

3.3 Hydrodynamics of wetlands

3.3.1 Introduction

Much has been written about the hydrology and hydrodynamics of wetlands (for example, Gilman 1994; Hughes and Heathwaite, 1995; Baird and Wilby, 1999). Here, we discuss some aspects that are particularly relevant to the *Wetland Framework* project[1].

In essence, the hydrodynamics of wetlands are determined by the characteristics of their main water sources and sinks, and the interaction of these with the topography of the site and its wetland substratum (peat, alluvium and so on). The importance of substratum properties relate particularly to their water storage capacity and hydraulic conductivity (resistance to water flow). All of these features can show much variation in wetlands and can result in the close juxtaposition of contrasting hydrological environments in some sites. For some purposes it may be appropriate to consider wetland sites as single, more or less uniform units, but from the perspective of wetland ecology and hydrodynamics, the detail is often of critical consequence, especially in determining surface and near-surface processes which often have the greatest relevance to biota. Thus, it is often necessary to consider the characteristics of ecohydrological units within sites rather than the sites as a whole.

3.3.2 Perspectives on water sources and supply

Any ecohydrological analysis of water supply mechanisms to wetlands needs to take account of water sources. In ecohydrological terms, the importance of specific water sources relates both to their quantitative contribution to the wetland or sectors of it, and to their role in determining the wetness characteristics and hydrochemical environment of the wetland surface (or the main rooting zone[2]). Some approaches to estimating the contribution of water sources to the water budgets of wetland sites may fail to assess their real importance to the biota (Box 3.7).

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[1] Notes on terminology, including the use of water supply terms (e.g. telluric water, ground water) and terms relating to groundwater outflow processes (e.g. springs, seepages etc.) are given in Chapter 2.

[2] The ‘rooting zone’ varies with species. Graminoid dominants (such as *Phragmites australis* and *Cladium mariscus*) can have very deep rooting structures, but most wetland plants – including almost all uncommon species – root in the top 15–20 cm of soil.

Importance of water sources

One source of confusion in assessing the importance of specific water sources to the ecology of wetlands is that the ecohydrological importance and function of these sources may vary between sites (and between habitats and vegetation types) (Table 3.6). Assessment of the specific role of particular sources is important, especially in terms of evaluating the impact of any reduction or substitution of inputs, but is not always of primary ecological significance. Ecological considerations are sometimes more complicated than purely hydrological ones, as they need to take account of *inter alia* water quality as well as quantity, and the ecological balance between contrasting water sources and the role of the substratum. Conversely, they may sometimes be simpler in the sense that "*providing its quality is appropriate, plants may not 'mind' too much from whence their water comes, or how it arrives*" (Wheeler, 1999a). For example, for a fen fed by surface water it may be of little, if any, ecological consequence whether vertical water flow downwards is restricted by a layer of clay or by a high aquifer head. In both cases the ecological water supply mechanism is essentially the same, though there are likely to be differences in vulnerability to groundwater abstraction between the two cases. It therefore follows that an ecohydrological framework for wetlands may wish either to subdivide or to fuse some purely hydrological wetland units.

A further complication is that different parts of a site may have rather different water supply mechanisms and characteristics. This may apply to different areas within a wetland site and to artificial excavated features. For example, dykes may sometimes cut through natural aquitards into the bedrock and can receive a much greater proportion of groundwater that would have naturally contributed to the water balance of the wetland. In this circumstance, a desire to conserve valued biological features of the dykes may demand water sources and inputs that are not a necessary requirement for the natural hydrological mechanisms of the wetland itself (and in some situations may run counter to them).

Table 3.7 summarises some of the relationships of water-source conditions and substratum characteristics in determining surface wetness conditions, for both little- and much-modified wetlands.

Table 3.6 Categories identifying the importance of potential water sources in maintaining the ecohydrological characteristics of wetlands

Importance of potential water source	Comments
Water source and mechanism of delivery determines surface wetness and hydrochemical environment	Water source is primary supply to surface and its quantity and quality determine surface conditions. Mechanism of delivery also helps regulate conditions affecting the vegetation (e.g. spring flow elevates oxidation–reduction potentials; co-precipitation of P onto calcite). Specific source usually irreplaceable.
Water source determines surface wetness and hydrochemical environment	Water source is primary supply to surface and its quantity and quality determine surface conditions. Can potentially be replaced or supplemented by a water supply of similar characteristics but different mechanism of delivery, if available.
Water source determines surface wetness, but the hydrochemical environment is determined by other factors	Water source is primary supply to surface but chemical conditions are determined mainly by character of the substratum (e.g. underlying clay). Can potentially be replaced or supplemented by water of different quality, providing it does not materially change the growing environment.
Water source supports another water source	Water source does not reach the surface.

Inputs of water source occur, but unimportant in determining surface conditions	Inputs are uncommon and not of general importance, or superfluous to requirements (e.g. precipitation inputs are of little significance to surface conditions in a strongly artesian, chalk-water seepage fen).
Small inputs of water source occur, unimportant in terms of water balance but important hydrochemically	Water supply is dominated by sources other than specific input, but of contrasting hydrochemical character (*e.g.* base-rich groundwater outflow onto a surface dominated by base-poor water supply).
No significant inputs of water source occur	Hydraulic connection to water source, but very limited water transmission (e.g. on account of very low hydraulic conductivity of peat or other layers).
No input of water source	

Box 3.7: Spatial scale and relevance of water budget and other studies

Hydrologists often try to estimate water budgets for individual wetland sites. However, the ecohydrological value of these depends considerably upon their scale and focus. Some studies may make a limited contribution to an ecohydrological understanding of particular sites, because they may take little account of within-site variation; they may examine catchment units that are too broad for some individual wetland features; and because a calculated quantity of, say, total water inputs versus outputs is not necessarily a very meaningful ecological parameter. An illustrative example is studies on Potters and Scarning Fen (Norfolk). This valleyhead site is principally composed of seepage faces adjoining a small stream. HSI/ECUS (1999) considered groundwater to be the primary water source for the fen as a whole, but a water budget for the site calculated by Adams, Gilman and Williams (1994) indicated that the proportionate contribution of surface water was greater than that of groundwater. In this case, the catchment-based estimate of the contribution of the surface-water component of the proposed budget for this site mainly represents water that passes through the wetland in a stream and has little, if any, real relevance to seepage slopes or even to the whole fen site, except in helping to regulate the water table in some lower parts of the wetland.

There are other sites and situations where, although certain water sources may feed into a wetland, they make little, if any, contribution to its ecohydrological character. For example, precipitation inputs onto a seepage face may be largely irrelevant to its ecohydrological character or to the height of its water table. Likewise, where watercourses flow along the base of a seepage slope, even if flooding occasionally occurs, it may only affect a small part of the slope and is probably superfluous to the normal hydrological functioning of the system (though it sometimes has ‘nuisance value’ by providing a local source of nutrients). From an ecohydrological perspective, a distinction needs to be made between water sources that are important to the character and normal water table of a wetland and those superfluous to it. For many wetland areas, the critical water source question is ‘What keeps this area wet in dry weather during the growing season?’ Hence, to be ecologically meaningful, water balance studies often need to relate (a) to specific ecohydrological components of wetland sites and (b) to specific periods of time.

These comments are not intended to denigrate the value of water budget studies but to stress that ideally, their focus should be upon specific wetland features. There are no doubt many situations in which it would be extremely valuable to have quantitative information on specific water sources; there is equally no doubt that such data would be difficult to acquire. Typical quantification problems include those associated with: (a) inputs from diffuse seepage sources, surface run-off and land drainage, especially where it is necessary to take into account interception of these sources by land-spring ditches and local variation in the permeability of the near-surface substratum; (b) inflows, outflows and water storage in floodplains associated with flooding episodes, especially where surfaces with strongly contrasting storage characteristics occur; (c) actual evapotranspiration rates from different types of wetland vegetation. In some circumstances, it is possible to estimate a component of the water budget as a difference term that is not accounted for by other, more readily quantified, components. However, several or all of the components may not be quantified accurately and the resulting ‘ball park figures’ may not always materially enhance an understanding of the ecohydrological functioning of a site, though they may help inform an expert judgement or best guess.

Likewise, whilst piezometric data are potentially of much value in assessing water supply to groundwater-fed wetlands, their limitations should also be appreciated. Examination of data from piezometers installed in Eastern England (Wheeler and Shaw, 2000a) indicated *inter alia* that: (a) measured piezometric heads can bear little relationship to water conditions within the wetland, especially where the piezometers are distant from the wetland areas in question; (b) even shallow piezometers located within, or alongside, a wetland area do not necessarily represent its known wetland water conditions – dipwell data are also required; and (c) data from piezometers and gauge boards are usually related to Ordnance Datum, but not always to the local ground level (which is more relevant to the biota).

Table 3.7 Some factors regulating surface wetness during the growing period (summer) in little-modified and much-modified wetlands

[G], [S], [O]: Factor is particularly relevant to groundwater-fed [G], surface water-fed [S] and ombrogenous locations [O].

Factor	Little-modified locations	Modified or managed locations
Surface wet in summer		
Groundwater pressure sufficient to maintain surface wet conditions [G]	Often associated with strong springs or artesian groundwater sources	Peat stripping may reduce surface level and remove some resistance to upward flow
Surface flow of water from seepages [G]	Often occurs where seepages are on slopes adjoining wetland	May flow into hollows created by peat extraction and so on
Surface flow of water from watercourses [S]	Surface flow is often unusual in summer, except where water levels are controlled by tidal events and so on	Often associated with subsidence of adjoining wetland (drainage) or dams in watercourses
Lateral sub-surface flow of groundwater and surface water [GS]	Upper substratum layers may be naturally transmissive and permit substantial sub-irrigation	Revegetated turf ponds can provide preferential flow paths. Dams in watercourses may help produce high surface water levels
High water storage	Upper layers may naturally have high specific yield, or contain water lenses and so on. May be some surface water, especially in winter-flooded sites	Turf ponds can act as water reservoirs. Dams can store surface water
Buoyant surface (rises and falls with changes in water table)	Vegetation raft or loose upper peats form an expansible mass	Turf ponds, or reflooded surfaces, can develop raft or loose upper peats
Surface dry in summer		
(Seasonally) low aquifer water table [G]	Aquifer water table may be naturally low in summer	Aquifer may be lowered by abstraction or drainage
(Seasonally) low water level in adjoining watercourses that supply wetland [S]	Water level in watercourse may be naturally low in summer	Abstraction from watercourse or water level management of watercourse may reduce level
Small direct precipitation input [O]	Climatic variability – droughts	
Aquifer head near or above wetland surface, but resistance to groundwater flow means that slow outflow does not compensate for surface losses [G]	Substrata with naturally low permeability result in surface being naturally summer-dry	Resistance may be increased by changes to substratum properties caused by drainage. [Often also associated with reduction in groundwater heads (by abstraction and so on)]
Water level in watercourses near level of wetland surface but restricted lateral sub-surface flow into wetland [S]	Substrata with naturally low permeabilities can result in naturally low summer water tables	Resistance may be increased by changes to substratum properties caused by drainage. However, excavated dykes, foot-drains and turf ponds may increase summer ingress of surface water

Drainage	Can affect site directly and level of potential water sources

3.4 Classification of wetlands

Classification of some type is a prerequisite for conceptual thought and communication. It is essentially a simplification process in which a number of real individuals (samples), differing in specific features (attributes), are condensed into a smaller number of abstracted units (classes) within which the members are more similar to one another – on the basis of some attribute(s) – than they are to members of other classes. Classes can be based on or reflect discontinuities in the variation found within a dataset – these are often the most meaningful units or easiest to apply – but classes can also be created around nodal points within a field of more or less continuous variation.

Wetlands are variable, diverse entities differing in a range of properties, including the situation in which they occur, their topography, water supply mechanisms, environmental conditions and vegetation types. (Table 3.8). Various attempts have been made to classify wetlands, but they have not always been rigorous and have met with varying degrees of success and agreement. Frequent difficulties associated with wetland classification and terminology include the following:

- Classifications vary in the criteria on which they are based, resulting in different classification schemes for the same set of objects.
- In some classifications the criteria on which the scheme is based are ill-defined; in others, different criteria have been used to identify different classes within a single classification, often leading to poor definition and overlap amongst the units (such as the CORINE classification). Sometimes composite categories are used, containing variables which to some degree vary independently of each other.
- Terms are used inconsistently across classifications by different workers; different terms are sometimes used to refer to the same object and the same term is sometimes used for different objects.
- Identified categories in classifications sometimes apply to an entire wetland site or to parts of a wetland site; sometimes the scope of categories is unclear and the same category (and term) may be used both at a whole-site and part-site level.
- Many wetland classifications have been top-down in approach, with categories identified and imposed by expert judgement rather than by an analysis of measured properties of individual sites or samples. Difficulties with this approach are that acknowledged experts are not always minded to agree with each other; that the categories generated may strongly reflect the preconceptions of individual workers; and that its informality has sometimes encouraged the proliferation of *ad hoc* categories, often poorly defined and based on inconsistent criteria.

3.4.1 Attributes of wetland types

A wide range of terms and criteria can potentially be used to subdivide (iclassify) wetlands (Table 3.8), but relatively few have been used to develop formal wetland typologies. In some cases, this is probably because they are seen as features not specific to wetlands (for example, management categories) or features that occur within wetlands (vegetation or soil types) rather than properties of the wetland *per se*, though the presence or absence of peat (above or below a specified depth, this varying with the individual classification) is sometimes seen as a important diagnostic wetland feature, and is reflected in some terminology.

In general, two main sets of features have figured prominently in the development of wetland types and terms: (a) certain environmental and hydrological characteristics; and (b) hydrotopographical attributes. It could be argued that a comprehensive wetland typology needs to take these terms into account, along with other attributes such as plant communities present, but in general this has not been done, though a few workers (such as Succow, 1988) have attempted such a holistic approach.

Table 3.8 Classification properties of wetlands (modified from Wheeler and Shaw, 1995a)

Situation in Landscape

Situation types

Specific geomorphological features

Water Supply and Development

Hydrotopographical elements

Hydrodynamics and mechanisms of water supply

Habitat Conditions

Broad hydrochemical types

Hydrochemical classes

Hydrochemical dynamics

Broad substratum types

Soil classification and description

Physicochemical properties of the substratum

Peat stratigraphical analysis

Management Conditions

Drainage status

Land utilisation

Wetland Modification Classes

Biological Features

Physiognomic vegetation types

Floristic vegetation types

Species composition

Palaeoecological, archaeological and historical features

3.4.2 Environmental and habitat classifications

A variety of environmental subdivisions of wetlands have been recognised, based on broad features such as substratum type, base status, nutrient status and water source, reflecting some of the main environmental gradients that have been identified Figure 3.1, Table 3.9). The development of the main wetland habitat categories and terms, in relation to the main ecological and floristic gradients, has recently been reviewed by Wheeler and Proctor (2000).

Table 3.9 Terms for broad wetland categories based on (a) substratum typ; (b) base status; (c) nutrient status; (d) main water source and reason by wetness; (e) water level; and (f) successional stage

Lines connect terms that are subdivisions

(a) Substratum type

WETLANDS

AQUATIC WETLANDS
(lakes, rivers, ponds)

PALUDIC WETLANDS
(waterlogged land)
(± mires)

PEATLANDS

BOGS

FENS
(strict sense)

WETLANDS
ON MINERAL
SUBSTRATA

FENS
(broad
sense)

MARSHES

(b) Base status (pH) (> sequence of increasing pH)

BOG POOR FEN RICH FEN

(c) Nutrient status (fertility)

OLIGOTROPHIC
(nutrient poor)

MESOTROPHIC
(moderate nutrient status)

EUTROPHIC
(nutrient rich)

(d) Water source

OMBROTROPHIC
surface fed only
by precipitation

MINEROTROPHIC
surface fed by precipitation
and telluric water

OMBROGENOUS
wetness maintained by
precipitation

TOPOGENOUS
wetness maintained by
topography of land
(*e.g.* basins)

SOLIGENOUS
wetness maintained by water flow
from 'soil' (usually sloping)

(e) Water level (> sequence of decreasing wetness)

OPEN WATER SWAMP MIRE / FEN / BOG 'DRY' WETLAND

(f) Successional stage

OPEN WATER SWAMP HERBACEOUS FEN SWAMP CARR CARR BOG

3.4.3 Hydrotopographical classifications

One of the most widespread approaches to the classification of wetland sites has been to identify hydrotopographical (or hydromorphological) wetland types, based upon the shape of the wetland and its situation with respect to apparent sources of water. The appeal of this approach is probably because the topography and water supply of wetlands may be regarded as their most fundamental defining features, and because of the apparent simplicity of categorising sites by their shape and situation. However, wetland topographies are not readily quantified, nor are hydrological mechanisms necessarily amenable to identification by casual inspection, and this approach has led to the propagation of various informal typologies.

In Britain, one of the most influential hydrotopographical classifications of British wetlands was that proposed by Goode (1972). It was subsequently incorporated into the *Nature Conservation Review* (Ratcliffe, 1977) and developed slightly by Wheeler (1984). It has much shaped the approaches of conservationists and other workers but has some clear limitations: particularly that it is not comprehensive; its categories are informal and not clearly defined; and some of its units are ambiguous, partly because they rest on a mixture of topographical and hydrological criteria which do not necessarily coincide. For example, 'open water transition mires' and 'soligenous mires' are identified as independent wetland types, but occur regularly as elements within other independent wetland types. [Likewise Lloyd *et al*. (1993), in an informal hydromorphological classification of East Anglian wetlands (Table 3.10), distinguished (at the same rank) 'schwingmoor' from 'basin fen' without recognising that 'schwingmoor' is a development *within* many basin fens]. There is a clear need to disambiguate such typologies if they are to have consistent or clear usage.

Wheeler and Shaw (1995a) recognised that, despite their limitations, hydrotopographical units were potentially useful as broad descriptive units. They suggested that the problem of units occurring within other units could largely be dealt with by recognising two independent layers of units: *situation types* and *hydrotopographical elements*. The situation type represented the broad landscape situation in which a wetland occurs. It was seen as a broad and informal category which is as variable as the landscape and which represents the first approximation for a wetland classification. The *hydrotopographical elements* were seen as units with distinctive water supply mechanisms and, sometimes, distinctive topographies in response to this. Many wetlands contain a number of hydrotopographical elements and the same element may occur in wetlands belonging to different *situation types* (Table 3.11).

Wheeler and Shaw (1995a) further suggested that the basic two-layered hydromorphological classification could be extended if required by using additional layers for other sets of wetland features (Table 3.8). The underlying concept was that each layer could be treated independently, thus providing a flexible classification scheme based on the permutations of different sets of wetland properties.

This approach to wetland classification was both comprehensive and consistent, but it was still essentially 'top down' in approach, being based on expert judgment rather than data, whereas the main units in such a classification would have more credibility if they were derived 'bottom-up', by synthesis and analysis of measured data relating to individual wetland sites and samples.

Table 3.10 Examples of hydromorphological wetland classifications

A. *Main hydromorphological types of wetland following Goode (1972) and the Nature Conservation Review (Ratcliffe, 1977).*		
Floodplain mire	Soligenous mire	Raised mire
Basin mire	Valley mire	Blanket bog
Open water transition mire		
B. *Hydromorphological classification of East Anglian wetlands (Lloyd et al. 1993, based partly on Ratcliffe, 1977*)		
Floodplain fen	*Schwingmoor*	Spring fen
Basin fen	Fluctuating mere	Valley fen
Open water transition mire	Non-fluctuating mere	Soakway

Table 3.11 Wetland situation types and component hydrotopographical elements (from Wheeler and Shaw, 1995a)

Situation type: Hydrotopo-graphical element	**Basin wetlands**	**Lakeside wetlands**	**Coastal/ Floodplain wetlands**	**Plateau–plain wetlands**	**Valleyhead wetlands**	**Hillslope wetlands**
Alluvial wetland			+++		+	
Waterfringe wetland	+++	+++	++			
Sump wetland	+++	+++	+++	+++	+	
Percolating wetland	+++	+	+++	+	+++	
Water track	+		++	+	++	
Spring-fed wetland	++	++	+	++	+++	+++
Run-off wetland	+	+	+	+	+++	+++
Soakway					++	+++
Topogenous bog	+++	++	+++	+++	+	
Hill bog	+	+	+	+	+	+++

+++: particularly characteristic of the situation type; ++: sometimes occurs within the situation type; +: of minor importance, or peripheral.

3.4.4 Hydrogeological classifications

The environmental classes listed in Table 3.9 include some broad categories of water source and reason for wetness. Lloyd *et al*. (1993) proposed a rather different approach, by classifying wetlands in East Anglia with reference to the main external sources of water and mechanisms of delivery (Table 3.12).

More recently, in a wide-ranging review of issues related to hydrological and hydrogeological aspects of impact assessment of wetlands, Acreman (2004) expanded the approach of Lloyd *et al.* (1993) to a wider range of wetland contexts. He identified the different forms of water transfer that can occur between wetland sites and their surroundings and proposed some conceptual models, which are referred to selected example sites. In an approach somewhat reminiscent of that of Wheeler and Shaw (1995a), Acreman made a clear distinction between landscape location and water transfer mechanisms to provide a systematic basis for the development of a wetland typology, but did not attempt, except informally, analysis of the recurrent combinations of water transfer mechanisms that regularly and generically occur within the various landscape types. This is significantly distinct from the parallel work in the development of the *Wetland Framework*, but there are – not surprisingly – some striking similarities with some of the conceptual diagrams used to illustrate certain WETMECs in this report (Chapter 6). Also, like Lloyd *et al*. (1993), Acreman (2004) did not really consider the role of the wetland infill itself in helping to determine actual water transfer mechanisms within wetland sites. He did, however, recognise that different transfer mechanisms often occur in different parts of individual sites, thereby pointing away from the development of simplistic whole-site typologies.

Table 3.12 A hydrological and hydrogeological classification for East Anglian wetlands (from Lloyd *et al*., 1993)

Class	Input	Topography	Geology in catchment
A	Surface water run-off only	Often in topographic hollow, also valley	Clay predominates
A'	Overbank flooding	Low relief adjacent to river	Clay predominates
B	Leaky aquifer and some surface water	Shallow valley	Low permeability but mixed – sand may exist; tufa?
C	Groundwater from superficial deposits	Shallow valley	Mixed typical clay–sand–gravel drift
D	Groundwater from superficial deposits and underlying main aquifer	Valley or closed depression	Sands and gravel over clays over main aquifer
E	Leaky aquifer	Closed depression, such as pingo	Clay overlying major aquifer, lateral isolated typical 'pingo'
F	Unconfined main aquifer	Wide range	No superficials. Main aquifer rock outcropping
G	Unconfined superficial aquifer	Shallow valley	Superficial sands and gravels overlying clays

3.4.5 The Wetland Framework and WETMECs

Some of the concepts underlying this framework represent a development of the hydrotopographical classificatory suggestions proposed by Wheeler and Shaw (1995a), enlarged and combined with elements of hydrological and hydrogeological approaches (*cf.* Lloyd *et al.* (1993) and Acreman (2004)).

The *Wetland Framework* essentially consists of three sets of units[1]:

Situation types: these largely correspond to the broad, informal landscape categories proposed by Wheeler and Shaw (1995a) and have broad similarities with the landscape location types of Acreman (2004).

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[1] For further information about the units of the 'Wetland Framework' and their derivation, see Chapter 4.

WETMECS: these are generic water supply categories derived by numerical analyses of stand data, which relate to the broad mechanism by which the wetland stand is kept wet, with particular reference to summer conditions; they are based primarily upon the characteristics of the main water source(s), topography of the stand and top-layer conditions of the stand (see Chapter 5) and the interactions between these features (see also Box 3.8)

Habitat types: these are separate categories used to encompass other environmental characteristics of wetlands; currently two separate sets of categories are used, relating to the base-richness and fertility of the wetland surface, based on subdivisions of these variables proposed by Wheeler and Proctor (2000) (see Appendix 2 – Data Sources and Analyses).

Distinctive features of the Wetland Framework approach

The *Wetland Framework* differs from other approaches for developing wetland classifications and typologies in a number of respects. Amongst its distinctive characteristics are that it is:

- ecohydrological, concerned with the development of categorisations of water supply and other environmental variables particularly relevant to vegetation and other biological features of the stands, aiming to identify distinctive, holistic, wetland habitats;
- based on stands within sites rather than on whole sites;
- primarily bottom-up in approach, based on the numerical analysis or categorisation of stand data;
- particularly concerned with the importance of top-layer conditions (see Chapter 5) in regulating water supply and influencing the types of habitat that occur;
- concerned with the importance of other environmental variables (base richness and fertility) as well as water supply.

Box 3.8: WETMECs and hydrotopographical elements

WETMECs have some broad similarities with the hydrotopographical elements proposed by Wheeler and Shaw (1995a), but there are important differences between the two sets of categories. The main differences are that:

(a) the hydrotopographical elements were informal units, derived by top-down expert judgement whereas WETMECs have been identified quasi-objectively using a bottom-up process based on the multivariate analysis of numerical data for a wide range of features from individual stands of vegetation within wetlands;

(b) WETMECs are less dependent upon the topographical context in which they occur (they represent a greater emphasis on the ‘hydro’ aspect of the former hydrotopographical elements).

None of the former hydrotopographical elements corresponds to a single WETMEC, but several equate with a group of two or more WETMECs. A few (such as sump wetlands) have been split across two or more WETMECs and are no longer recognisable within the WETMEC list.

PART 2:

THE WETLAND FRAMEWORK

4 Approach, rationale and analyses

4.1 Approach and rationale

One of the fundamental questions of wetland ecohydrology is ‘Why is this wetland wet?’ (or very often, ‘Why isn’t it as wet as it is thought it should be?’). This question can often be difficult to answer, not least because of the sparsity of hydrometric data available for many wetland sites and because the exact details of water supply may well be unique to each wetland site. Nonetheless, it seems likely that there are some broad, generic supply mechanisms which are applicable to a number of similar sites. As a simple – if rather superficial – example, ombrogenous surfaces are, by definition, fed directly and exclusively by precipitation (though the details of this supply mechanism, such as the distribution of meteoric water within the mire and its interactions with any underlying telluric water, may well differ between sites).

Whilst water supply is a key component of the ecohydrological characteristics of wetlands, it is not the only feature of importance: certain hydrochemical conditions are also known to exert a strong influence upon the ecological character and biota of wetlands (Chapter 3), often in interaction with the water supply.

The *Wetland Framework* was developed in an attempt to make a holistic analysis and categorisation of water supply, water conditions and other environmental variables in wetlands in order to help identify (a) generic water supply mechanisms (WETMECs); (b) wetland habitats; and (c) the relationship of these ecohydrological categories to specific plant community types.

Three sets of categories are used in the Framework: situation types, WETMECs and habitat units.

4.1.1 Situation types

Situation types largely correspond to the broad, informal landscape categories proposed by Wheeler and Shaw (1995a). No attempt has been made to identify these units objectively: they represent broad, often rather ill-defined units, as variable as the landscape of which they form part. However, experience has suggested that some categories additional to those proposed by Wheeler and Shaw (1995a) should be recognised, or some existing types subdivided, which helps to provide a slightly clearer definition for some of these units (Table 4.1, Section 4.4).

4.1.2 Water supply mechanisms (WETMECs)

WETMECs are generic categories of mechanisms of water supply to vegetation within wetland sites. Their identification involved three main stages:

i. Acquisition of field and other data on water conditions and water-related variables from individual stands of a large number of contrasting wetland sites in lowland England and Wales (see 4.2).

ii. Use of multivariate clustering procedures to identify recurrent combinations of field conditions (see 4.3.1 and 4.3.2) and of other univariate and multivariate statistical procedures to examine inter-relationships amongst the ecohydrological variables (including the identification of potentially causal relationships).

iii. Interpretation of the clusters generated, and inter-relationships identified, in terms of apparent water supply mechanisms (WETMECs) (see Appendix 2).

It is important to appreciate that whilst the extracted clusters of recurrent combinations of field conditions are quasi-objective units, subject to the limitations of the original dataset and the idiosyncrasies of multivariate clustering algorithms, the end units (WETMECs) are derivative units which provide interpretations of the cluster analysis in terms of water supply. They should therefore not be seen as *ex cathedra* assertions but as hypotheses to be tested.

The WETMEC approach differs from some other attempts to identify water supply types and wetland habitats, particularly in that:

- It is stand based, where the sampling units are individual patches of relatively uniform vegetation (stands) and not whole sites. This is because water supply mechanisms do not necessarily operate on a whole-site level and different parts of the same site, and different plant communities within it, may experience different water supply regimes.

- It is 'bottom-up' in approach, based on numerical analyses of field data rather than on a 'top-down' recognition of different water supply situations based on expert judgement. A benefit of the bottom-up approach is that, as well as being based on field data, it identifies the main combinations of conditions that *do* occur rather than those which *could* occur. A disadvantage is that the units identified are critically determined by the precise compass of the available dataset and that – particularly given the vagaries of multivariate clustering routines – distinctive units represented by only a small number of samples may not be identified as clearly as they deserve and may even be subsumed within other types.

WETMECs (see Figure 6.1 and Table 6.1, Section 6.2) are water supply units and not wetland habitat units; they take no account of other environmental variables (such as water pH) and are in principle independent of these (though in practice, some WETMECs are strongly correlated with particular hydrochemical conditions). Wetland habitat units have been identified separately.

4.1.3 Wetland habitat units

Wetland habitats (the environmental conditions in which wetland animals and plants live) are defined by water regime and supply and by a range of other conditions, especially their hydrochemical environment. In the Phase 1 analyses, an attempt was made to identify composite 'ecohydrological units' by multivariate procedures, by including hydrochemical terms together with water supply terms in the cluster analyses, but the end units proved difficult to interpret. Thus a layered approach was adopted, in which wetland habitats were identified by particular combinations of three nominally independent layers of variables, namely:

- water supply mechanism (WETMEC);

- base status (pH, Ca, alkalinity);

- nutrient status (fertility, N, P, K).

These three sets of variables correspond to the three main gradients of environmental variation observed in wetlands (Wheeler and Shaw, 1995b; Wheeler and Proctor, 2000). This approach was continued in the present study. The subdivisions of base status and nutrient status are identified below (see Section 4.4).

4.2 Sites and data

Ideally, any attempt to identify wetland types and water supply mechanisms would include a similar number of representative examples for each category, selected across the whole range of wetland variation. An obvious constraint upon this approach is that it requires the pre-identification of the types which are to be extracted from the data and from which samples can be taken. Another practical limitation is that appropriate vegetational, ecological and hydrological data are available only for certain sites. As this study aimed primarily to collate existing data, with acquisition of new data only where strategically important, the sites (and stands) included in the project have mainly been determined by data availability. The range of sites encompassed within the study was made as wide as possible by the use of categorised estimates for some variables, rather than measured data. Nonetheless, most of the sites for which substantive data exist are of SSSI status, which means that low quality sites are under-represented in the Framework.

The pilot study for the project (Wheeler and Shaw, 2000a) was carried out in Eastern England, which has some of the most investigated wetland sites. Expansion from this targeted specific regions with mires which were thought likely to complement those in Eastern England. The additional regions were: Southern England (especially the New Forest and Dorset); West Midlands (mainly the so-called ‘Meres and Mosses’ district); North-West England (especially Cumbria); and Wales. Within each region, sites were selected on the basis of complementarity and data availability. A few sites in other regions (South Midlands and North-East England) for which relevant data were available were also included. Some additional sites from other regions, or from which fewer data were available, were used to test and validate identified WETMECs

Within each site, samples were collected from discrete stands of vegetation: distinct, more or less uniform patches of vegetation which correspond (in most cases) to individual communities or sub-communities of the National Vegetation Classification (Rodwell 1991a, b, 1995). Not all of the communities present in individual sites were necessarily sampled. However, some information was not collected in the field (such as geology, rainfall) and was often available only for whole sites, though in sites with contrasting geology and so on, it was sometimes possible to link different stands to different situations.

A list of sites and details of data sources and categories used in the study is given in Appendix 2.

4.3 Identification of WETMECs

4.3.1 Relationships amongst variables

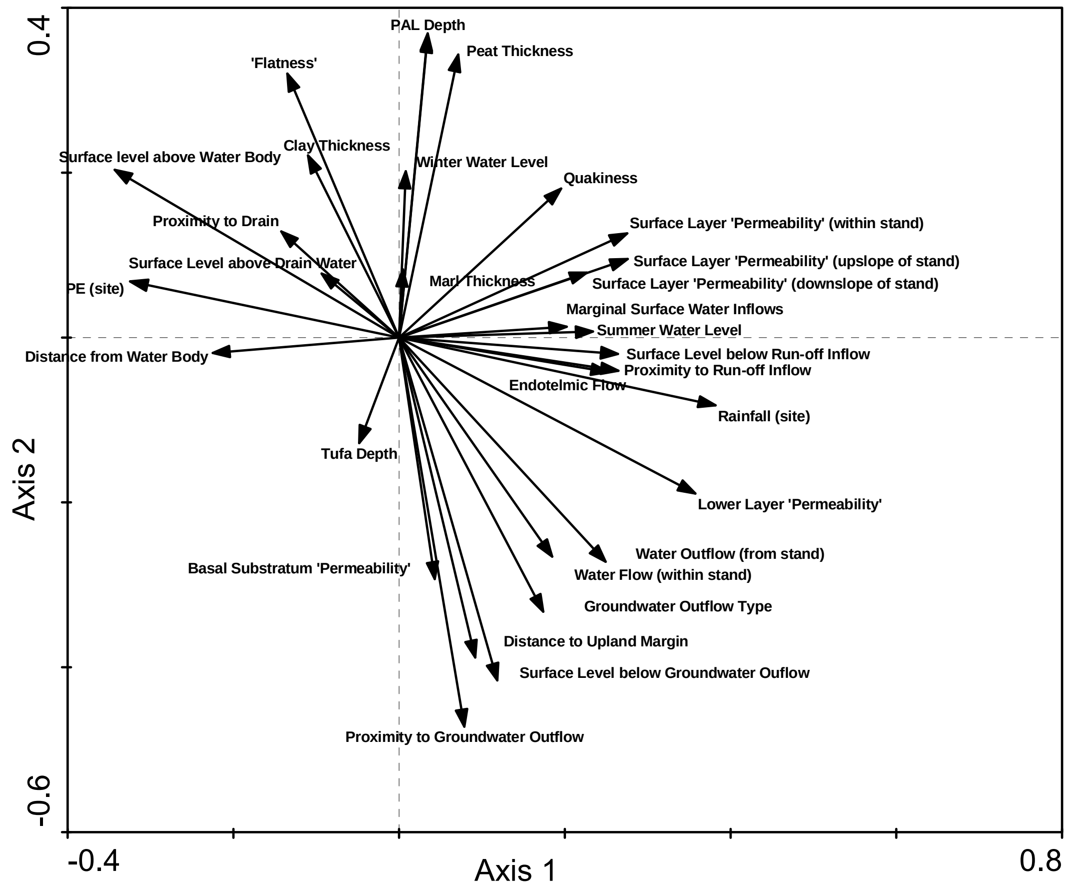
Canonical correspondence analysis (CCA) is a multivariate analytical technique which can be used to help identify the relationships between environmental variables and the species composition of vegetation. The procedure helps to identify the environmental variables that are most important in accounting for the main extracted directions of floristic variation, and in so doing also show the inter-relationships between different environmental variables within this analytical context.

CCA was used to explore the relationships between environmental variables and vegetation, with a view to helping identify some of the main ecohydrological processes relevant to wetland vegetation and to the identification of WETMECs. The entire dataset was examined and numerous subsidiary analyses were made on data subsets. The CCA analysis was based on variables relating to water level and flow, rainfall and potential evaporation; height of the surface in relation to any known groundwater and surface water sources, and distance from these; topographical context of the stand (slopes and so on); characteristics of the upper and lower layers of wetland infill within the stands (and between the stands and any known water sources or sinks); and characteristics of the uppermost layer of mineral material below the wetland infill of the stand (referred to as the 'basal substratum'). Other variables for which data were available (such as vegetation, hydrochemistry, topography and landscape situation of the site) were excluded from these 'water supply' analyses.

Further details of the method and the results of the CCA analyses are given in full in Appendix 2. The results of a CCA of all samples (Figure 4.1) point to a number of significant inter-relationships within the dataset, summarised below:

- The main direction of species composition variation corresponds to a gradient of summer water table, in which high water tables are particularly associated with high rainfall totals, and low water tables with proximity to drainage structures and distance from potential surface water sources.
- The second most important direction of species composition variation corresponds largely to a topogenous–soligenous gradient, in which the topogenous sites are generally on deeper peat and wetter in winter than sloping soligenous sites.
- Soligenous sites mostly have groundwater outflow as their primary source of telluric water; groundwater is generally less important in topogenous situations, for various reasons, though there are numerous exceptions to this generalisation.
- Surface run-off can be significant in both topogenous and soligenous situations, but is generally less important than groundwater outflow, especially in soligenous sites. Its importance increases in high rainfall regions.
- Groundwater outflow on soligenous slopes is generally, but not exclusively, associated with a high permeability basal substratum.
- The presence of a loose, quaking or buoyant surface layer is associated with high summer water tables, especially in topogenous circumstances. This is suggestive of some hydroregulatory function by the surface layer.

Some of these relationships, and others, are explored further in Chapter 5.



Terms included are explained and units given in Appendix 2. Unless otherwise indicated, variables refer to individual stands. Abbreviations are: PAL: Peat and alluvium; PE: Potential evaporation.

Figure 4.1 Axes 1 and 2 of a CCA ordination of species composition and values of water-related variables in all samples included in the *Wetland Framework* analysis

4.3.2 Cluster analysis and abstraction of WETMECs

The rationale for the cluster analyses was to identify recurrent quantitative combinations of the water and water-related variables based on values from individual stands (samples). The clusters thus created essentially represent composite units reflecting the co-occurrence of combinations of the estimated hydrological, topographical and stratigraphical variables.

Details of the cluster analysis are given in Appendix 2. In essence, the 36-cluster stage was selected for examination based on a Moving Average Best Cut Significance Test (t-statistic). This model was then refined by reallocation of some samples using a k-Means Analysis, based on Euclidean Sum of Squares. Interpretation of the resulting clusters took account *inter alia* of the results of the CCA and various univariate statistical relationships, and resulted in the segregation of the 36 clusters into 20 discrete WETMECs. Thus, each end cluster does not necessarily correspond to a separate WETMEC: some have been allocated to WETMEC sub-types.

Five main groups of wetland were recognised: (i) ombrogenous and near-ombrogenous mires (fed primarily by rainfall); (ii) floodplains (fed mainly from watercourses); (iii) floodplains and valley bottoms fed mainly by groundwater (and often part-drained); (iv) seepage systems; and (v) other systems fed mainly by water flow from the upland margins, sometimes mainly groundwater sourced (such as flushes), but sometimes with limited (or no known) groundwater supply. The validity and utility of the WETMECs identified has, as far as possible, been checked by reference to some samples that were not included within the analyses.

4.4 Main units of the Wetland Framework

4.4.1 Situation types

The landscape situation types identified are tabulated below (Table 4.1). Note that in many instances a single site belongs to just one situation type, but some larger complex wetlands may be partitioned into different situation types.

Table 4.1 List of situation types used in the *Wetland Framework*. Types listed in italics are sub-types of the preceding type

Situation Type	Notes
Basin wetlands	Associated with discrete basins and ground hollows (such as *Delamere Forest Mires, Border Mires*).
Closed basins	Surface inflows and outflows are little developed or absent (such as Abbots Moss, Lin Can Moss).
Throughflow basins	Basin topography, but with a strongly throughflowing watercourse (such as Biglands Bog, Cranberry Rough, Finglandrigg Moss).
Valleyhead basins	Basins embedded within, or forming, valleyheads; often quite strong outflow; inflow from seepages or small streams rather than a throughflowing watercourse (such as Cors Llyn Coethlyn, Eycott Hill Mires, Silver Tarn, Trefeiddan Moor).
Coastal and flood plain wetland	Associated with river floodplains and coastal plains, including active and inactive examples (when their inactivity is largely a product of drainage and water management) (such as Suffolk and Norfolk Broadland; Test Valley).
Hillslope wetlands	On sloping ground and hillslopes, typically well upslope of, and separated from, valley bottoms; includes small areas of wetland developed on flat benches embedded within some hillslopes; supports a wide range of wetlands from soligenous fen to blanket bog, e.g Banc y Mwldan (Cardigan).
Lakeside wetlands	Associated with large lakes, such as Esthwaite Water, Malham Tarn, or smaller water bodies when these represent the only or main situation in which wetland occurs. Where comparatively small water bodies occur within other situation types (such as pools within basin wetlands, ox-bow lakes within floodplain wetlands), they are subsumed within these.
Plateau–plain wetlands	On flat or slightly undulating ground without close association with lakes, rivers or discrete, shallow basins; kept wet by high rainfall, impermeable substratum, high groundwater level and so on. Includes sites on former river floodplains, terraces and some high-level plateaux (such as Wedholme Flow and Bowness Common, Cumbria).
Trough (or valley-bottom) wetlands	Associated with the bottoms of valleys or other depressions, in contexts that are not really floodplains, or where the floodplain forms only a small proportion of the site, and often with a visibly sloping bottom. Includes some sites that are spatially transitional between the valleyhead and floodplain zones of rivers, and usually have many topographical similarities with valleyheads, but in a location well downstream of the actual valleyhead (such as Swangey Fen, Norfolk).
Valleyhead wetlands	Associated with the upper reaches of valleys; mainly soligenous (such as New Forest valley mires); valleyhead topography is clear (not obscured by a fairly deep peat infill with a ‘flat-across’ surface), though some may have been created by peat removal from such valleyhead troughs.
Valleyhead troughs	Peat-filled troughs in broadly valleyhead contexts (such as Cranesmoor). Includes some former basin, or valleyhead basin, sites where peat has accumulated sufficiently to obscure the underlying basin topography (such as Cors Erddreiniog, Great Cressingham Fen, Stable Harvey Moss).

4.4.2 WETMECs

WETMEC types and sub-types identified are shown in relation to the cluster analysis dendrogram that produced them (Section 6.2, Figure 6.1, Appendix 5).

4.4.3 Habitat units

Base richness categories

These categories are based on pH boundaries. They correspond to the subdivisions recognised by Wheeler and Proctor (2000) and relate broadly to subdivisions used by some other workers. The split between base-rich plus sub-neutral and base-poor plus acidic, at around pH 5.5, corresponds to a more or less natural subdivision of the bimodal distribution of samples along the pH gradient, in which one mode (pH < 5.0) appears to represent waters buffered by humic material and the other (pH > 6.0), waters buffered by the bicarbonate system. However, further subdivisions within these two categories are largely arbitrary:

Base-rich	pH 6.5 – 8.0	Fen
Sub-neutral	pH 5.5 – 6.5	Fen
Base-poor	pH 4.0 – 5.5	Bog (~Poor fen)
Acidic	pH < 4.0	Bog

Fertility categories

Fertility categories are based on phytometric estimates of the fertility of fresh soil samples, obtained by growing equal-aged, matched seedlings of a test species (*Phalaris arundinacea*) on the samples in controlled conditions for a standard (10-week) period. Values are mean shoot dry weight (mg) of the seedlings.

Phytometric data do not suggest any obvious discontinuities within the fertility gradient, so any subdivision of the phytometric scale must be largely arbitrary (Wheeler and Proctor, 2000):

Oligotrophic	< 8 mg phytometer
Mesotrophic	8 – 18 mg phytometer
Eutrophic	18 – 38 mg phytometer
Hypertrophic	> 38 mg phytometer

5 Top-layer control

5.1 Introduction

Top-layer control refers to influences upon the hydrodynamics of mires imposed by superficial deposits. These include the paludogenic deposits of the wetland (such as marl, gyttja and peat), together with the immediately underlying mineral material (the basal substratum). This latter (often Head or Till) is frequently variable and poorly characterised, especially in terms of local variation in composition, and is sometimes completely unmapped. Top-layer conditions appear to have considerable local influence upon the occurrence and character of mires. They are often not considered in groundwater models and may provide an explanation of the poor fit between modelled and observed water tables in some mire systems. They have been given particular attention in the current investigation. Possible top-layer effects are discussed in detail in the accounts of individual WETMECs, but some general considerations are outlined here.

The following components of the top layer are recognised:

- **Basal substratum**: the mineral layer that immediately underlies the paludogenic deposits. In a very few skeletal systems, this can be the only layer present.
- **Paludogenic deposit** (**wetland deposit)**: the entire wetland infill. This includes peat, muds, and alluvial clays. It can vary considerably in character and hydrological properties, both horizontally and vertically within a site as well as between sites. Often the uppermost layer (surface layer) and any deeper deposits (lower layer) are distinctly different from each other.
  - ***Surface layer***: uppermost layer of deposits (surface and immediate sub-surface material, typically to about 0.5 m depth), usually including the main rooting zone. This is a subset of the paludogenic deposit and can often, though not always, have different properties to any deeper deposits. In some shallow deposits, the surface layer is essentially equivalent to the entire paludogenic infill. It effectively includes the 'acrotelm' layer recognised for some deposits (Box 6.39). It is mostly absent from a few, highly skeletal, wetland surfaces.
  - ***Lower layer***: paludogenic material below the surface layer and often, though not always, of noticeably different character and/or composition. Can show considerable horizontal and vertical variation in character. May be absent where the paludogenic deposit is thin.

This chapter provides an introduction to top-layer control, along with some examples. Some data collected for the project are used to identify relationships between top-layer conditions and water supply to different types of wetlands.

5.2 Some properties of wetland deposits

The nature of the paludogenic infill varies considerably in the wetlands considered here. Paludogenic deposits include alluvium, lake muds (gyttja and dy), marl and tufa, but the predominant material in most of the sites examined is peat. Few measured data on hydraulic conductivity are available for most deposits, but in general alluvial clays and silts, consolidated lake muds and marls are thought likely to have rather low permeabilities and may act as local aquitards. By contrast, peat is a very variable deposit, and reported hydraulic conductivities span the range from clays to gravels (Table 5.1), so peat deposits may act both as local aquifers and aquitards, depending on their properties. Wetland deposits also vary considerably in their capacity to store water, and may show important differences in yield.

Table 5.1 Permeability of different substrata (indicative values only)

Substratum	Permeability (m per day)	Source
Chalk	10^{-5} to 10^{-2}	Allen *et al.* (1997)
Sand	1 to 10^{2}	Kruseman and de Ridder (1994)
Gravel	10^{2} to 10^{3}	Kruseman and de Ridder (1994)
Sand and gravel	5 to 10^{2}	Kruseman and de Ridder (1994)
Clays	10^{-8} to 10^{-2}	Kruseman and de Ridder (1994)
Till	10^{-3} to 10^{-1}	Kruseman and de Ridder (1994)
Poorly decomposed, loose peats	10^{-1} to 10^{-2}	Measurements made in Broadland sites
Loose moss peat	*1.65 x* 10^{-2}	Upton Fen, Norfolk (van Wirdum *et al.,* 1997*)*
Surface fen peat	*2.17*	Sutton Fen, Norfolk (van Wirdum *et al.,* 1997; Baird, Surridge and Money, 2004)
Amorphous peats	*c.* 10^{-3}	Measurements made in Broadland sites
Amorphous greasy peat	*1.87 x* 10^{-3}	Catfield Fen, Norfolk (van Wirdum *et al.,* 1997; Sutton Fen, Baird *et al.*, 2004)
Humified/brushwood peats	10^{-3} to 10^{-4}	Measurements made in Broadland sites
Humified brushwood peat	*4.0 x* 10^{-3}	Berry Hall Fen, Norfolk (van Wirdum et al., 1997)
Firm brushwood peat	*5.04 x* 10^{-3}	Catfield Fen, Norfolk (van Wirdum et al., 1997)
Humified peat with monocot and brushwood remains	*9.42 x* 10^{-4}	Reedham Marshes, Norfolk (van Wirdum et al., 1997)
Acrotelm bog peat (K_h)	10 to 10^{2}	Romanov (1968)
Acrotelm bog peat (K_v)	< 10	Romanov (1968)
Catotelm bog peat (K_h)	10^{-2} to 10^{-4}	Boelter (1965); Romanov (1968)
Catotelm bog peat (K_v)	10^{-2} to 10^{-4}	Boelter (1965); Romanov (1968); Beckwith *et al.* (2003)

The interaction between the nature of the wetland substratum and water supply is often recursive and may vary through time. The substratum is not just a medium which may impose particular constraints upon present-day water flow, but its hydraulic properties are often themselves partly a product of the hydrological environment in which the deposit accumulated. For example, a dense, well-humified peat with wood fragments may not just provide considerable resistance to present-day groundwater flow, but may also have formed in circumstances in which there was little groundwater input (or at least where inputs were insufficient to maintain surface-wet conditions during most summers). By contrast, loose fresh peats have often formed in particularly wet circumstances and may facilitate water transfer under present conditions, although any such effect may not persist over long time periods due to ongoing processes such as compaction and decomposition. It may be possible to use peat stratigraphy as a proxy indicator of present-day, and to some extent former, water supply mechanisms. This is potentially important and useful in wetlands, particularly those based upon quite deep peat and alluvial deposits.

The characteristics of the peat infill of an individual mire may vary considerably, both laterally and vertically. Peat layers themselves are often anisotropic. Lateral hydraulic conductivities have sometimes been reported as being greater than vertical hydraulic conductivities, but greater vertical values have also been found (Surridge, 2005). However, these differences may be small compared to gross lateral and vertical variation in the character of the peat. In general, lateral variation in any one layer of the deposit tends mainly to reflect local variations in the depositional environment, whereas variation with depth may reflect both variation in the depositional environment and post-depositional changes (decomposition and so on). Gross differences in the ecohydrological properties of peat are reflected in the concepts of the acrotelm, catotelm and rafts (Box 6.39).

The deeper peats of fens (and some bogs) can show pronounced layering and vertical variation in hydraulic conductivity, sometimes with layers of high permeability, or even pipes, but the hydrological significance of permeable layers deep in the peat deposit is often difficult to assess without detailed investigation, because it depends critically upon their lateral continuity and (in some cases) upon the topography of the deposit, as well as the nature of the basal substratum.

The surface layer of a peat deposit is frequently formed of material that is noticeably fresher and less consolidated than the deeper deposits. However, this is not always the case and the surface layer can vary substantially from very loose, thin rafts (which may be more living rhizomes than peat) to dense, solid material. In some circumstances (especially in cut-over or part-drained locations), the surface layer may be very similar to the deeper horizons, or even more dense and solid. Dense surface layers are frequently associated with low water tables, but nonetheless sometimes support high water tables and rates of water flow. For example, the thin surface layer of some soligenous slopes may be composed of rather amorphous, dense material, but these sites may show visible surface water flow funnelled into skeletal runnels between the slightly elevated organic surfaces.

Box 5.1: Acrotelms, catotelms and vegetation rafts

The concepts of the acrotelm and catotelm have been particularly used with reference to ombrogenous peatlands (see the account for WETMEC 1 Domed Ombrogenous Surfaces ('raised bog' *sensu stricto*)). As outlined by Ivanov (1981), the *acrotelm* is the thin (< 1 m) active layer that forms the surface skin of peatlands, superimposed upon a less active *catotelm* (which usually represents the bulk of the deposit).

Ivanov suggested that the key feature of the acrotelm is its fluctuating water table, which enables it to function both as an aerated layer and a peat-forming layer. He proposed that the thickness of the acrotelm is "*equal to the distance from the surface of the mire to the average minimum level of water in the warm season*". Hence the catotelm is often defined as being permanently saturated, with the acrotelm as an unsaturated layer. However, whereas most peatlands have a surface unsaturated layer, this does not necessarily have all of the properties of the acrotelm identified by Ivanov (such as locations where the natural surface has been removed by peat extraction or otherwise damaged).

In a natural ombrogenous bog, the acrotelm layer may provide some hydrological regulation, dependent specifically upon properties such as high hydraulic conductivity and water yield (Ivanov, 1981; Ingram, 1992; Joosten, 1993; Schouwenaars, 1996). Ivanov (1981) suggested that the acrotelm has hydroregulatory functions through rapid dissipation of water excess without a significant rise of water level and by prevention of drying (reduction or cessation of horizontal seepage). It thus provides a positive feedback mechanism in which the plants that form the acrotelm help to produce conditions appropriate for their continued growth. Such regulation may be especially important in ombrogenous peatlands, particularly in regions subject to periodic droughts (Joosten, 1993), though the magnitude and mechanisms of such postulated hydroregulation have yet to be established critically.

The hydrological importance of the acrotelm in fens is not well established. Most fens have a periodically unsaturated surface layer, but the depth of this can vary considerably and its hydroregulatory function may be strongly context-dependent. It is possible that the loose spongy surfaces of some fens may have a capacity for hydroregulation comparable to that of bogs (Ingram, 1992), but the hydrodynamics of many fens are controlled by external events independent of any properties of their surface layers. For example, the stable water regimes of some groundwater-fed fens may be imposed more by the constancy of groundwater inputs than by internal mechanisms, whilst in many other fens seasonal variation in recharge generates strongly fluctuating water levels.

Vegetation rafts may provide hydroregulatory functions similar to those of the acrotelm, in terms of water storage beneath the structure, which helps reduce water level change, and of buoyancy, which can help dampen water level fluctuations relative to the vegetation surface. Buoyancy is a particular feature of thin, unstable rafts and may largely account for the low variance of summer water tables recorded for these, which rarely experience either low or high water levels relative to the surface. This property diminishes in less buoyant rafts, which can experience low summer water tables or summer flooding. As these are in many cases an older, thicker seral derivative of more mobile rafts, it appears that any hydroregulatory function provided by rafting diminishes with maturation, until eventually the raft becomes grounded. Thus, the key difference between some rafts and an acrotelm is that whereas water tables fluctuate within an acrotelm, the surface of a mobile raft can retain a fairly stable position relative to the level of a fluctuating water table. Of course, less mobile vegetation rafts may also have an acrotelm in terms of a surface unsaturated layer which, as the raft progressively thickens and consolidates, may supervene raft-based hydroregulation.

Little is known about the permeability characteristics of vegetation rafts in topogenous mires, nor about the mechanisms which give them buoyancy. Their generally loose, unconsolidated character is suggestive of a rather permeable deposit, but the small number of studies on buoyancy mechanisms point to entrapment of gases, particularly methane, within the raft as a main cause of buoyancy, and this may constrain water flow within or through the raft.

5.3 Wetland surfaces and water tables

In this section, some relationships between the character of the wetland surface and water conditions are examined using data collected for the project.

5.3.1 Relationships between surface layer characteristics, water tables and slope

Dense, solid peat surfaces generally have lower summer water tables than loose, unconsolidated ones. This effect occurs both in sloping and topogenous contexts, but is particularly pronounced in the latter (Table 5.2). The reasons for this relationship may vary between samples, but may often stem from an interaction between water levels and peat type. High water tables can encourage the formation of a loose, unconsolidated surface deposit (which in some topogenous locations may be little more than a loose rhizome mat) and hence may drive the observed relationship. On the other hand, as different categories of surface layer (Table 5.2) may have contrasting permeabilities, the high water tables associated with loose peat surfaces (particularly in topogenous cases) may partly be a product of greater recharge through particularly transmissive surface layers. Where the surface layer is formed from a buoyant raft (mostly in topogenous contexts), its vertical mobility may help dampen water level fluctuations relative to the raft surface (see Box 6.39). In sloping situations, the relationship between summer water tables and peat type is more muted; loose, quaking surfaces are probably much less common on slopes than in topogenous contexts. Relationships between water tables and slope are explored further below (5.3.4 and 5.4).

5.3.2 Surface layer characteristics, water levels and distance from water sources in topogenous mires

A relationship can be found between the surface water level in some topogenous mires and the distance of samples from surface water bodies, with respect to the surface-layer conditions, expressed either as surface stability (Table 5.3) or substratum characteristics (Table 5.4). Samples in this analysis were restricted to those from topogenous sites where the water levels of adjoining water bodies (dykes, pools and lakes) were high (and thus not obviously acting as drains), and also to locations where any water input from the upland side of the mire was likely to be small. The results show that compared with fresh/loose peat, where solid surfaces on firm peat adjoin the water body: (a) water levels were generally lower in the wetland substratum; and (b) there was a much stronger decline in the water table with distance from the water body.

Table 5.2 Relationship between the character of the surface layer and mean summer water tables, categorised by slope

Character of surface layer	All topogenous locations	All sloping locations	Moderate to steep slopes
Dense, solid peat/silts/clay	–37.6	–7.6	–7.6
Well-decomposed firm peat	–13.7	–6.5	–6.6
Firm, moderately decomposed peat	–7.1	–3.0	–1.6
Fresh herbaceous peat	–3.7	–0.8	–2.2
Loose plant material/fresh peat	+0.3	–0.1	0.04
Very loose plant material	+2.4	+0.4	–0.5

All values are mean summer water table (cm relative to surface)

Interpretation of these observed relationships is tricky, and may vary between locations. In these 'flat' circumstances, the surface water body may act variably as a water sink and source, depending on hydraulic gradients which can vary in direction with time. Also, the recorded water table has been measured relative to the surface and may therefore itself be a partial product of the capacity of the surface for vertical movement in response to water level change. However it is clear from these data that, in general, where the top layer is loose, apparently permeable and often buoyant or expansible, much higher summer water tables persist with increasing distance from a potential surface water source than is the case on a solid surface.

Table 5.3 Relationship between mean summer water table and distance from a surface water body in topogenous mires, categorised by stability of the wetland surface

Distance from open water body	Firm or solid surface	Soft, quaking or buoyant surface
>100 m	–25.4	–2.3
30 – 100 m	–23.3	–1.1
10 – 30 m	–7.1	–1.4
3 – 10 m	–11.9	–0.5
Adjoining	–9.2	0.3

All values are mean summer water table (cm relative to surface)

Table 5.4 Relationship between mean summer water table and distance from a surface water body in topogenous mires, categorised by surface-layer characteristics

Distance from open water body	Silt/clay – firm peat	Fresh – very loose peat
>100 m	–27.6	–2.9
30 – 100 m	–21.5	–0.7
10 – 30 m	–11.1	–2.9
3 – 10 m	–4.6	1.1
Adjoining	–6.4	1.3

All values are mean summer water table (cm relative to surface)

5.3.3 Surface stability and summer water tables

The stability of wetland surfaces can vary significantly from dense, solid surfaces (sometimes concretions) to very loose, thin semi-floating rafts. Surface stability is difficult to measure, and was estimated here using six ranked categories (Table 5.5). Soft (spongy) surfaces are widespread and are probably quite transmissive. They may have some vertical expansibility but are not usually rafts, and are well seen in spongy *Sphagnum* surfaces. Buoyant and semi-floating surfaces are invariably a form of raft, over water or fluid muds of variable depth. Vegetation rafts are mostly associated with hydroseral colonisation of small, mostly shallow water bodies, both in natural wetlands and in reflooded turbaries (turf ponds). They vary enormously in their character and thickness, from thin skins of hydroseral vegetation formed from the entangled rhizomes of hydrophytes growing over deep water and muds, to thick accumulations of relatively solid peat fractured across a once-continuous column. The thicker examples are generally the least mobile and some rafts are grounded except at high water levels.

Although the stability categories used are crude and subjective, they show a clear relationship to the summer water table of topogenous mires (Table 5.5). Decreasing surface stability (increased quakiness) is associated with a consistent increase in the mean and minimum summer water tables, and with a decrease in the variance within each stability category. There is also a tendency for the maximum summer water table to be lower with decreasing stability. No examples of very unstable (semi-floating) surfaces with deep standing water in summer were recorded, but overall the trend of maximum water table was not as consistent as that of the minimum and mean values.

Little is known about the permeability characteristics of vegetation rafts in topogenous mires, nor about the mechanisms which give them buoyancy (see Box 6.39). It is possible that the mechanisms which enable the raft to float may also reduce its hydraulic conductivity (*cf.* Baird and Waldron, 2003), leading to relatively summer-dry conditions on the surface of maturing rafts except in climates with high rates of summer rainfall. Few data are available on this, but it is certainly the case that maturing rafts are often rapidly colonised by woody plants, and have surfaces that are readily carpeted by *Sphagnum* species, even in contexts where the telluric water of the mire is base rich (see also section on water supply in the account for WETMEC 2, Buoyant Ombrogenous Surfaces).

Table 5.5 Relationship between summer water table of topogenous mires and surface stability (estimated rank categories)

Stability	Mean	Minimum	Maximum	SD
Solid	–38.8	–180.0	66.6	54.8
Firm	–14.8	–80.0	33.2	18.2
Soft (spongy)	–2.8	–30.2	50.0	10.5
Very soft (quaking)	0.9	–22.0	21.6	7.9
Buoyant	0.7	–17.0	20.6	7.5
Semi-floating	1.7	–5.6	3.6	1.2

All values are mean summer water table (cm relative to surface)

5.3.4 Water tables and slope

There is a clear relationship between the mean depth of wetland infill and the slope categories on which mires occur: mean depth of infill decreases with increasing slope (Table 5.6). Nonetheless, some ‘flat’ sites can also have very shallow wetland infills.

When considered across all samples, summer water table bears no consistent relationship to the slope categories (Table 5.7): samples from steeply sloping locations have a mean summer water table that is one of the highest of all the slope categories, and higher than that of topogenous (more or less flat) locations. This is probably because most sloping locations sampled, especially the more steeply sloping ones, are fed by springs and seepages which are kept consistently wet by high rates of water supply. There is some evidence that some topogenous locations can be drier in summer than the sloping locations sampled, but this effect is small, and overall the percentage distribution of the drier categories of summer water table is very similar between topogenous and sloping sites (Table 5.8). Differences between the two types are more evident in the higher water level categories. Sloping sites lack the highest water level categories, both in summer and winter, probably because of the sparsity of topographical constraints upon surface drainage in most strongly sloping locations. The modal category of summer water table is the same in both sloping and topogenous types (–5 to +1 cm), but proportionately more samples fall into this in the sloping context than in topogenous circumstances.

Table 5.6 Mean depth of wetland deposit partitioned into five categories of slope

Slope	Mean depth of wetland deposit (m)
More or less flat	2.7
Very gentle	1.5
Slight	0.6
Moderate	0.4
Steep	0.2

Table 5.7 Mean summer water table (relative to surface) in wetlands partitioned into five categories of slope

Slope	Mean summer water table (cm bgl)
More or less flat	–4.8
Very gentle	–6.8
Slight	–3.5
Moderate	–2.6
Steep	–6.4

Table 5.8 Percentage distribution of summer and winter water level categories in the wetlands examined, partitioned into topogenous (more or less flat) and (slight–steep) sloping locations

	Summer water level		Winter water level	
Water level category	Topogenous locations	Sloping locations	Topogenous locations	Sloping locations
< –75 cm	1%			
–75 to –40 cm	4%	4%	0.5%	0.2%
–40 to –18 cm	13%	13%	0.5%	1%
–18 to –5 cm	24%	23%	7%	14%
–5 to +1 cm	37%	51%	35%	61%
+1 to +10 cm	19%	9%	40%	23%
+10 to +25 cm	2%		15%	
+25 to + 50 cm	1%		3%	

In winter conditions there is a general shift towards wetter surfaces, but the effect is greatest in topogenous locations where the modal water level category changes to +1 to +10 cm. In sloping locations the modal category remains the same as in summer, but proportionately more samples are allocated to it than in summer conditions.

5.4 Sloping (including valleyhead) mires

5.4.1 Surface-layer controls

The majority of sloping mires examined had thin, or very thin, paludogenic deposits, the mean depth decreasing with steepness of slope (Table 5.6). In many examples, the entire deposit was equivalent to the surface layer. It might be expected that these thin deposits exert little control on associated water regimes but, although there is much variability, there is a general trend for highest summer water tables in sloping sites to be associated with surface layers that are suggestive of higher permeabilities (Table 5.9). However, whatever the trends in mean values, it is clear that quite high summer water tables are sometimes associated with *all* of the surface-layer types (Table 5.9). [No samples had very high summer water tables, presumably because of the slope; where above-surface values were recorded, these relate to small, shallow pools and depressions embedded within the slope.]

Table 5.9 Relationship between the character of the surface layer and summer water tables in wetland samples from moderate to steep slopes

Character of surface layer	Mean	Minimum	Maximum
Dense, solid peat/silts/clay	–6.6	–15	–3
Well-decomposed firm peat	–9.9	–26	+1
Firm , moderately decomposed peat	–3.0	–16	+1
Fresh herbaceous peat	–2.2	–8	+1
Loose plant material/fresh peat	+0.5	–7	+4
Very loose plant material	+0.2	–5	+4

All values are cm relative to surface

5.4.2 Basal substratum controls in sloping mires

There is little clear relationship between summer water tables and the basal substratum categories in sloping sites (Table 5.10). Low and high summer water tables were recorded both in locations on substrata likely to have low permeability and on substrata likely to have high permeability. A number of possible explanations can account for the absence of an overall relationship, including:

i. On permeable deposits, water levels in the mire may reflect the aquifer head, which can vary considerably. Some slopes regularly dry out in summer conditions, whereas others, associated with a high aquifer head, usually remain summer wet.

ii. Low permeability deposits may in some locations constrain groundwater upflow, resulting in low summer water tables. In other locations, groundwater outflow occurs at the top of the low-permeability deposits and flows downslope over them, often resulting in high summer water tables on the low-permeability material.

Table 5.10 Relationship between the character of the basal substratum and summer water tables in wetland samples from sloping mires with moderate to steep slopes

Basal substratum	Mean	Minimum	Maximum
Heavy silts and clays	–2.7	–8	+4
Silt/clay loam	–6.4	–20	–1
Sandy clays/silts	–2.7	–16	+4
Sandy clay/silt loam	–6.4	–20	0
Sandy loam	–3.6	–26	+1
Sand/gravel/permeable bedrock	–1.3	–8	+1

All values are mean summer water table (cm relative to surface).
The basal substratum categories represent an approximate sequence of likely permeability, from low-permeability heavy silts and clays, to permeable sand/gravel/bedrock.

Whilst it is difficult to detect clear *overall* relationships between summer water tables and basal substratum types in the sloping mires examined, clear relationships can be observed at some individual sites. For example, in many sites where there are discrete springs and seepages (as opposed to a more or less continuous spring line), the springs are associated with high permeability basal substrata and are flanked laterally by drier surfaces over lower permeability basal substrata with less groundwater outflow. Lower-permeability surfaces may also occur below the outflows and because they are fed by these, they are often as wet, or wetter, than the outflows themselves. Thus in a single seepage slope, low-permeability basal substrata may be associated both with high and low water tables.

The origins of the basal substratum patterns associated with seepages are often not well known. In some cases (such as Buxton Heath, Norfolk), it appears that the stronger groundwater outflows are associated with natural variations in the composition of the Drift, with stronger outflows being associated with more sand- or gravel-rich patches. In other cases (such as Tarn Moor, Sunbiggin), where strong springs are fed from a Carboniferous Limestone aquifer, it seems that the location of the outflows (from fracture flow in the Limestone) may determine the distribution and depth of the Drift – the superficial clays appear to have been eroded in the vicinity of the main outflows (Holdgate, 1955).

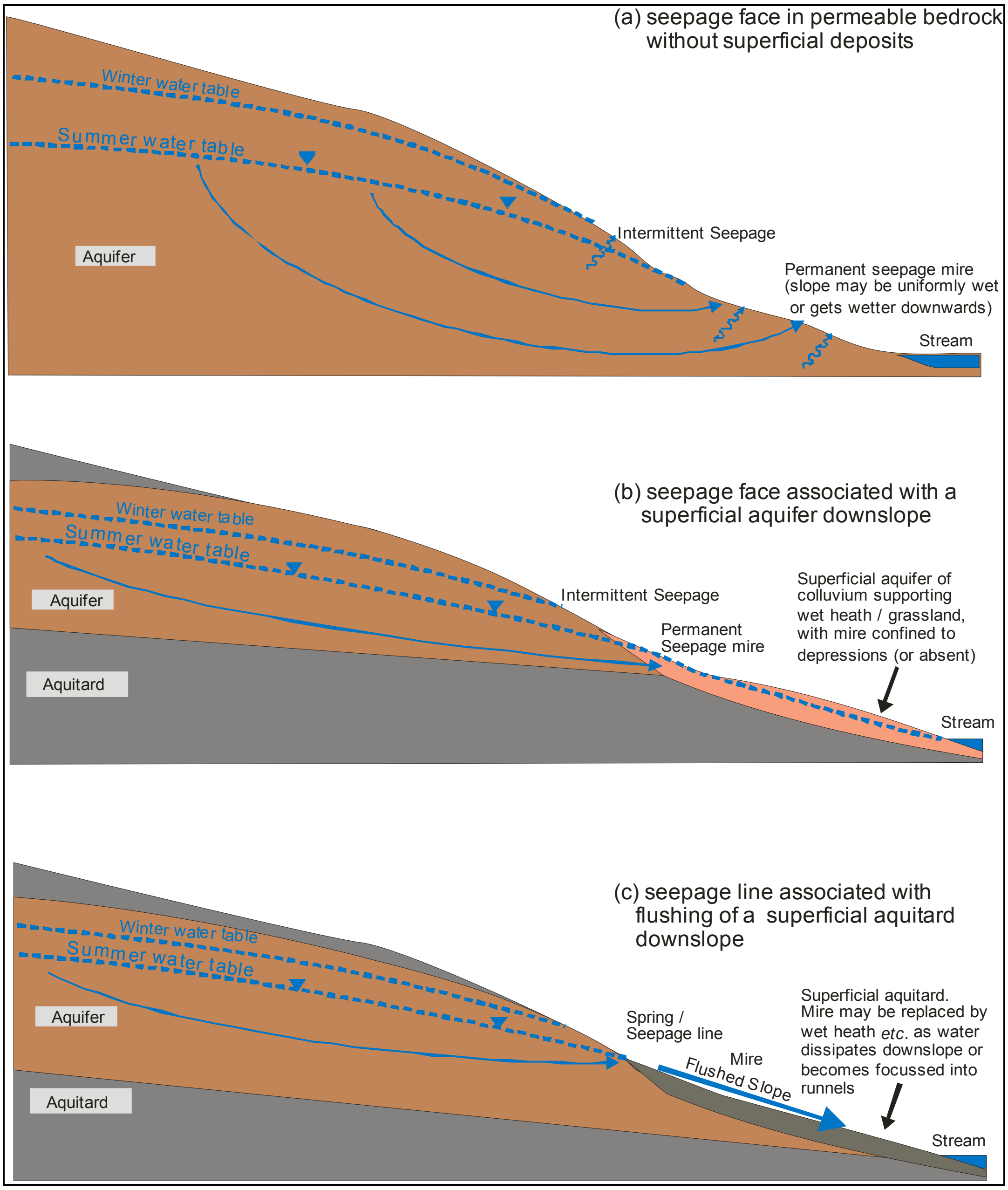


Figure 5.1 Schematic sections showing the influence of superficial deposits of varying composition downslope of groundwater outflows upon the gross patterns of water flow and the habitats that develop

In many locations, groundwater-fed sloping mires occupy the lower slopes of small valleys and valleyheads and are bordered directly downslope by an axial stream or ditch. However, some examples occur as more isolated perched units, which grade into drier ground downslope. Various circumstances may favour this latter development including the dissipation of water downslope, its funnelling into discrete runnels, or the occurrence of higher permeability deposits downslope. Some of the more complicated valleyside patterns occur in parts of southern England, such as the New Forest, where deposits of colluvium (Head) can both obscure and modify the patterns of groundwater outflow from underlying bedrock aquifers and aquitards, and can themselves act variably as superficial aquifers or aquitards (Figure 5.1). Unfortunately, the local characteristics of Head are generally poorly known (the deposit is omitted completely from some published geological surveys) and may often be variable. In some sites, low-permeability Head appears to provide a surface aquitard with groundwater outflow along the upper edge and with flushes downslope; in others, Head appears to form a superficial aquifer which supports seepages well downslope of the boundary of an underlying bedrock aquifer/aquitard conjunction. In these circumstances, surface layers of Head can provide a conduit for near-surface water flow for considerable distances down the valley slopes. Where the water table is near the surface, which is most often the case towards the top of the slope, mire may develop, but if the water table is mostly significantly below the surface, the deposit can support wet heath or wet grassland habitats rather than mire (or in some cases, even dryland habitats). Thus the precise expression of wetland habitats on the superficial deposit below a seepage line can depend considerably upon its lithological variation, depth and topography and may bear only a limited relationship to the disposition of underlying bedrock aquifers and aquitards.

It thus appears that local variation in superficial deposits can act as a major determinant of the characteristics of wetland habitats on slopes, and can therefore much influence their response to potentially damaging operations such as groundwater abstraction or ditching. In the absence of detailed information on their hydraulic properties, and because of local variation in these, top-layer deposits can form a significant constraint on the simple application of regional groundwater models to assess hydrological conditions in mire sites. Borehole logs and piezometric data can sometimes provide useful insights, but may be too sparse to provide conclusive information for heterogeneous sites, especially as boreholes may not be located within, or even close to, areas of greatest ecological interest (partly in response to concerns about possible damage). In some sites (such as Badley Moor (Gilvear *et al.*, 1989)), the hydraulic pathways are highly localised and developed in what are, in effect, geological anomalies. Such a perspective makes it easier to appreciate why certain habitats and communities are rare and why a sparse piezometer network may be inadequate to characterise their water supply mechanisms, unless the installations are positioned carefully to provide critical information (the alternative option of large numbers of piezometers may be unsatisfactory on grounds of cost, practicability, possible damage to sensitive habitats and even modification of groundwater conditions). In some situations it may be possible to use surrogate information (such as water quality) to help deduce water sources, but this approach often rests on assumptions.

5.5 Mires in topographical basins

Mires in topographical basins range from very large subsidence hollows (such as Chartley Moss, around 42 ha) to small ground ice depressions (< 1 ha). Tiny basins can also be embedded within some sloping systems, but may show properties similar to the larger examples.

5.5.1 Surface-layer controls

Surface-layer conditions in basin sites vary considerably from relatively solid to buoyant, but some of the most distinctive (and conservationally valued) WETMECs (for example, 13 (Seepage Percolation Basins) and 20 (Percolation Basins)) most typically possess loose, quaking or buoyant surfaces. The generic relationships between surface-layer characteristics and water tables identified for topogenous sites (above) apply to mires in topogenous basins.

Small, shallow hydroseral basins provide some of the most favourable locations for the development of vegetation rafts. Little is known about the dynamics of raft formation, but evidence suggests that rafting can occur in at least three circumstances (which are not mutually exclusive):

- direct colonisation of shallow water by a floating mat (may be restricted to water of depth less than two metres; see for example Tallis, 1973);
- subsidence of the basin beneath an existing mire surface (the deep *schwingmoor* systems of Chartley and Wybunbury Mosses appear to have originated by this mechanism);
- flooding of a solid peat surface associated with subsequent detachment and flotation of formerly rooted vegetation.

However, the surface layer in many topogenous basins is not buoyant, nor sometimes even spongy. It is not clear to what extent this 'solid' state represents a natural condition. It is often associated with surfaces that have been partly drained, grazed and/or from which some peat has been removed. These processes can promote the development of a solid surface condition where this was not already present naturally.

Some mires in topographical basins may be fed by groundwater upflow, but in many sites upflow is probably much constrained by the paludogenic infill or the basal substratum (see 5.5.2), so that any telluric water sources are primarily lateral surface or sub-surface inflows from the margins. In consequence, in larger basins with an infill of dense, solid peat there is often a tendency for the surface to become increasingly isolated from groundwater or surface water sources further away from the margins (except, of course, where telluric water bodies are embedded within the basin and can feed into the adjoining mire). These processes may be expressed in decreasing summer water tables and increasing dependency upon precipitation as a water source with distance from the margins. In addition, bases and nutrients can be stripped from any telluric water sources transferring into the mire from the margins, by adsorption onto the peat and/or uptake by vegetation. Combined with an increased dependency on precipitation, this can lead to base-impoverishment in the more central locations, which may be largely ombrotrophic (though not necessarily ombrogenous). In some sites this condition may have been caused, or enhanced, by modification to natural water supply mechanisms (such as drainage), but in others the ombrotrophic condition is probably natural, even when the surface has been modified. In some locations, this is reflected in the occurrence of remnants of ombrogenous peat. Where there is an ombrotrophic surface on fen peat, but no evidence of ombrogenous peat, it is possible the latter may have been removed by peat cutting.

Acidification and nutrient impoverishment of locations away from the margins is not an exclusive feature of basins with a solid peat infill. This can also occur extensively in some examples with buoyant surfaces; indeed, it is often particularly obvious in these because, unlike many examples on solid peat which may tend to become summer-dry, acidifying rafts remain relatively wet year round and can support extensive and prominent carpets of *Sphagnum.* Walker (1970) noted the ontogenic tendency for *Sphagnum* surfaces to form towards the centre of small basin mires, and attributed this to the capacity of peripheral vegetation to strip bases and so on from marginal water sources (as suggested above). However, in a comparative study of contrasting basin mires in the Scottish Borders, Tratt

(1998) observed that the central *Sphagnum* surfaces are thicker and more buoyant than those closer to the margins, suggesting that the propensity for acidification may be a function of the buoyancy of the raft and the concomitant vertical isolation from telluric water that it provides.

5.5.2 Basal substratum controls

The possible role of the basal substratum in regulating the hydrodynamics of basins has generally been little considered, perhaps partly because in many basins the basal layers are buried beneath several metres of peat and water, and thus not readily obvious; and because much of the ecohydrological character of basins is a product of impeded drainage of a water body, which may partly obscure the dynamics and patterns of water exchange with sources such as the regional aquifer. Nonetheless, it is likely that the basal substratum can considerably influence both discharge from, and recharge to, an aquifer within which a basin is embedded although, depending on its topographical and hydrogeological context, it is not always clear which material may provide an effective aquitard. It should be recognised that individual mire basins may be separated from proximate aquifers by deposits that can be very variable in character, and thus give rise to different hydrological mechanisms operating at individual sites, even when these are in close proximity.

In broad terms, basins range from those embedded in a thick, low-permeability deposit (such as glacial or alluvial clays), and which function essentially as water tanks, to those within freely transmissive sands and gravels. However, even at the extremes of this range, the precise relationship of water conditions in the basins to proximate groundwater sources is not always certain. For example, at one extreme (some of the mire basins near St David's (Pembrokeshire) such as Trefeiddan Moor and Dowrog Common) it is possible that excavation of basal clay deposits from within the basins may have compromised locally the natural separation of the mire water table from the underlying aquifer. At the other extreme, various workers have long suspected that some basins embedded within glaciofluvial sands and gravels are not in as free connection with the regional aquifer as might be expected.

For example, Reynolds (1979) suggested that "*it is probable that many basins may be partially or wholly sealed by a lining of secondary deposits, including solifluction and inwashed clays from the surrounding drifts and organic sediments, including material originating in the lake itself*", though relevant stratigraphical data are sparse (Tallis, 1973). Johnson, Franks and Pollard (1970) give a detailed account of the infill of an elongate basin in a meltwater channel in East Cheshire: the basin is flanked by Head and floored by plastic silty clays, which appear to have formed from fines washed from the Head into standing water. Likewise, the tiny Lin Can Moss (near Ruyton-XI-Towns in Shropshire) embedded within glacial sands and gravels, also appears to be underlain by clay (Harding, 1996). However, in many cases the absence or sparsity of stratigraphical data means that the localised occurrence of clay layers and lenses in specific association with mire basins is generally not known. Nonetheless, Tallis (1973) speculated that a perched water table could explain the curious long-term fluctuations in water level that appear to be a feature of some basins in the Delamere Forest region (see Box 5.2).

A complicating consideration is that accumulations of paludogenic deposits may also influence water exchange between the basins and the regional groundwater. Many basins seem once to have sustained an open water phase and have considerable accumulations of lake marls or muds (gyttja) in addition to any allochthonous inwash. Such deposits tend to have low permeabilities and may seal at least the bottoms of the basins. Depending on their context and distribution, they may either largely isolate the basin from the mineral aquifer or restrict groundwater exchange to largely horizontal flow with the upper parts of the basin. In addition, accumulations of peat and other organic material ("sealing muds") may also help to seal the basins. Such layers have generally been given rather little attention in Britain, but are considered important by workers elsewhere, such as in North-East Germany (where there are numerous kettle-hole mires embedded within glacial outwash material).

For example, Timmermann and Succow (2001) comment (in translation) that "*it is generally accepted that loamy and silty–fine-sandy substrates of late-glacial origin, and especially organic linings, seal the hollow to a large extent*". Moreover, they suggest that this has ontogenic implications: "*the gradual sealing of the hollow by organic linings lets the mire water body rise gradually so that this can outgrow the influence of the regional water body*". It is not known to what extent this process has also occurred in comparable mire basins in Britain. Of course, such "organic seals" may not necessarily provide full hydraulic isolation of basins and can presumably be breached to some degree by peripheral drainage ditches.

Box 5.2: Basin mires in the Delamere Forest (Cheshire)

The glaciofluvial deposits of the Delamere Forest area consist of Middle Sands with some thin, but laterally extensive, clay layers within the sandsheet. The clay layers can generate differences in hydraulic connectivity between individual basin mires and the sandsheet aquifer. For example, Flaxmere occupies a small kettle hole within this deposit and appears to be completely clay-lined; both Tallis (1973) and Reynolds (1979) considered that it supported a perched water table.

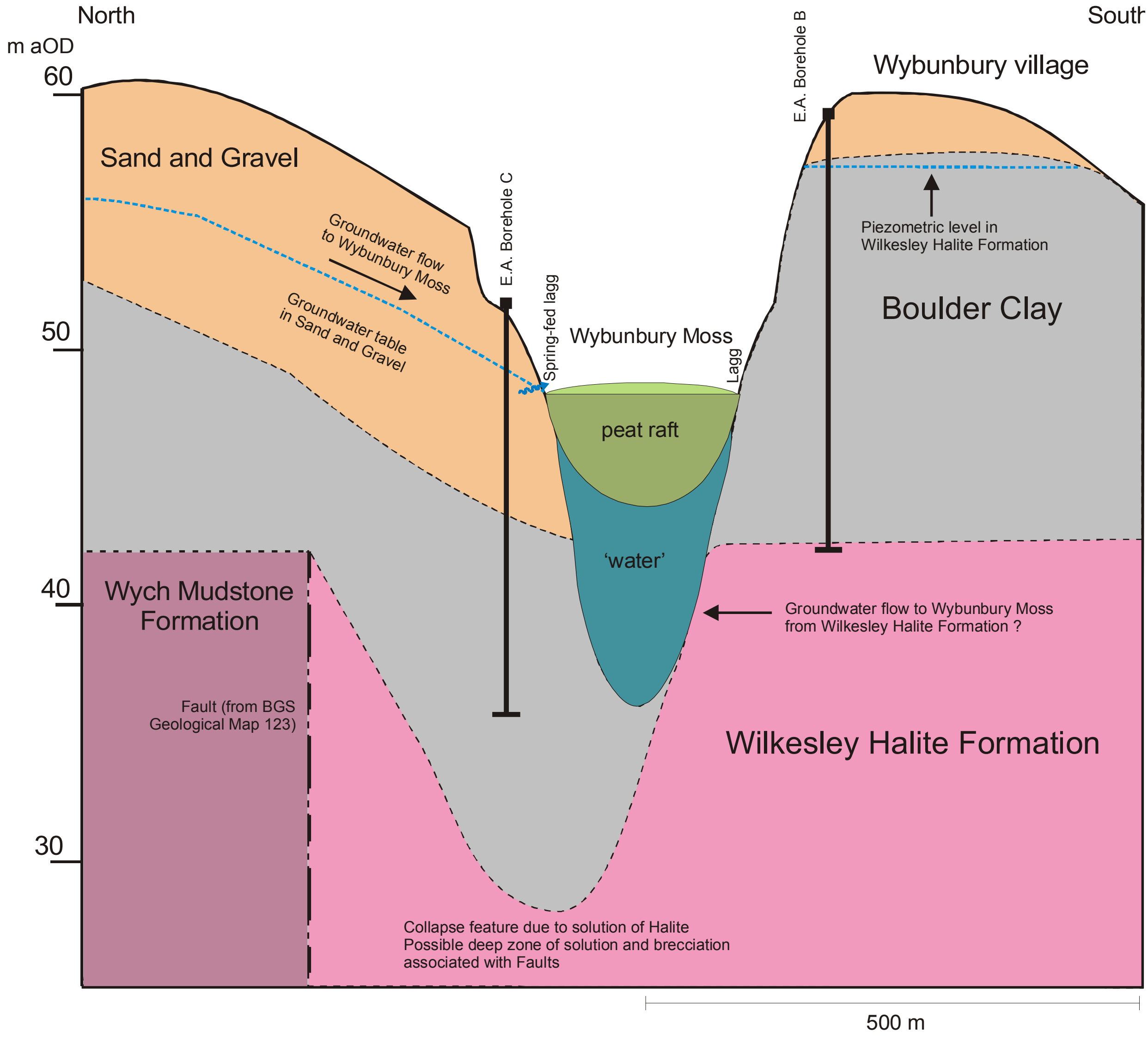
Where the mire basins are embedded directly within the sands and gravels, with little known evidence for low-permeability deposits, good hydraulic connection between the basin and the aquifer is generally assumed. In some instances this assumption is almost certainly correct, as at Oakmere (WMC, 2003). This site (which was not included in the current study) is primarily an open water body and is more important for its distinctive, sandy shoreline vegetation than for its mire. It has long been known to have a quite strongly fluctuating water table in excess of one metre (Lind and Boyd, 1951) and the unusual shoreline vegetation developed in response to this, which includes such notable species as *Calamagrostis neglecta*, is quite different to that of most of the Delamere meres and mosses. On the basis of piezometric data, both from within Oakmere and from its surroundings, WMC (2003) concluded that: (a) there is good hydraulic connection between Oakmere and the Delamere sandsheet aquifer and the lake is effectively an expression of the local water table (thereby confirming the observations and views of Lind and Boyd (1951)); (b) Oakmere is on the crest of the groundwater divide and this may help explain its marked water level fluctuations; and (c) Oakmere appears to recharge the sandsheet aquifer during wet conditions, but receives some groundwater discharge in dry summer periods.

Extrapolating from their observations, WMC (2003) considered it "*unlikely … that a significantly different situation to that at Oakmere exists at [the nearby] Abbots Moss, and it is therefore tentatively assumed that Abbots Moss is in hydraulic continuity with the groundwater system*". This view may be correct, but piezometric data are available only from the sandsheet around Abbots Moss, not from within the mire basin itself, and there are reasons to suspect that Abbots Moss may show a rather different relationship to the sandsheet aquifer than Oakmere, not least the fact that its vegetation and water quality is strikingly different (Bellamy, 1967). Also, there is a layer of grey clay, some 40–50 cm thick, across the bottom of the six to seven metre deep Abbots Moss basin, which apparently overlays Zone IV (Pre-Boreal) lake muds (Tallis, 1973; Gray, 1987), though available data are insufficient to assess either if this basin is completely clay-lined or the likely hydraulic role of the basal material.

Labadz and Butcher (2005) suggest that at Abbots Moss, the pools "*have higher levels of cations than would be expected for purely ombrogenous situations, suggesting groundwater inputs*". However, the proposition can be challenged. First, Proctor (1992) has shown that the water chemistry of ostensibly ombrogenous sites can vary considerably with variation in rainfall composition. He recorded cation concentrations in mire water from Wybunbury Moss which were much greater than those from Abbots Moss, yet concluded that there is "*no evidence from the present data that Wybunbury Moss is not ombrogenous*". Second, although there is no doubt that parts of the Abbots Moss basin are fed by telluric water, it is not easy to distinguish, hydrochemically, between weak groundwater and run-off inputs. Ionic concentrations measured at Abbots Moss in September 1960 (Bellamy, 1967) are most notable for their *small* magnitude, even in the peripheral minerotrophic lagg, suggesting very limited input of telluric water from *any* source (and perhaps indicating that some enrichment has occurred subsequently).

Even in basins known to be fed by groundwater, there may be constraints on its outflow into the basin. Reynolds (1975) has suggested that various aspects of the water balance and limnological characteristics of Crosemere (Shropshire) could be explained if it is assumed that groundwater outflow into the lake is localised to a near-surface layer above the lip of a low-permeability limnogenic deposit, so that below a certain threshold level the groundwater supply can effectively be 'turned off'. A buried clay layer at Hartlebury Common (Worcestershire) also seems to isolate the mire (now wet heath) surface from the aquifer when groundwater tables sink below the clay (Hughes, 1991). At Wybunbury Moss (Cheshire), on the south side, the lower part of the basin is formed from Wilkesley Halite, suggesting the possibility of some groundwater contribution to the mire from these weathered sandstones (Figure 5.2). However, the Halite aquifer, which is capped by a thick layer of Till, has a piezometric head that is well (around 10 m) above the level of the moss surface within about 100 m of the basin (Seymour, 2003), which suggests that there may be only rather limited discharge from the Halite aquifer into the moss basin. This could be because the paludogenic infill or "sealing muds" provide a partially confining layer.

It would be convenient to assume that the occurrence of ombrogenous surfaces within basin mires was indicative of little water exchange between the basin and adjoining mineral aquifers, but this is not possible. An ombrogenous surface is, by definition, not fed by telluric water, but it can develop serally in basins which are, in part, groundwater-fed. Wybunbury Moss, whatever the uncertainties about groundwater supply along the southern side, undoubtedly receives groundwater outflow along the northern edge, from glacial sands and gravels (Figure 5.2). Even here, the extent to which these groundwater sources materially contribute naturally to the water balance of the ombrogenous part of the basin (as opposed to being intercepted by a peripheral lagg stream and drains) is not really known.



The figure has been redrawn and slightly modified from Seymour, 2003

Figure 5.2 Geological cross-section and conceptual model of Wybunbury Moss, Cheshire

Conversely, the occurrence of weakly minerotrophic conditions in some ombrogenous or near-ombrogenous basin mires is not necessarily indicative of groundwater supply, as is sometimes suggested. This is partly because telluric conditions in small basins may be mainly a product of surface run-off rather than groundwater supply but, more fundamentally, it also relates to the chemical signature of ombrotrophy, which is regionally variable (Proctor, 1992) (see Box 5.2). Equally, the occurrence of largely ombrotrophic conditions in basins does not itself provide evidence for *lack* of connection with a mineral aquifer: hydrochemical evidence for telluric sources may be masked by the seral development of an ombrogenous surface. Another possibility in some contexts is that basins may function mainly to recharge a connected regional aquifer, rather than receiving its discharge.

Overall, these considerations point to the difficulty of assessing water supply to mires in topographical basins in the absence of hydrometric data from within the basins themselves. Where, in the absence of significant surface water inflows, basins show consistent surface water outflow, even in summer-dry climatic conditions, it is likely that at least parts of the basins receive significant groundwater from the regional aquifer. However, the absence of surface water outflow in dry conditions is not necessarily indicative of little connection with the regional aquifer: some examples may effectively be a local expression of the regional water table.

It could be instructive to examine more rigorously the question of hydraulic connection with the regional aquifer in basin mires with regard to variations in the ecological status of the basins, for example to establish whether the development of an ombrogenous surface is completely independent of connectivity between the basins and the regional aquifer, or whether it is favoured in basins which are significantly sealed from the aquifer. Topogenous basins of contrasting ecological character sometimes occur in close juxtaposition, but lack an obvious hydrogeological explanation for their differences. For example, the three basins of the Crosemere complex (Shropshire) all occur within the same hydrogeological context, but are strikingly different in character (Crosemere: a lake with a narrow fringe of reedswamp and calcareous fen; Sweat Mere: a terrestrialising, mesotrophic pool; Whattall Moss: a former basin bog, now drained and afforested). It is possible, but by no means certain, that top-layer controls contribute to the differences between these basins[1].

5.6 Floodplain mires

5.6.1 Introduction

Wetlands on the floodplains of watercourses share many ecohydrological features with examples in topographical basins, and a number of similar principles apply. The generic relationships between surface-layer characteristics and water tables identified for topogenous sites (see above) also apply to many floodplain systems. However, mires on floodplains often have a number of additional complications, relating to the variable role of the watercourse (drainage *versus* water supply) and the sometimes complex and contrasting character of the alluvial sediments. The relationship between water levels in the river and in the adjoining wetlands is often not well understood nor, in many cases, well known. Many former floodplain wetlands have been considerably drained and modified and, although the remaining examples are sometimes extensive, with the important exception of the fens of the Norfolk Broadland floodplain mires are not particularly well represented in the *Wetland Framework* dataset.

5.6.2 Alluvial stratigraphy and water supply

Some of the alluvial sequences beneath extant floodplain wetlands are complex, show much local variation and are not necessarily dominated by peat. For example, the alluvial stratigraphy of some of the Test valley (Hampshire) fen sites consists of layers of strongly humified peat, silts and clays above basal river terrace gravels. There are also locally interstratified beds of calcareous marl and nodular tufa, which sometimes form shallow mounds on the surface of the floodplain. Any surface peat is frequently very localised, often thin and quite strongly oxidised. It is frequently located upon silts and clays but in some locations (such as Bransbury Common), shallow peat is situated directly upon gravels (thought to be river terrace gravels) and in places these gravels are exposed within the floodplain, forming low ridges.

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[1] These sites were not included in the framework because of particular uncertainties about controls on their water supply, though there can be no real doubt that at least Crosemere is substantially groundwater-fed (Reynolds, 1975).

The water level in the River Test is thought to be in equilibrium with the water level in the adjacent chalk and is directly related to the piezometric head of the Chalk aquifer. However, little is known about the relationship between river water levels and the water table of the adjoining floodplain. In some places there may be some groundwater upflow into the wetland, for example where shallow surface peats are located directly upon river terrace gravels (which may be in hydraulic connection with the Chalk aquifer). However, even in these cases the importance of upflow *versus* lateral groundwater exchange is not known. In other locations, where river gravels are capped by interlayered peats, silts and clays, and lenses of marl, the Chalk aquifer may be locally confined. The degree to which this occurs, and its local variation, does not appear to be known, but it may help explain why large parts of these floodplains support seasonally wet grassland rather than fen.

The presence of local aquitards within river valley deposits does not necessarily imply separation from underlying aquifers: hydraulic connections may be circuitous, by flow along laterally connecting layers of higher permeability. For example, the buried valley infill beneath the Waveney–Ouse fens of the Norfolk–Suffolk border contains layers of clay and marl which may well impede locally water upflow from the Chalk aquifer, but the water table in the valley infill beneath Lopham Little Fen is reported to be lowered in response to a reduction of chalkwater heads (ENTEC, 1998). ENTEC (1998) also report piezometric heads in the Chalk to be ‘consistently and significantly above the shallow drift groundwater levels’. However, this does not necessarily mean that that chalkwater was naturally an important direct groundwater source to the fen *surface*, despite the relative piezometric heads; hydrochemical data point to the likelihood of a significant influence from a local, superficial sand and gravel aquifer (Wheeler and Shaw, 2000b).

The Broadland fens

In general, the alluvial infill of the Broadland valleys is relatively simple and shows some clear spatial trends (Figure 5.3). The infill is mostly fairly deep (typically four to eight metres) and, over large areas, is mainly peat-based. In the upper parts of the valleys peat forms a continuous column from the surface to the underlying mineral material, but downstream increasingly thick and broad deposits of estuarine clay occur, representing material deposited during former marine transgressive overlaps. The most important of these (the so-called Romano-British transgression) peaked at about 400 AD and has resulted in a thick layer of clay intercalated with peat in the upper part of the profile over much of the lower reaches of Broadland (in the drained lowest reaches, this is exposed at the surface as Breydon Formation material).

The Broadland fens are mostly underlain by a Crag deposit, but in many locations their peat is separated from this by a low-permeability clay of uncertain provenance smeared upon the Crag (Jennings, 1952). The lateral persistence of this deposit is not well known, and in places it appears to be absent (note that in parts of Upton Fen where the peat appears to be underlain by gravel, this is itself apparently underlain by clay (G. van Wirdum, personal communication).

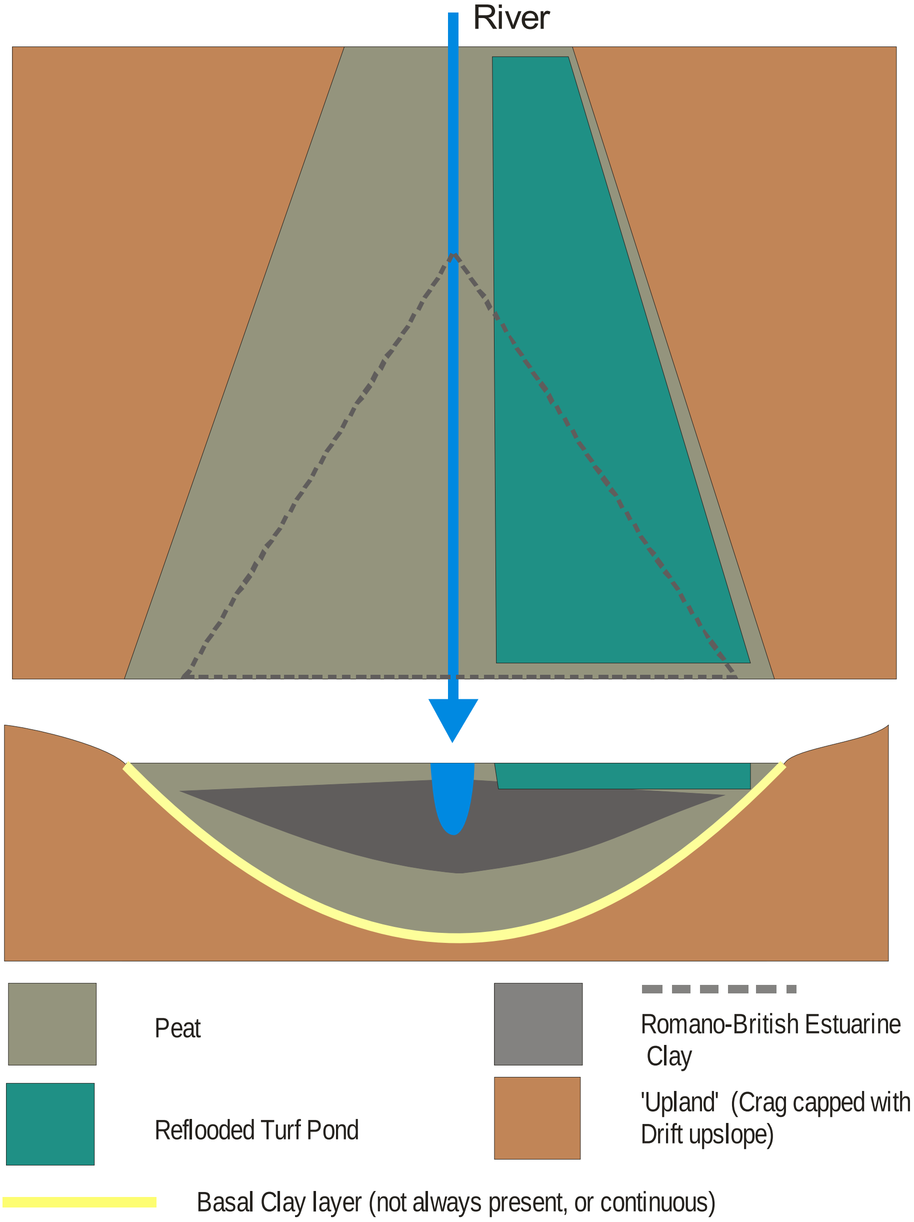


Figure 5.3 Schematic distribution (plan and transverse section) of the alluvial infill of the Broadland valleys (based on the mid–lower reaches of the River Ant)

In some, perhaps many, locations in Broadland the piezometric head of the underlying Crag or Crag/Chalk aquifer is within, or even above, the peat deposit and it is possible that it may supply some of the water to some sites. However, where they occur, the basal and estuarine clays are likely to impede groundwater upflow, and the peat infill – particularly the lower, dense brushwood peats – may also form partial aquitard units.

Few hydrological studies have been carried out in the Broadland fens (Gilvear *et al.*¸ 1997, van Wirdum *et al.*, 1997; Baird *et al.*, 2004; Surridge, 2005), but all of these provide little piezometric evidence for groundwater upflow into the peat, even in locations without intercalated estuarine clay. At Strumpshaw Fen, where groundwater abstraction had been suspected of lowering fen water tables, Surridge (2005) considered that "*although hydraulic gradients exist between the peat and the underlying mineral aquifer, these are not translated into substantial volumes of groundwater flow*" and that the peat effectively formed a perched aquifer. It has been suggested that at Catfield Fen, 'windows' in the lining of basal clay may support localised groundwater upflow (Gilvear *et al.*, 1997). However, at Strumpshaw Fen, Surridge (2005) found no evidence for basal clays separating the peat from the underlying Crag, or for significant groundwater upflow. The actual constraints on upflow have yet to be identified: possibilities include the thick layers of compressed, wood-rich peat towards the base of the peat, and perhaps a layer of fine mud and sand at the interface between the peat and the underlying Crag.

The observed constraints upon groundwater upflow in Broadland suggest that any inputs of groundwater from the mineral aquifer into the peatlands may be restricted largely to horizontal flow from the upland margin of the mires. This could occur directly into the peat deposits or, in some cases, indirectly via groundwater-fed dyke systems that extend through the peatlands. However, the actual importance of groundwater outflow into the dyke system is not known, and may often be difficult to disentangle from surface run-off supply. Hydrochemical and vegetation gradients often provide little reason to suspect substantial supply from either source. The hydrodynamics of the Catfield fens, in locations separated from the influence of the River Ant and connected dykes, appear primarily to be determined by rainfall and evapotranspiration (Gilvear *et al*., 1997; van Wirdum *et al.*, 1997). Nonetheless, in some other sites, most notably Upton Fen, there can be little doubt that groundwater is the primary source of telluric water (van Wirdum *et al.*, 1997). At this fen, groundwater may outflow into the basin of one or both of the broads, where this has been dug down to the Crag, though this proposition has yet to be substantiated.

5.6.3 Surface-layer controls

Only a few estimates are available of the hydraulic conductivity of surface-layer peats in the floodplain wetlands examined. In the Broadland mires, the character of the surface layer is very variable and K estimates range between about 3 x 10^{-2} cm s^{-1} and 5 x 10^{-7} cm s^{-1}. The highest values are associated with the loose infill of reflooded turf ponds and so on, whilst the lowest values are a feature of solid peat.

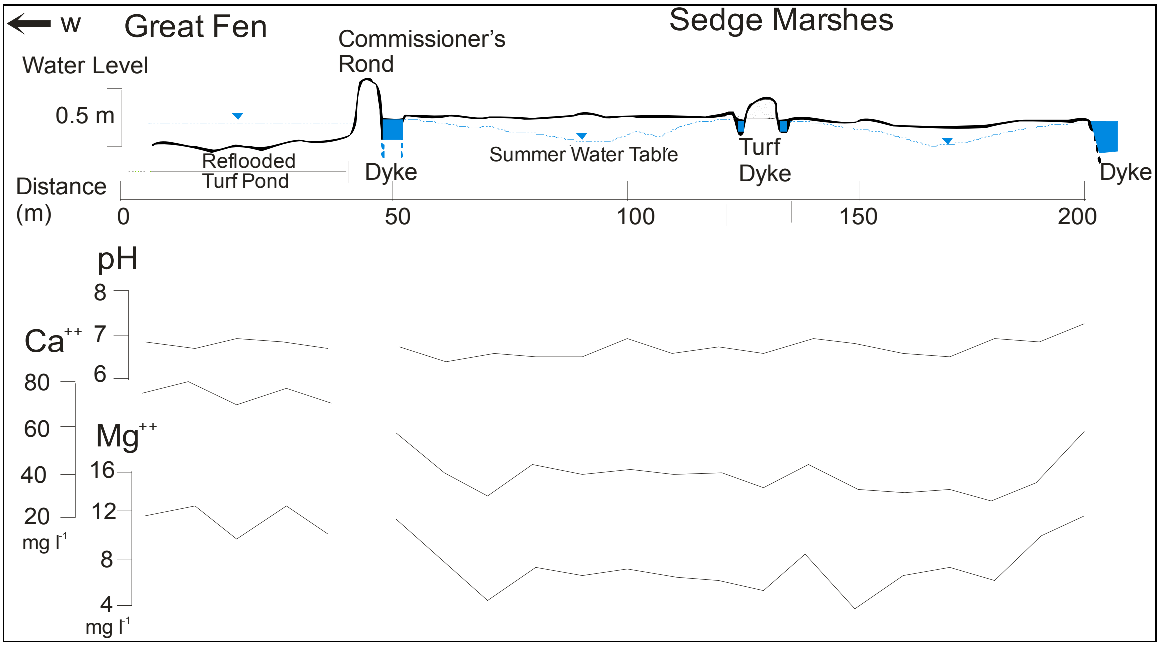
Empirical demonstrations of the low permeability of the undisturbed peat infill of the Broadland mires are provided by the narrow ronds of solid peat left *in situ* alongside the watercourses, to facilitate peat extraction in the interior of the fens. Some turbaries were dug to a depth of about four m bgl and using only simple drainage facilities. The following observations by Lambert *et al.* (1960) are instructive:

> "*The possibility of deep digging of peat in the Norfolk fenland even today is often underestimated. Provided the area is isolated from tidal flooding, practical experience has shown that considerable depths can be attained comparatively easily in places where the general water table is only a little below the fenland surface. For instance, an ornamental swimming pool has recently been excavated in the Hickling marshes to a depth of nearly 3 metres entirely by intermittent hand labour without the use of elaborate pumps, with the men working well below the level of the water in the nearby dykes; and it is estimated that even greater depths could have been reached without difficulty (M. Pallis, 1956; also in litt.). Similarly, it is reported that little trouble with inflow directly through the peat was encountered when the Lound reservoirs (cf. p. 40) were dug out upstream of Fritton Lake; most of the water accumulating in the excavations in fact came from a small stream entering at the western end and from springs on the uncovered valley sides (K. B. Clarke, in litt., 1956). And furthermore, a recent excavation of a new length of drain for the Brograve pump, dug to a depth of about 3 metres through the peat, is stated to have remained perfectly dry for several days even though there was a full dyke only a short distance away* (K. E. Cotton, *in litt*., 1956)."

Measurements on a solid peat rond alongside the River Ant indicate low K values (0.48 to 12.48 x 10^{-6} cm s^{-1}) and suggest very limited transmission of water through this material, a proposition which is compatible with measurements of summer fen water tables (van Wirdum *et al.*, 1997). In a modelled simulation, the response of the water tables in the fens to drainage by the river was negligible, with evidence of drawdown only within about five metres of the river edge. Similarly, the practical experience of conservationists is that many such sites tend to dry out in summer away from the watercourses, even when water levels remain high. This can be illustrated from water table data from solid peat at Sedge Marshes (Catfield Fen) (Figure 5.4).

In other locations, somewhat higher *K* values have been reported from ostensibly solid peat. In the surface layer of peat at Strumpshaw Fen, Surridge (2005) reported values of 1×10^{-4} to 16×10^{-4} cm s^{-1}, which generally declined downwards. He observed that the orientation of rooting structures was predominantly horizontal in this layer, which may account for the rather high measured lateral permeability. Nonetheless, the water table at 25 m from a dyke was unresponsive to a single tidal pulse propagated through the dyke network in winter conditions. The sparsity of *K* measurements means that controls on permeability variation within floodplain peats are little understood. Variation in species composition, the depositional environment and drainage initiatives (past and present) may all contribute to variation in observed *K* values. It is also possible that some solid peat surfaces actually represent the infill of very old turbaries rather than undisturbed deposits. Areas of solid peat are often crossed by dykes, but these may also have only limited impact upon the summer water level in the adjoining peat deposits. However, historically, foot-drains have been dug across the solid peats in some Broadland fens, to facilitate water exchange with areas remote from dykes. These have mostly become overgrown and their current effectiveness is unknown.

Many of the Broadland fens have been dug for peat and the reflooded, recolonised turf ponds usually have a loose, transmissive infill (in the uppermost 50–80 cm of the profile) which, when in connection with rivers or river-connected dykes, appears to provide an effective sub-irrigation system. Estimates of *K* from loose surface peats in Broadland range from between about 3×10^{-2} to 7×10^{-6} cm s^{-1} (Baird *et al.*, 1998; van Wirdum *et al.*, 1997). The majority of these are from locations that are unambiguously reflooded turbaries, but the status of the root mat at Sutton Fen, examined by Baird *et al.* (1998) is less clear. Unconsolidated surfaces can also be created by the reflooding of previously drained peat.



Transect runs from Great Fen (reflooded turf pond with river connection) to Sedge Marshes (solid peat, isolated from the River Ant by the Commissioner's Rond and sluice).

Figure 5.4 Variation in summer water level, pH and concentrations of Ca^{2+} and Mg^{2+} in samples of near-surface interstitial peat waters collected along a transect in Catfield Fen, Broadland

The relationship between the water table of a loose transmissive infill and a solid infill can be illustrated empirically by data from the Catfield Fens (Figure 5.4). However, higher *K* values *per se* are only one variable that may contribute to generally higher summer water tables (relative to the surface) in the turbaries. Others are the expansibility or buoyancy of the infill (see Box 6.39); water storage provided by the peat pits; and the lower surface level within the peat workings. The relative importance of each of these to the maintenance of summer-wet conditions in the reflooded turf ponds is not known, but there is reason to suspect that turf ponds that are effectively isolated from summer surface water sources are generally drier in summer than ones with better river connections. Whatever the exact cause, there can be no doubt that the excavation of turf ponds and other drains helps to maintain wetter conditions over large parts of the Broadland fens than might naturally be the case (Figure 5.5).

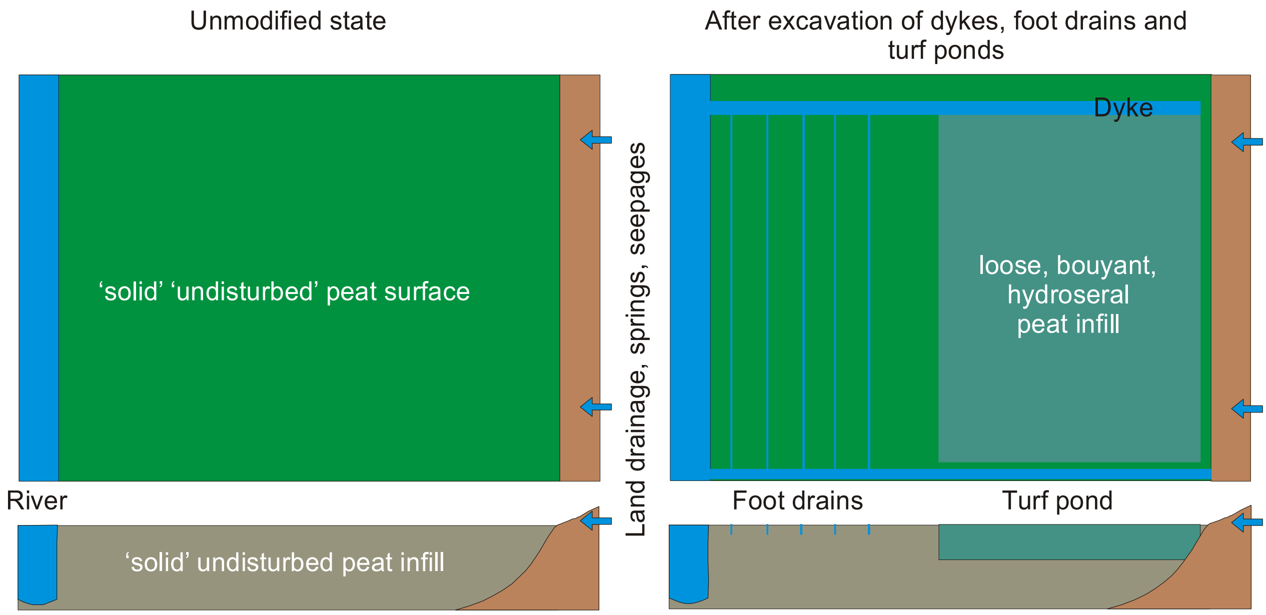


Figure 5.5 Schematic plans and sections to illustrate the impact of peat extraction and water management structures upon the undisturbed surface of a Broadland fen

These considerations suggest that the character of the uppermost peats is important in determining the hydrological mechanisms operating in the Broadland fens, not least because they may substantially determine the extent to which surface water (from whatever source) can contribute materially to the water balance of the fens, and particularly, the extent to which this helps maintain the water table in the fens during the growing season. It may therefore be difficult to draw meaningful conclusions about the water supply mechanisms of these wetlands without due consideration of at least the gross stratigraphy of their upper peat layers.

6 WETMECs and ecological types in lowland herbaceous wetlands

6.1 Introduction

In this section, the twenty main wetland water supply mechanism types (WETMECs) that have been identified by multivariate procedures (see Part 2) are described, together with the ‘ecological types’ recorded within them. In combination, the WETMECs and ecological types define and constitute composite ‘ecohydrological habitats’. These are not identified and named as separate units, but as WETMEC-ecological type combinations.

Individual WETMECs are described in detail below. To help users identify and navigate around the WETMECs, a summary and synoptic overview of the WETMECs is also provided (Section 6.2). The WETMEC summary tables and figures are available in a supplement to this report.

It is important to recognise that the WETMECs identified here have been extracted from a dataset of real samples: their identity and characteristics therefore reflect the overall range and properties of samples in the dataset. Hence, the WETMECs represent those categories of wetland that *do* occur (in the dataset), not those which *could* occur (outwith the dataset).

The list of sites included in the analyses is given in Appendix 2. Details of NVC communities mentioned in the text are given in Appendix 1. Descriptions of the main herbaceous wetland NVC types are given in Part 3.

6.2 WETMECS in summary

6.2.1 WETMEC types and sub-types

Figure 6.1 is based on output from the hierarchical multivariate clustering procedure that was used to identify the WETMECs. It serves as a summary index of the WETMECs and their sub-types, and shows their inter-relationships expressed as a one-dimensional linearisation, based on cluster affinities. It also provides a crude indication of their relationship to main water sources.

Table 6.1 provides a reference list of WETMEC names; Section 6.2.4 provides a synopsis of WETMECs and Table 6.2 summarises some of the salient features of the WETMECs and their sub-types. Not all characteristics are listed, nor are variants identified, to help keep Table 6.2 within manageable proportions. This table can be used to help identify the WETMEC to which a particular area of wetland can be assigned. It must, however, be appreciated that WETMECs intergrade both in concept and in the field, so it is to be expected that some surfaces may have characteristics that are intermediate between two (or more) WETMECs. Moreover, because WETMECs represent a simplification and conceptualisation of real field circumstances, some surfaces may not correspond well to *any* WETMEC. This may be because the surface in question is ecohydrologically idiosyncratic, or because it is peripheral to the main range of wetland habitats examined, and therefore undersampled.

6.2.2 WETMEC types in relation to main water source (summer conditions)

The importance of the main sources of water in the maintenance of the summer water table of individual WETMECs was estimated using information collected for the identification of WETMECs. This was categorised into the contribution made by groundwater, surface water and rainfall and these data are presented as mean values for each community along the three axes of a ternary plot (Figure 6.2). The precipitation data are based on estimates provided by the Environment Agency from Low Flows 2000[1], whereas the contribution of groundwater and surface water are based on estimated rank values. All data values were normalised in order to produce a ternary plot.

As precipitation inputs occur irrespective of whether or not there are also significant inputs of groundwater or surface water into wetlands, the disposition of some WETMECs into the precipitation-dominated apex of the triangle (the bottom left-hand corner) primarily reflects the small, or negligible, contribution made by either groundwater or surface water, rather than suggesting particularly high precipitation values. Thus, examples of WETMECs 1, 2 and 4 are not necessarily associated with the wetter regions of England and Wales. In point of fact, most examples of WETMEC 1 were recorded from northern England, but this may be more because former examples further south and east have been destroyed than because these regions are too dry for ombrogenous mire. WETMEC 4 is also of particular interest: this unit is essentially based on some examples of drained mires, both ombrogenous and topogenous, and the tendency of the latter to be located close to the precipitation apex reflects the disruption by drainage of the natural hydrological mechanisms that once maintained these sites as fen.

Groundwater is an important water source for a number of WETMECs, and these form a cluster in the groundwater apex (bottom right hand) of the diagram. The wet, seepage-based WETMECs (such as 10 and 14) are, as might be expected, particularly tied to groundwater-based supply. In general, surface water sources appear to have little importance for this group of WETMECs. This does not necessarily imply that no surface water inflows occur, but rather that the maintenance of the summer water table in these WETMECs is strongly dominated by groundwater. Also, the positions of points on the plot represent mean values, and surface water sources may be more important for some individual samples than is suggested by the mean value. Variation in the plotted position of WETMECs in the groundwater cluster reflects different proportions of contribution of precipitation and surface water to individual WETMECs. Some of these, such as WETMECs 7 and 8, represent sites which are either partly drained or which have surfaces distant from marginal groundwater sources (or both) and in which precipitation makes a more important contribution to overall supply. Some may once have supported an ombrogenous surface, since removed by peat extraction.

Surface water supply is not a dominant feature of most WETMECs. The main exception is provided by WETMECs 5 and 6, which are both WETMECs of floodplains and which may experience (variable) inflows from watercourses. The proportionate contribution of surface water to WETMEC 3 is also relatively high. This WETMEC essentially represents wet surfaces that are perhaps mainly precipitation-fed, but which have some contributory surface run-off inflow. The role of groundwater in examples of this WETMEC is thought generally to

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[1] With the permission of Wallingford Hydrosolutions Limited

be small, though there are some uncertainties about this, as discussed in the entry for WETMEC 3.

Uncertainties about the contribution of groundwater also underlie some of the samples included within the ‘central’ group of WETMECs (18 – 20). These include surfaces which are known to receive significant inflows of surface water and groundwater, but also include examples where groundwater inflow is likely, but where evidence for this is sparse. There is also considerable variance associated with the mean values of these WETMECs, so that in some examples groundwater, or surface water, is much more important than in others.

6.2.3 WETMECs in relation to vegetation and EU habitats

The occurrence of some of the main herbaceous wetland NVC community types in individual WETMECs is shown in Table 6.3. The occurrence of the main wetland EU SAC-habitat types thought to be present in each WETMEC is also indicated (Table 6.4). This information is presented in more detail in the conservation value section in each individual WETMEC account.

6.2.4 Synopsis of WETMECs

This synopsis provides a descriptive summary of the main features of WETMECs, as derived from multivariate analyses (Figure 6.1). It should be used in conjunction with the WETMEC Summary Table (Table 6.2) and the summary and full accounts of individual WETMECs. The WETMECs are aggregated into WETMEC groups, which may themselves have some broad-scale descriptive value.

The following points should be noted:

- Individual WETMEC categories are not fully discrete entities, but can merge into one another. Some samples may therefore have characteristics that are intermediate between two or more WETMECs.
- The WETMEC groups broadly reflect the structure of the multivariate dendrogram (Figure 6.1) and have been given names that reflect their main character. However, some individual samples, or even some WETMEC sub-types, do not necessarily conform to the descriptive label.
- WETMECs are composite entities derived by multivariate classification using a wide range of characteristics. They are thus influenced by dominant features within the dataset and do not necessarily correspond exactly to variation in individual characteristics. This can cause some untidiness when allocating them to WETMEC groups. For example, within the macro-group of ‘groundwater-fed surface’ a main division is between mires fed by groundwater seepage and groundwater-flushed examples, the latter being over an aquitard. However, one of the sub-types of WETMEC 15, which is unambiguously clustered within the ‘seepage’ types, tends to occur over an aquitard, and in this respect has similarities with the ‘flushed’ types. Such ambiguities could, of course, be tidied-up, and the WETMEC classification more clearly structured, simply by relocating WETMEC 15a, but this would be at the expense of the multivariate classification and would violate some of the common features of WETMECs 15a and 15b. This problem is essentially an expression of the difficulty of trying to summarise the multi-dimensional variation of the dataset within a few clear and coherent categories.

- The names of the sub-WETMECs have been formulated to be short and self-standing and therefore do not always incorporate generic elements of the parent WETMEC name.
- GW: Groundwater; SW: Surface Water.

WETMEC Group: OMBROGENOUS BOGS AND RELATED MIRES

Includes ombrogenous surfaces that are more or less exclusively fed by precipitation (WETMECs 1 and 2), and some topogenous surfaces exposed to only weakly minerotrophic telluric (WETMEC 3) and some drained surfaces (in both bogs and fens) that are (now) mostly fed exclusively by precipitation (WETMEC 4). Although the latter has, for convenience, been grouped within the 'ombrotrophic' WETMEC group, it is of interest that the clustering dendrogram suggests that its closest affinities are with 'surface water-fed floodplains', of which it represents a particularly dry example.

WETMEC 1: Domed Ombrogenous Surfaces ('raised bog' *sensu stricto*)

Domed surfaces mostly fed exclusively by precipitation. Includes classic raised bogs and 'ridge-raised' ('intermediate' bogs), and also solid ombrogenous surfaces within basins, and residual baulks of uncut peat within some peat-cutting complexes.

WETMEC 2: Buoyant Ombrogenous Surfaces (quag bogs)

More or less flat, buoyant surfaces more or less exclusively fed by precipitation. Includes bogs in (usually small) basins (basin bogs), but also surfaces in wet depressions within some peat-cutting complexes. Sub-types reflect nature of any significant inflows of telluric water into the basins; these do not feed the mire surface but may support it, or otherwise influence the hydrodynamics of the basin as a whole.

WETMEC 2a: Ombrogenous Quag

WETMEC 2b: Ombrogenous Quag (GW-Fed Basin)

WETMEC 2c: Ombrogenous Quag (SW-Fed Basin)

WETMEC 3: Buoyant Weakly Minerotrophic Surfaces ('transition bogs')

More or less flat, buoyant surfaces of basins and hollows, fed in part by telluric water, but with surface largely fed by precipitation (because of buoyant character) and/or telluric water weakly minerotrophic. Sub-types relate to the apparent absence of significant water inflows/outflows in the basin, or to their presence (especially outflows)

WETMEC 3a: Bog-Transition Quag (± closed basin)

WETMEC 3b: Bog-Transition Quag (± open basin)

WETMEC 4: Drained Ombrotrophic Surfaces (in bogs and fens)

Drained, more or less solid peat surfaces, often flat, with low water tables. Precipitation is more or less exclusive water source to surface or near-surface, but in the case of WETMEC 4b this is because of disruption of former mechanisms of telluric water supply.

WETMEC 4a: Drained Ombrogenous Bog

WETMEC 4b: Drained Ombrotrophic Fen

WETMEC Group: SURFACE WATER-FED FLOODPLAINS

Includes floodplain sites in which telluric water is derived from adjoining watercourses (either by episodic flooding (WETMEC 5) or lateral flow through peat (WETMEC 6)). May be supplemented by minor rain-generated run-off or land-drainage, or groundwater outflow.

WETMEC 5: Summer-Dry Floodplains

Floodplain sites fed mainly by episodic flooding from watercourse, though some examples are uncoupled from this. Precipitation often dominates hydrodynamics and may be more or less the exclusive supply to wetland surface during summer or low-flow conditions. Sub-types largely reflect incidence of flooding and retention of surface water (such as in depressions)

WETMEC 5a: Rarely Flooded Floodplain

WETMEC 5b: Alluvial Floodplain

WETMEC 5c: Winter-Flooded Floodplain

WETMEC 5d: Floodplain Sump

WETMEC 6: Surface Water Percolation Floodplains

Surfaces partly fed in dry conditions by lateral flow of water from proximate water bodies, through transmissive near-surface layers of peat (most usually the infill of reflooded turbaries), driven by an evapotranspiration-induced hydraulic gradient. In wet conditions hydraulic gradient may be reversed and surfaces drain towards water bodies. May also be subject to episodic inundation. Sub-types mainly relate to stability and elevation of peat surface and to degree of connection to water bodies.

WETMEC 6a: Solid SW Percolation Surface

WETMEC 6b: Grounded SW Percolation Quag

WETMEC 6c: SW Percolation 'Boils'

WETMEC 6d: Swamped SW Percolation Surface

WETMEC 6e: Wet SW Percolation Quag

WETMEC 6f: SW Percolation Water Fringe

WETMEC Group: GROUNDWATER FLOODPLAINS

A poorly defined unit containing samples from floodplain contexts, about which little information is generally available. Requires further examination, especially to establish better the relationships to 'groundwater bottoms'

WETMEC 7: Groundwater Floodplains

A poorly defined unit containing a small number of floodplain surfaces alongside groundwater-fed watercourses, with water levels apparently related to the piezometric head of the source aquifer. Degree and mechanism of any groundwater supply to adjoining mire surface is often uncertain (they are frequently located over complex, and often low-permeability, alluvial sequences). In some cases, natural hydraulic relationships between the watercourse and mire have been dislocated, especially by lowering of river levels and other forms of water management. Sub-types relate to proximity to watercourse and to apparently permeability of underlying material.

WETMEC 7a: Groundwater-Fed River Fringe

WETMEC 7b: Groundwater Floodplain

WETMEC 7c: Groundwater Floodplain on Aquitard

WETMEC Group: GROUNDWATER BOTTOMS

Mire surfaces in topogenous contexts (basins, troughs and former river floodplains) with some apparent groundwater supply from aquifer, either from the margins across an aquitard (WETMEC 8) or more generally across the 'bottom' (WETMEC 9). Permeability of the wetland infill is often quite low and/or groundwater head is sub-surface, so most of surface is not apparently fed by groundwater (cf. WETMEC 13), but this may support other sources, especially precipitation. Relationship of examples on (former) floodplains to 'groundwater floodplains' requires clarification (a main separating difference in the current analysis is that the depth of peat is often considerably greater in groundwater bottoms than in groundwater floodplains).

WETMEC 8: Groundwater-Fed Bottoms with Aquitard

Basins, troughs and small floodplains with (often quite deep) peat over a laterally extensive aquitard formed from the wetland infill (such as marl, gyttja) or from underlying material (such as Till), so that groundwater outflow into the mire is largely restricted to the margins. Water supply to much of the surface may be dominated by precipitation, but telluric water may be close to surface in places, especially in depressions or alongside drains. Sub-types reflect presence or absence of dykes and drains that may intercept/ distribute marginal groundwater outflows.

WETMEC 8a: Groundwater Percolation Bottom

WETMEC 8b: Groundwater-Distributed Bottom

WETMEC 9: Groundwater-Fed Bottoms

Similar to WETMEC 8, but lacking a laterally extensive aquitard (though patchy aquitards sometimes occur). Can sometimes form a zone separating WETMEC 8 from the upland margin. Many examples are now drier than was once the case, because of over-deepening of watercourses or a lowering of groundwater levels in the connected mineral aquifer. Sub-types effectively reflect degree of wetness of system. Wet examples of WETMEC 9a are transitional to WETMEC 13 and can be difficult to distinguish from this.

WETMEC 9a: Wet Groundwater Bottom

WETMEC 9b: Part-Drained Groundwater Bottom

WETMEC Macro-Group: GROUNDWATER-FED SURFACES

This macro-grouping of WETMECs includes systems that can be considered to be seepages *sensu lato*, *that is, systems where there is groundwater outflow at, or very close to, the surface, either permanently or episodically. In this respect they differ from 'groundwater bottoms' in which groundwater outflow rarely irrigates the* surface *of the wetland, though the two categories undoubtedly intergrade.*

A primary distinction is made between seepages (surfaces irrigated by direct groundwater outflow) and flushes (surfaces over aquitards fed indirectly by groundwater outflow at the margins). Seepages are subdivided broadly on topography into 'seepage slopes' (essentially soligenous systems, with shallow peat, which are typically (but not always) sloping and where the high water table is maintained primarily by groundwater outflow); and into 'seepage basins and bottoms', which are effectively rheo-topogenous systems (with a high water table maintained both by occupying topographical hollows and by groundwater outflow).

WETMEC Group: **SEEPAGE SLOPES**

Outflows of groundwater, typically on slopes but occasionally on more or less flat ground where there is water outflow. The high water table is maintained in what is essentially an unfavourable topographical context (sloping) by high rates of groundwater outflow (they are soligenous systems). Groundwater outflow varies from more or less permanent (WETMEC 10) to intermittent (WETMEC 11), though in some examples of the latter the water table is consistently sub-surface. Examples of WETMEC 12 are conceptually transitional between 'seepage slopes' and 'seepage basins'.

WETMEC 10: Permanent Seepage Slopes

Seepage surfaces developed at, and sometimes below, the point of groundwater discharge. Sub-types reflect the strength and localisation of the outflows.

WETMEC 10a: Localised Strong Seepage

WETMEC 10b: Diffuse Seepage

WETMEC 11: Intermittent and Part-Drained Seepages

Intermittent seepage surfaces, or partly drained former seepages where the water table is now consistently sub-surface. A widespread and heterogeneous unit, developed on slopes or fairly flat surfaces. Low water levels may be due to low aquifer water tables and/or to resistance to water upflow caused by a fairly low-permeability top-layer deposit (WETMEC 11b).

WETMEC 11a: Permeable Partial Seepage

WETMEC 11b: Slowly Permeable Partial Seepage

WETMEC Group: SEEPAGE BASINS AND BOTTOMS

Rheo-topogenous seepage systems developed in various topographical contexts, usually with lateral water flow, probably mainly through the surface layer, except for WETMEC 12 which is characterised by quite strong vertical water levels fluctuations, rather than lateral flow, and which is not always closely coupled to the mineral aquifer. WETMEC 13 is characteristically topogenous, whereas examples of WETMEC 14 can range from visually flat to sloping; the latter have conceptual and (often) spatial affinities with WETMEC 10. Concentrations of surface flow are particularly characteristic of WETMEC 14 (though are not exclusive to it) and form a separate unit (WETMEC 15).

WETMEC 12: Fluctuating Seepage Basins

This unit is conceptually intermediate between more or less flat 'seepage slopes' and 'seepage basins and bottoms'. In effect, it represents a WETMEC 11 mechanism within a shallow depression, where the topography permits the accumulation of surface water, which can sometimes persist year round. Sub-types are informal units that have not been derived by multivariate analyses.

WETMEC 12a: Fluctuating Seepage Basins with permanent standing water

WETMEC 12b: Fluctuating Seepage Basins with winter standing water, summer water table sub-surface or near surface

WETMEC 12c: Fluctuating Seepage Basins with shallow winter standing water, summer water table sub-surface or near surface

WETMEC 12d: Fluctuating Seepage Basins, winter 'wet', summer 'dry'

WETMEC 12e: Fluctuating Seepage Basins with winter standing water, 'dry' by early summer

WETMEC 13: Seepage Percolation Basins

Groundwater-fed basins, typically with a buoyant surface and a transmissive surface layer, often with a quite strong outflow from the basins. Water is thought to flow primarily through the surface layer. Accumulating deposits of marl and gyttja may constrain groundwater upflow and help confine outflow to the margins of the basins. Sub-types reflect buoyancy of surface and proximity to groundwater outflow.

WETMEC 13a: Seepage Percolation Surface

WETMEC 13b: Seepage Percolation Quag

WETMEC 13c: Seepage Percolation Water Fringe

WETMEC 13d: Distributed Seepage Percolation Surface

WETMEC 14: Seepage Percolation Troughs

Peat-filled troughs, more or less flat to gently sloping, fed by groundwater outflow directly from underlying deposits or flanking slopes (WETMEC 10). Water flow often becomes focussed into axial Flow Tracks (WETMEC 15). Embedded sumps may support WETMEC 13.

WETMEC 15: Seepage Flow Tracks

Water flow tracks, mostly narrow and treacherous, sourced primarily by groundwater outflow, but sometimes with a surface run-off component. May be some direct groundwater outflow (especially WETMEC 15b), but much water is derived from flanking groundwater-fed WETMECs (especially WETMECs 10 and 14). Sub-types reflect slope, topography, peat depth and permeability of underlying mineral material. As variation in these components does not entirely coincide, the two sub-types must be seen to some as composite entities.

WETMEC 15a: Topogenous Seepage Flow Tracks

WETMEC 15b: Sloping Seepage Flow Tracks

WETMEC Group: GROUNDWATER-FLUSHED BOTTOMS

Groundwater-Flushed Bottoms effectively represent a flat(-tish) version of Groundwater-Flushed Slopes and are broadly analogous to Seepage Percolation Troughs (WETMEC 14), differing primarily in being underlain by a continuous, extensive aquitard, so that groundwater outflows occur mainly at the mire margin and flow laterally across the mire.

WETMEC 16: Groundwater-Flushed Bottoms

This WETMEC is a flushed analogue of WETMEC 14, and some examples are more or less indistinguishable from this except in terms of the groundwater flushing mechanism. However, peat depth is often considerably shallower in WETMEC 16; the surfaces tend to become drier (at least in summer) with distance from the margins; and flow tracks are generally much less evident (note that flow tracks sampled all clustered within WETMEC 15). Sub-types reflect inflows from axial surface-water sources (WETMEC 16b) or disconnection from the groundwater outflow source (WETMEC 16c).

WETMEC 16a: Groundwater-Flushed Bottom

WETMEC 16b: Groundwater-Flushed Bottom + watercourse inputs

WETMEC 16c: Groundwater-Overflow Bottom

WETMEC Group: GROUNDWATER-FLUSHED SLOPES

Groundwater-Flushed Slopes are analogous to seepage slopes (WETMECs 10 and 11), differing primarily in being underlain by a continuous aquitard, so that groundwater outflows occur mainly along the top edge of the mire (as a seepage face) and flow downslope through WETMEC 17.

WETMEC 17: Groundwater-Flushed Slopes

WETMEC 17 is a distinctive but heterogeneous unit, with sub-types that are broadly comparable with seepage-based WETMECs (WETMEC 17a with 10; 17b with 11; and 17d with 15). A strong case could be made for elevating the WETMEC 17 sub-types to independent WETMEC status, but ideally these would be based on more samples than were available in the current analysis.

WETMEC 17a: Groundwater-Flushed Slopes

WETMEC 17b: Weakly Groundwater-Flushed Slopes

WETMEC 17c: Distributed Groundwater-Flushed Slopes

WETMEC 17d: Groundwater-Flushed Flow Tracks

WETMEC Group: TROUGHS, BASINS AND BOTTOMS WITH LIMITED OR INDETERMINATE GROUNDWATER SUPPLY (OR NONE)

WETMECs 18 to 20 are analogues of the groundwater-fed WETMECs 14, 15 and 13 (respectively), and differ from these primarily in groundwater supply being apparently much less important, or absent, or in some cases not known. These WETMECs mainly occur over low permeability, and surface water sources (primarily rain-generated run-off) make a proportionately greater contribution of telluric water. Because of their broad geological characteristics, it was initially thought likely that these sites received little or no groundwater, but it has since become apparent that many occupy locations where there may be groundwater outflow from a superficial aquifer in fracture systems within the rocks. The hydrological importance of such groundwater outflow is generally not known, but it may have hydrochemical effects (especially localised base enrichment) disproportionate to its quantitative contribution. A corollary of this is that in this study, few sites were found in which it was certain that groundwater outflow made no contribution to the mire.

WETMEC 18: Percolation Troughs

An analogue of WETMEC 14, recorded mainly in North-West England and Wales in valleyheads and troughs, some of which have developed over former lake basins (or from WETMEC 20), thereby obscuring the underlying basin topography. Water flow through the peat often becomes focussed into Flow Tracks (WETMEC 19).

WETMEC 19: Flow Tracks

An analogue of WETMEC 15, recorded mainly in North-West England and Wales. Most often embedded within WETMEC 18, but can occur in other WETMECs (for example, 20) or even as an independent entity.

WETMEC 20: Percolation Basins

An analogue of WETMEC 13, recorded mainly in North-West England and Wales. The status (with respect to groundwater supply) of some examples is uncertain, and some are transitional with WETMEC 13. Some have undoubtedly been dug for underlying clay and the possibility that some examples are largely artificial in origin cannot be discounted.

WETMEC 20a: Percolation Quag

WETMEC 20b: Percolation Water Fringe

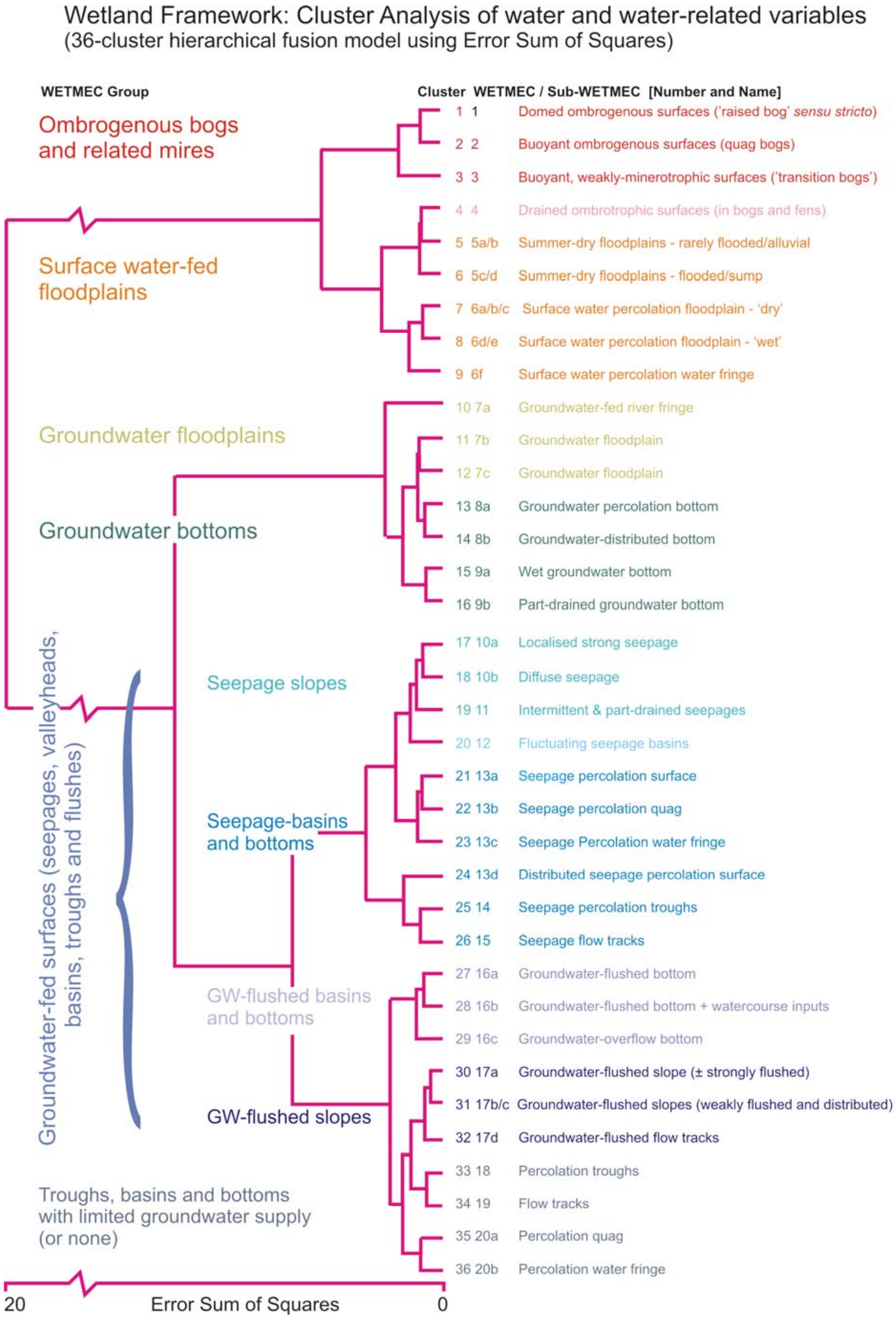
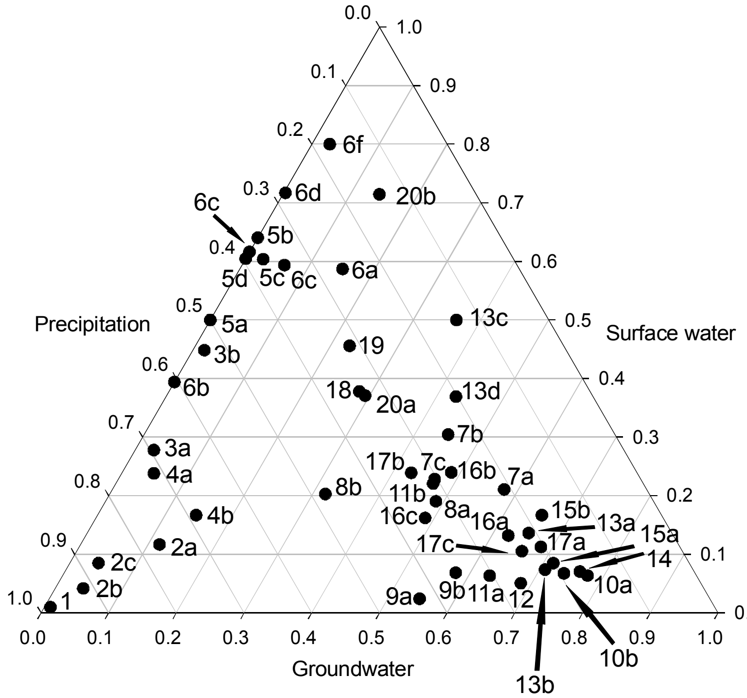


Figure 6.1 Cluster analysis (36-cluster hierarchical fusion model using error sum of squares) of water and water-related variables showing derivation of WETMEC types



Note: the contribution of each water source was assessed independently on a 5-point scale (see text). The figures here represent the mean score for each WETMEC sub-type, normalised (by SigmaPlot) in order to produce a ternary plot.

Figure 6.2 Relative contribution of different water sources to each WETMEC sub-type

See Table 6.1 for WETMEC numbers and names.

Table 6.1 List of WETMECs and WETMEC sub-types

WETMEC GROUP: OMBROGENOUS BOGS AND RELATED MIRES

WETMEC 1: Domed Ombrogenous Surfaces ('raised bog' *sensu stricto*)

WETMEC 2: Buoyant Ombrogenous Surfaces (quag bogs)

WETMEC 2a: Ombrogenous Quag

WETMEC 2b: Ombrogenous Quag (GW-Fed Basin)

WETMEC 2c: Ombrogenous Quag (SW-Fed Basin)

WETMEC 3: Buoyant Weakly Minerotrophic Surfaces ('transition bogs')

WETMEC 3a: Bog-Transition Quag (± closed basin)

WETMEC 3b: Bog-Transition Quag (± open basin)

WETMEC 4: Drained Ombrotrophic Surfaces (in bogs and fens)

WETMEC 4a: Drained Ombrogenous Bog

WETMEC 4b: Drained Ombrotrophic Fen

WETMEC GROUP: SURFACE WATER-FED FLOODPLAINS

WETMEC 5: Summer-Dry Floodplains

WETMEC 5a: Rarely Flooded Floodplain

WETMEC 5b: Alluvial Floodplain

WETMEC 5c: Winter-Flooded Floodplain

WETMEC 5d: Floodplain Sump

WETMEC 6: Surface Water Percolation Floodplains

WETMEC 6a: Solid SW Percolation Surface

WETMEC 6b: Grounded SW Percolation Quag

WETMEC 6c: SW Percolation 'Boils'

WETMEC 6d: Swamped SW Percolation Surface

WETMEC 6e: Wet SW Percolation Quag

WETMEC 6f: SW Percolation Water Fringe

WETMEC GROUP: GROUNDWATER FLOODPLAINS

WETMEC 7: Groundwater Floodplains

WETMEC 7a: Groundwater-Fed River Fringe

WETMEC 7b: Groundwater Floodplain

WETMEC 7c: Groundwater Floodplain on Aquitard

WETMEC GROUP: GROUNDWATER BOTTOMS

WETMEC 8: Groundwater-Fed Bottoms with Aquitard

WETMEC 8a: Groundwater Percolation Bottom

WETMEC 8b: Groundwater-Distributed Bottom

WETMEC 9: Groundwater-Fed Bottoms

WETMEC 9a: Wet Groundwater Bottom

WETMEC 9b: Part-Drained Groundwater Bottom

Table 6.1 ***contd.***

WETMEC Macro-Group: GROUNDWATER-FED SURFACES

WETMEC GROUP: SEEPAGE SLOPES

WETMEC 10: Permanent Seepage Slopes

WETMEC 10a: Localised Strong Seepage

WETMEC 10b: Diffuse Seepage

WETMEC 11: Intermittent and Part-Drained Seepages

WETMEC 11a: Permeable Partial Seepage

WETMEC 11b: Slowly Permeable Partial Seepage

WETMEC GROUP: SEEPAGE BASINS AND BOTTOMS

WETMEC 12: Fluctuating Seepage Basins

WETMEC 12a: Fluctuating Seepage Basins with permanent standing water

WETMEC 12b: Fluctuating Seepage Basins with winter standing water, summer water table sub-surface or near surface

WETMEC 12c: Fluctuating Seepage Basins with shallow winter standing water, summer water table sub-surface or near surface

WETMEC 12d: Fluctuating Seepage Basins, winter 'wet', summer 'dry'

WETMEC 12e: Fluctuating Seepage Basins with winter standing water, 'dry' by early summer

WETMEC 13: Seepage Percolation Basins

WETMEC 13a: Seepage Percolation Surface

WETMEC 13b: Seepage Percolation Quag

WETMEC 13c: Seepage Percolation Water Fringe

WETMEC 13d: Distributed Seepage Percolation Surface

WETMEC 14: Seepage Percolation Troughs

WETMEC 15: Seepage Flow Tracks

WETMEC 15a: Topogenous Seepage Flow Tracks

WETMEC 15b: Sloping Seepage Flow Tracks

WETMEC GROUP: GROUNDWATER-FLUSHED BOTTOMS

WETMEC 16: Groundwater-Flushed Bottoms

WETMEC 16a: Groundwater-Flushed Bottom

WETMEC 16b: Groundwater-Flushed Bottom + Watercourse Inputs

WETMEC 16c: Groundwater-Overflow Bottom

WETMEC GROUP: GROUNDWATER-FLUSHED SLOPES

WETMEC 17: Groundwater-Flushed Slopes

WETMEC 17a: Groundwater-Flushed Slope

WETMEC 17b: Weakly Groundwater-Flushed Slope

WETMEC 17c: Distributed Groundwater-Flushed Slopes

WETMEC 17d: Groundwater-Flushed Flow Tracks

Table 6.1 ***contd.***

WETMEC GROUP: TROUGHS, BASINS AND BOTTOMS WITH LIMITED, OR INDETERMINATE, GROUNDWATER SUPPLY (OR NONE)

WETMEC 18: Percolation Troughs

WETMEC 19: Flow Tracks

WETMEC 20: Percolation Basins

WETMEC 20a: Percolation Quag

WETMEC 20b: Percolation Water Fringe

Table 6.2 Summary table of WETMECs and their characteristics

WETMEC 1	1: Domed Ombrogenous Surfaces ('Raised Bog')
Key character combination	Summer-wet, often domed surface, remote from and/or elevated well above telluric water tables; often over low-permeability deposits.
Example sites	Bowness Common, Fenns, Whixall & Bettisfield Moss, Flaxmere, Rhos Gôch Common
Landscape context	Basins or floodplains. [Accumulating peat may sometimes grow beyond limits of basins and obscure underlying topography.]
Topography	Surface typically domed, with more or less flat and sloping, elements
Summer water level and main source	Near surface.
	Exclusively fed by precipitation, but may be supported by telluric water.
Association with GW	Limited supply to margins of dome, or none. GW level mostly well below surface and often distant.
Association with watercourse (WC)	Most sites are isolated from WCs, but can occur alongside rivers [WC level is well below surface
Association with upslope SW	Margins may receive limited RGR or field drain supply and drains sometimes dug across dome. SW levels well below surface or distant.
Surface flooding	Small pools often occur and can expand in high rainfall conditions, but excess ppt often held within an expansible surface.
Water flow: within stand (IS);	IS: Not visible
from stand (OS)	OS: Not visible
Summer water outflow from (sub-)site	Often none obvious.
Dept of PAL	Often deep (> 4m), typically consisting of a deep layer of ombrogenous peat, usually over telluric peat.
PAL 'permeability'	Spongy surface (acrotelm) or consolidated in drained examples; over consolidated catotelm peat. Acrotelm typically very permeable
Basal substratum 'permeability'	Variable but usually low-permeability: from dense clays to sands and gravels

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 2	2: Buoyant Ombrogenous Surfaces (Quag Bogs)	2a: Ombrogenous Quag	2b: Ombrogenous Quag (GW-Fed Basin)	2c: Ombrogenous Quag (SW-Fed Basin)
Key character combination	Quaking, summer-wet surface or raft elevated slightly above telluric water tables; often in basins, over potentially high or low permeability deposits.	No obvious telluric supply to basin	Some GW supply to basin (adjoining springs etc.)	Biglands Bog, Cliburn Moss, Cors y Llyn, Tarn Moss
Example sites		Cranberry Bog, Lin Can Moss, Abbots Moss	Chartley Moss, Wybunbury Moss	
Landscape context	Basins			
Topography	More or less flat – may form a very shallow dome, but this is not normally apparent.			
Summer water level and main source	Near surface. Surface thought to be fed exclusively by ppt, but supported by near-surface telluric water.			
Association with GW	Significant supply to margins in a few sites. Degree of penetration below dome is unknown. Level usually slightly (0.5 – 1 m) below surface.	Probably little	Groundwater feed to basin: penetration beneath WETMEC uncertain.	
Association with watercourse (WC)	None			
Association with upslope SW	Margins may receive RGR or field drain supply and may penetrate into dome by drains, peat diggings etc sometimes dug across dome. SW level usually slightly (0.5 – 1 m) below surface			Drains and stream feeds to basin.
Surface flooding	Small pools sometimes occur and may expand in high rainfall conditions.			
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible			
Summer water outflow from (sub-)site	Often none	None	Often visible to strong flow.	Usually evident outflow except in dry conditions
Dept of PAL	Often deep (> 4m), typically consisting of a shallow layer of ombrogenous peat, usually over weakly-telluric peat.			
PAL 'permeability'	Quaking or semi-floating surface; usually over a similarly quaking, or more liquid, peat deposit. Top layer typically permeable, lower layers more variable (mid-layers sometimes very watery).			
Basal substratum 'permeability'	Variable: from dense clays to sands and gravels, but the latter often smeared with clay etc. Usually separated by a low-permeability infill or clay lining.			

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 3	3: Buoyant Weakly Minerotrophic Surfaces ('Transition Bogs')	3a: Bog-Transition Quag (± Closed Basin)	3b: Bog-Transition Quag (± Open Basin
Key character combination	As [2], but surface little above influence of telluric water. [2] and [3] may both occupy the same basin, [3] as a lagg.	No obvious telluric supply to basin.	Surface water inflows
Example sites		Abbots Moss, Forest Camp, Hollas Moss	Cliburn Moss, Cors y Llyn, Tarn Moss
Landscape context	Basins		
Topography	Flat		
Summer water level and main source	Near or at surface. May receive weakly telluric water, but ppt probably a significant component of budget.		
Association with GW	Connectivity with aquifers often uncertain. Outflow likely in a few sites. In some cases may recharge aquifer. GW level often just sub-surface.		
Association with watercourse (WC)	None		
Association with upslope SW	Some sites have locally significant stream or field-drain inflow in addition to RGR.		
Surface flooding	None		
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible		
Summer water outflow from (sub-)site	Often none	None	Visible, but often weak.
Dept of PAL	Often deep (> 3m), but can be shallow		
PAL 'permeability'	Quaking or semi-floating surface; usually over a similarly quaking, or more liquid, peat deposit. Surface peat usually more permeable than the lower substrata.		
Basal substratum 'permeability'	Variable: from dense clays to sands and gravels, but the latter often smeared with clay etc. Usually separated by a low-permeability infill or clay lining.		

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 4	4: Drained Ombrotrophic Surfaces In Bogs And Fens	4a: Drained Ombrogenous Bog	4b: Drained Ombrotrophic Fen
Key character combination	Surface 'dry' year round – telluric water in drains well below surface. No obvious or proximate GW sources. Often over low permeability material.	Drained bog peat at surface (naturally ombrotrophic)	Drained fen peat at surface (ombrotrophic by drainage).
Example sites		Holme Fen, Meathop Moss, Cors Erddreiniog (?)	Corsydd Erddreiniog and Nantisaf, Lakenheath Poors, Woodwalton Fen
Landscape context	Floodplains, basins or troughs.		
Topography	Flat or slightly sloping.		
Summer water level and main source	Deep below surface. Surface fed exclusively by ppt, but may be supported by telluric water at depth.		
Association with GW	GW sources may be present, but usually remote and only proximate where deep GW-fed ditches have been dug. GW level well below surface.		
Association with watercourse (WC)	May be associated with WC, but typically isolated from them; may be pump drained. Level variable, but usually uncoupled from wetland.		
Association with upslope SW	Significant in some sites, but level (usually in adjoining drains) is well below surface	Only proximate where deep SW-fed ditches have been dug.	No ombrogenous peat (but may have been removed at some sites).
Surface flooding	None		
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible		
Summer water outflow from (sub-)site	Not visible		
Dept of PAL	Often deep (> 4m)	Remnant ombrogenous peat, usually over minerotrophic deposit.	
PAL 'permeability'	Firm surface on consolidated, amorphous peat of low permeability.		
Basal substratum 'permeability'	Usually over low-permeability clays etc		

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 5	**5: Summer Dry Floodplains**	**5a: Rarely Flooded Floodplain**	**5b: Alluvial Floodplain**	**5c: Winter-Flooded Floodplain**	**5d: Floodplain Sump**
Key character combination	Surface often fairly summer-dry, but wet or flooded in winter. May experience episodic flooding from water courses. Peat infill 'solid' and low K (cf. [6]).	Rarely flooded (usually sites isolated from natural river-supply mechanisms.	Alluvial surface (rather than peat); often regularly flooded from adjoining watercourse	The 'typical' state; wet or flooded in winter, drier in summer. Summer wetness varies with location and year	Poorly-drained, shallow depressions which remain wet for much or all of summer.
Example sites		Wicken Fen, Woodwalton Fen	Biglands Bog, Cors Gyfelog, Drabblegate Common, Esthwaite North Fen, Wheatfen	Many Broadland sites, Cranberry Rough	Burgh Common, Catfield Fen, Cranberry Rough
Landscape context	Floodplains				
Topography	Flat				Shallow depressions or other low-lying areas.
Summer water level and main source	Often well below surface. Water supply dominated by ppt + episodic flooding and/or supply from dykes etc	Typically with particularly low summer water tables.		Summer water levels occasionally quite high where high levels are maintained in dykes.	Summer water levels often higher than other sub-types, but seasonal fluctuations can be greater.
Association with GW	Generally unimportant; may sometimes contribute to water level in dykes (which is often well below peat surface).				
Association with watercourse (WC)	Adjoins stands, either as watercourses or as dykes in connection with these. Dyke level often well below peat surface.		Mostly alongside watercourse.	High dyke water levels sometimes maintained by sluices.	
Association with upslope SW	May contribute to dyke levels, but water level in these often well below surface.				
Surface flooding	Rare or frequent (mostly winter) flooding.	Flooding absent or rare, even in winter.	Flooding often frequent, but sometimes rare (because of flood control measures etc.).	Often shallow flooded in winter, but may often be ponded-back precipitation rather than river water, or a mixture.	As [5c]
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible				
Summer water outflow from (sub-)site	Usually not visible except at times of high flow; dykes sometimes seasonally bidirectional.				
Dept of PAL	Usually deep (> 4 m), often with a particularly dense, wood-based, deposit at depth.	Often a rather 'dry', solid peat, at least near surface.	Peat enriched with alluvium or ± pure clays and silts, at least near surface.		
PAL 'permeability'	Firm, consolidated and fairly amorphous surface, generally of low permeability.		Often alluvial surface.		
Basal substratum 'permeability'	Mostly over low-permeability clays etc; alluvial deposits sometimes interlayered within the peat.				

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 6	6: Surface Water Percolation Floodplains	6a: Solid SW Percolation Surface	6b: Grounded SW Percolation Quag
Key character combination	Surface usually quite wet in summer and wet or flooded in winter. Peat top-layer often loose, sometimes buoyant and mostly high K..	On 'solid' peat near watercourses. Transitional to [5]	Fairly consolidated but 'recent' top-layer; summer dry and isolated from SW sources in summer.
Example sites		Burgh Common, Strumpshaw Fen, Wheatfen	Catfield Fen, Hulver Ground, Reedham Marsh
Landscape context	Floodplains		
Topography	Flat		
Summer water level and main source	Usually slightly subsurface. Fed mainly by SW, often from dykes connected to watercourses.	WT lower than mean.	Lower than the mean.
Association with GW	Generally unimportant; may sometimes contribute to water level in dykes. Dyke level usually somewhat below surface.		
Association with watercourse (WC)	Adjoins stands, either as watercourses or watercourse-connected dykes. Dyke level usually somewhat below surface.	Often close to water bodies or connected dykes.	May be isolated from water courses and dykes by banks of 'solid' peat.
Association with upslope SW	May contribute to dyke levels, but probably mainly during winter.		
Surface flooding	Rare to frequent winter flooding.		Regular flooding, but in some sites may be largely ponded-back precipitation.
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible		
Summer water outflow from (sub-)site	Usually not visible; dykes sometimes seasonally bidirectional.		
Dept of PAL	Usually deep, often > 4 m. Peat, sometimes with thick alluvial intercalations.		
PAL 'permeability'	Spongy, sometimes quaking or semi-floating surface. Top layer of peat typically permeable, over a less permeable lower layer.	Firm, fairly consolidated peat.	Fairly consolidated, sometimes 'grounded' 'raft'.
Basal substratum 'permeability'	Most often over low-permeability clays etc. Alluvial deposits sometimes interlayered with peat. A few examples over permeable, sandy deposits		

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 6 (cont.)	6d: Swamped SW Percolation Surface	6e: Wet SW Percolation Quag	6f: SW Percolation Water Fringe	6c: SW Percolation 'Boils'
Key character combination	Poorly-drained, shallow depressions with loose top-layer; remain wet for much of all of summer.	The 'typical' state: quaking or buoyant surface over rhizome mat; wet or flooded for much of year.	As [6e] but encroaching directly upon open water body.	Often unstable surface, but elevated above WT (year round). Transitional to [3]
Example sites	Berry Hall Fens, Cranberry Rough, Hall Fen, Ward's Marsh	Many Broadland sites	Barton Broad, Hoveton Broads, Esthwaite North Fen	Catfield Fen, Hickling Broad, Reedham Marshes
Landscape context				
Topography				
Summer water level and main source	High	Slightly sub-surface	High	Lower than the mean. Surface mainly fed by ppt, supported by telluric water.
Association with GW				
Association with watercourse (WC)	Can be isolated from water courses and dykes by embankments.		Directly adjoins water bodies or connected dykes.	
Association with upslope SW				
Surface flooding				Flooding absent or rare, even in winter.
Water flow: within stand (IS); from stand (OS)				
Summer water outflow from (sub-)site				
Dept of PAL				
PAL 'permeability'	Spongy or swamped, not usually obviously buoyant.	Buoyant surface	Buoyant to very buoyant surface, or swamped.	Surface fairly to very buoyant, but mostly held well above telluric water table.
Basal substratum 'permeability'				

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 7	7: Groundwater Floodplains	7a: Groundwater-Fed River Fringe	7b: Groundwater Floodplain	7c: Groundwater Floodplain On Aquitard
Key character combination	Floodplains of GW-fed WCs, often rather dry. Often complex alluvial sequence with only shallow peat. Water supply and relationship to river and aquifer mostly uncertain	Alongside GW-fed rivers and irrigated by these.	On floodplain surface, often quite close to WC, and on potentially high permeability deposits.	On floodplain surface, often quite close to WC, but underlain by low permeability material.
Example sites		Bransbury Common, Greywell Fen, Tarn Moor (Sunbiggin)	Bransbury Common, Chilbolton Common, Greywell Fen	Chippenham Fen, Stockbridge Fen
Landscape context	Floodplains			
Topography	Flat			
Summer water level and main source	Generally rather low WT except by rivers. GW may be main telluric source, but this is not well established.	Summer WT can be around surface level.	Summer WT variable – can be low.	Summer WT variable – can be low except immediately alongside some dykes etc.
Association with GW	Springs and seepages mostly absent. River levels related to aquifer water table; this probably determines mire WTs, at least locally.		May receive upflow through permeable deposits. Weak seepages upslope in a few cases.	Generally no evidence for either upflow or peripheral seepages. Deep adjoining ditches may be spring fed.
Association with watercourse (WC)	On floodplains, but river levels often below mire surface in summer. Occurrence of inundation uncertain.	Directly connected to watercourse.	Often near WC, but relationship to water level not certain.	May be near WC, but relationship to water level uncertain, and possibly uncoupled
Association with upslope SW	Generally not evident.			
Surface flooding	Not known – possibly infrequent.	Some inundation likely.	May sometimes occur, but little information.	May sometimes occur, but little information.
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible	IS: Not visible OS: May have both inflow from and outflow to WC		
Summer water outflow from (sub-)site	Ditches across floodplain may drain to river, but water levels and flows are often controlled artificially.			May be outflow from GW-fed dykes and ditches, but this may be independent of mire.
Dept of PAL	Often deep alluvial sequence, but only shallow surface peat.			
PAL 'permeability'	Usually solid, amorphous peat, mostly of low permeability, but sometimes with more permeable, unconsolidated horizons.			
Basal substratum 'permeability'	Often cut into permeable rocks, but locally extensive low permeability aquitards (clays and marls) can occur in alluvial sequence.		Usually underlain by permeable deposits (e.g. gravel in hydraulic connection with Chalk aquifer).	Underlain by low permeability deposits (marls, putty chalk etc).

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 8	8: Groundwater-Fed Bottoms With Aquitard	8a: Groundwater Percolation Bottom	8b: Groundwater- Distributed Bottom
Key character combination	Troughs or basins, usually on quite deep peat upon aquitard; if on floodplains, usually isolated from river. WT often below solid surface. Often marginal springs / seepages. Distinguished from [16] by topography and deeper peat.	Some lateral GW flow from margins; WT often decreases away from edge.	GW flow from margins intercepted by dykes and drains; often 'dry' except close to edge.
Example sites		Cors Goch, Cors Geirch, Newham Fen	Corsydd Eddreiniog and Nantisaf, Kenninghall & Banham Fens, Great Cressingham Fen, Upton Fen
Landscape context	Floodplains, basins, troughs and valleyheads		
Topography	Flat		
Summer water level and main source	Associated with GW outflow at margins, but penetration of this into wetland probably limited. WT often well below surface	Some (limited?) lateral flow of GW from margins. WT tends to decline away from edge.	Marginal GW outflow intercepted by dykes and distributed across / removed from wetland.
Association with GW	Aquifer episodically at, above or near surface, but WT in wetland may fall well below GW table at margins.	Marginal springs and seepages are often evident	GW in dykes often well below wetland surface, which may depend strongly on ppt.
Association with watercourse (WC)	Quite often associated with water courses but usually isolated from these, and (well) above them.		Dyke level may be determined by watercourse level or by sluices.
Association with upslope SW	May be some rain-generated run-off, but much infiltrates into ground above site, or intercepted by catchwater drains.		
Surface flooding	None		
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible		
Summer water outflow from (sub-)site	Sometimes (weak) outflow visible.		
Dept of PAL	Shallow to deep		
PAL 'permeability'	Firm, often rather amorphous, peat, mostly of moderate to low permeability.		
Basal substratum 'permeability'	Mostly over low-permeability clays and silts, and / or with prominent deposits of marl or gyttja.		

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 9	9: Groundwater-Fed Bottoms	9a: Wet Groundwater Bottom	9b: Part-Drained Groundwater Bottom
Key character combination	Similar to [8] but no aquitard and marginal springs / seepages often less evident. GW supply often inferred from hydrogeological data. Distinguished from [12] by topography and deeper peat.	Fairly summer-wet, often in small areas near edge.	Typically summer-dry, sometimes 'dry' year round.
Example sites		Blo' Norton & Thelnetham Fens Cors Geirch, Limpenhoe Meadows, Poplar Farm Meadows	Hopton Fen, Pakenham Meadows, Tuddenham Turf Fen, Pashford Poor's Fen
Landscape context	Floodplains, basins, troughs and valleyheads		
Topography	Flat	Mainly near upland margins.	Much of bottom, sometimes including margin.
Summer water level and main source	Apparently GW fed, but GW WT often well below surface, sometimes because of drainage.	Near or not far below surface	WT ± consistently well below surface.
Association with GW	Aquifer may be episodically at, above or near surface, but is often low (and more or less in equilibrium with wetland WT)	Apparent seepage, sometimes localised.	
Association with watercourse (WC)	Often associated with water courses, but usually isolated from these and (well) above them.		May adjoin drains or overdeepened water courses.
Association with upslope SW	May be some rain-generated run-off, but much infiltrates into ground above site, or intercepted by catchwater drains.		
Surface flooding	None		
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible		
Summer water outflow from (sub-)site	Sometimes weak outflow visible, or seepage into drains etc within wetland.		
Dept of PAL	Shallow to deep.		
PAL 'permeability'	Firm amorphous peat, mostly of moderate permeability.		
Basal substratum 'permeability'	Mostly over sands and sandy clays. Sometimes local lenses of marl or gyttja. Usually quite permeable.		Often over sands, gravels and sandy loams.

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 10	10: Permanent Seepage Slopes	10a: Localised Strong Seepage	10b: Diffuse Seepage
Key character combination	Summer-wet surface, usually sloping and shallow peat; springs / seepages usually visible, over permeable substratum.	Localised, often small, strong springs and seepages, often corresponding to variations in basal material (locally high K).	Often elongated seepages, often forming a valleyside zone (below [11]).
Example sites		Badley Moor, Cors Bodeilio, Gooderstone Common, Great Close Mire, Nantisaf, Sheringham Bog, Tarn Moor (Sunbiggin), Warwick Slade Bog	Buxton Heath, Cors Bodeilio, Holmhill Bog, Scarning & Potters Fen
Landscape context	Valleyheads and slopes		
Topography	Steep to v. gentle slopes, occasionally in more or less flat pans.	May adjoin a spring head or form a spring mound.	Often forms a broad valleyside zone.
Summer water level and main source	Just sub-surface. Primarily fed by groundwater		Generally slightly lower than 10a, but often visible or oozing.
Association with GW	GW outflow, often visible as springs or seepages. WT at or immediately below outflow.	Visible strong springs etc. Sometimes embedded within 10b	Point discharges usually not evident.
Association with watercourse (WC)	Often WC in valley bottom, but usually well below WETMEC 10, though lower slopes can sometimes be flooded.		
Association with upslope SW	May be some rain-generated run-off, but much infiltrates into ground above site, or intercepted by catchwater drains.		
Surface flooding	WT often above surface in shallow pools or runnels. Rarely flooded by SW or WC.		
Water flow: within stand (IS); from stand (OS)	IS: Often visible flow OS: Often visible flow, sometimes strong	IS: Usually visible	IS: Not visible, or only in runnels etc
Summer water outflow from (sub-)site	Typically visible, sometimes strong, outflow.		
Dept of PAL	Very shallow, often skeletal.		
PAL 'permeability'	Amorphous peat or mineral deposit of variable permeability.		
Basal substratum 'permeability'	Sands, gravels, sandy loams. Predominantly quite permeable.	Outflow associated with permeable deposits, but may be adjoined by less permeable material.	Often more uniformly permeable than 10a.

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 11	11: Intermittent & Part-Drained Seepages	11a: Permeable Partial Seepage	11b: Slowly Permeable Partial Seepage
Key character combination	As [10] but WT well below surface in summer or year round; also more often on flat surfaces or in sumps. Latter are transitional to [9] but have shallower peat.	Over permeable material, with dryness determined by GW surface.	Over less permeable material, with dryness determined also by greater resistance to flow. Often smaller and more heterogeneous than [11a].
Example sites		Foulden Common, Hemsby Common, Roydon Fen, Scarning Fen	Buxton Heath, Clack Fen, Cors Nantisaf, Cors Goch, Cors y Farl, Drayton Parslow Fen, Forncett Meadows, Holly Farm Meadows, Tarn Moor (Sunbiggin)
Landscape context	Mostly valleyheads.		
Topography	Sloping to flat; occasionally sumps.	May form zones above [10b].	Sometimes more or less surrounds examples of [10a].
Summer water level and main source	Primarily fed by groundwater, but summer WT often well below surface.		
Association with GW	Aquifer episodically at or near surface, but often low in summer.		
Association with watercourse (WC)	Often not associated with watercourses or, if so, elevated (well) above WC level.		
Association with upslope SW	May be some rain-generated run-off, but much infiltrates into ground above site, or is intercepted by catchwater drains.		
Surface flooding	Rare or absent.		
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Not visible		
Summer water outflow from (sub-)site	Not visible.		
Dept of PAL	Mostly very shallow.		
PAL 'permeability'	Amorphous peat or mineral deposit of moderate to low permeability.		
Basal substratum 'permeability'	Sands and gravels to sandy clays of moderate to low permeability. May be similar to [10] or less permeable.	Sands, gravels and sandy loams.	Sandy loams to sandy clays.

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 12	12: Fluctuating Seepage Basins	12a-e
Key character combination	Small sumps with strongly fluctuating WT, often from well below surface to flooded, which may relate to aquifer levels. Like [11] but topography permits sustained inundation.	Sub-types distinguished informally based on water regime in sump.
Example sites		
Landscape context	Valleyheads and basins	
Topography	Shallow sumps (differs from [11] by having swamp / standing water for at least part of year).	
Summer water level and main source	Mainly GW fed. WT variable, depending on topography and aquifer level; fluctuates strongly	Sub-types distinguished informally based on water regime in sump.
Association with GW	Aquifer episodically at, above or near surface. Water level sometimes in (slow) equilibrium with aquifer level, but relationship sometimes obscure	
Association with watercourse (WC)	Mostly not associated with water courses, but sometimes lateral to, and above, WC.	
Association with upslope SW	Little evidence for SW inflows (except where sumps have been connected by drains).	
Surface flooding	Usually inundated episodically (some drained examples are 'dry' year round and difficult to distinguish from [11]).	
Water flow: within stand (IS);	IS: Not visible	
from stand (OS)	OS: Usually none except when water tables are very high; outflow sometimes through drains.	
Summer water outflow from (sub-)site	Usually none except when water tables are very high; outflow sometimes through drains.	
Dept of PAL	Very shallow to moderate	
PAL 'permeability'	Amorphous organic material. Variable permeability, but mostly moderate.	
Basal substratum 'permeability'	Mostly sands and gravels to sandy clays of moderate permeability; some evidence for low permeability layers in basin lining.	

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 13	13: Seepage Percolation Basins	13a: Seepage Percolation Surface	13b: Seepage Percolation Quag
Key character combination	Unconsolidated (quaking / buoyant) surface in GW-fed basins and sumps etc. Similar surface to [6] but GW-fed, and to [14] but flatter and more 'water collecting'.	Ill-defined: fairly solid surface, or buoyant but v small (and often embedded within [10]).	The 'typical' state: quaking or buoyant surface over rhizome mat; wet for much of year, but often not much flooded.
Example sites		Badley Moor, Cothill Fen, Stoney Moors, Whitwell Common, Wilverley Bog	Arne Moors, Bryn Mwcog, Cors Goch, Cors y Farl, East Walton Common, Malham Moss, Parc Newydd, Shortheath Common, Silver Tarn, Smallburgh Fen, Sunbiggin Tarn and Moors
Landscape context	Basins, floodplain margins, sometimes in small depressions in valleyheads	Basins or small depressions in valleyheads..	Basins and sumps, rarely floodplain margins.
Topography	Sumps (or 'flat' areas in larger basins). Some examples in valleyheads may be embedded within slopes of [10].		
Summer water level and main source	Near surface. Mainly GW fed		
Association with GW	Springs and seepages often visible around periphery, or aquifer head at or above wetland surface.	May be embedded within seepages [10].	
Association with watercourse (WC)	Either not associated with water courses or fairly distant from them; when present, water level in WC may influence water level in basin.		
Association with upslope SW	May be some RGR, but much infiltrates into ground above site; some examples have small drain inflows.		
Surface flooding	Surface sometimes flooded (but buoyant surface often accommodates WT change)		
Water flow: within stand (IS); from stand (OS)	IS: Not visible OS: Sometimes visible outflow		
Summer water outflow from (sub-)site	Often visible outflow (in streams etc sourced by WETMEC).		
Dept of PAL	Shallow to moderate.	Mostly shallow	Often deep
PAL 'permeability'	Often quite permeable, loose, quaking or semi-floating; sometimes more 'solid'. Often in turf ponds, over more solid basal peat of lower permeability.	Solid or quaking	Loose, quaking or semi-floating
Basal substratum 'permeability'	Sands, gravels etc, but basin often with marl or gyttja.		Often thick deposits of marl or gyttja.

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 13 (cont.)	13c: Seepage Percolation Water Fringe	13d: Distributed Seepage Percolation Surface	WETMEC 14: Seepage Percolation Troughs
Key character combination	As [13b] but encroaching directly upon open GW-fed water body; may also receive upslope GW outflow.	As [13b] but basins not directly GW fed (receive GW outflow distributed by the SW system).	Soft or quaking (rarely buoyant) surfaces in GW-fed valleyheads and troughs. More sloping than [13] (which may occupy sumps embedded in [14]).
Example sites	Barnby Broad, Cors Erddreiniog (Llyn yr wyth Eidion), Cors y Farl, Sunbiggin Tarn, Upton Broad	Broad Fen, Dilham, Upton Fen & Doles	
Landscape context	Basins and lake margins	Floodplain margins	Valleyheads, occasionally in troughs.
Topography			Trough
Summer water level and main source	Much water is from GW-fed water body.		Mainly GW fed. WT at or near surface for much of the year.
Association with GW	May be fed by GW outflow upslope.		High GW table (aquifer head may be well above wetland); sometimes lateral springs and seepages visible.
Association with watercourse (WC)			No water course, or remote and well below surface (may be endotelmic water-track or stream within [14]).
Association with upslope SW		Groundwater distributed by SW system. May be small SW inflows. Level in dykes often high (maintained by sluices etc).	May be some rain-generated run-off into [14], but much infiltrates into ground above site.
Surface flooding			Flooding under extreme conditions.
Water flow: within stand (IS); from stand (OS)			IS: Occasionally visible, but not normally OS: Often visible
Summer water outflow from (sub-)site			Often strong outflow.
Dept of PAL	Deep to shallow, depending on location.	Often deep	Shallow to deep.
PAL 'permeability'	Loose, quaking or semi-floating	Loose, quaking or semi-floating.	Spongy to strongly quaking; mostly quite permeable.
Basal substratum 'permeability'	May be layers of marl or gyttja.	May be thick deposits of marl or gyttja.	Often moderately permeable sands, gravels and sandy loams, but examples on deep peat may have basal clays etc of low permeability.

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 15	15: Seepage Flow Tracks	15a: Topogenous Seepage Flow Tracks	15b: Sloping Seepage Flow Tracks
Key character combination	GW-fed flow paths in mires, often embedded in [14] but occasionally alone. Unconsolidated watery surface	Flattish flow paths on deep peat	Usually sloping flow paths, mostly on shallow peat and over permeable material.
Example sites	Many New Forest mires, Bicton Common, Cors Geirch, Cors Graianog, Cors Gyfelog, Folly Bog, Great Ludderburn Moss, Hartland Moor, Thursley Common etc	Many New Forest mires, Bicton Common, Thursley Common	Beeston Bog, Clayhill Bottom, Cors Geirch, Roydon Common, Stoney Moors
Landscape context	Mainly valleyheads, but in all (semi-) topogenous contexts.		
Topography	Trough. Often embedded within [14] but can be with other WETMECs or (rarely) alone.		
Summer water level and main source	Mainly GW fed. WT at surface (this, plus greater flow rates and wider topographical context, is main distinction from [14]).		
Association with GW	High GW table (aquifer head may be well above wetland); sometimes lateral springs and seepages visible.		
Association with watercourse (WC)	No water course, or remote and well below surface (WETMEC is itself an endotelmic flowpath).		
Association with upslope SW	May be some rain-generated run-off, but much infiltrates into ground above site.		
Surface flooding	Normally with surface water		
Water flow: within stand (IS); **from stand (OS)**	IS: Usually visible, sometimes strong OS: Visible, sometimes strong		
Summer water outflow from (sub-)site	Visible, often strong.		
Dept of PAL	Usually shallow, but occasionally deep.		
PAL 'permeability'	Mostly unconsolidated and very permeable; sometimes semi-floating.		
Basal substratum 'permeability'	Often quite permeable sands, gravels and sandy loams, but some examples on low-permeability clays etc	Silts, clays and sandy clays, or sands and gravels beneath deep 'solid' peat.	Sands, gravels and sandy loams.

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 16	16: Groundwater-Flushed Bottoms	16a: Groundwater-Flushed Bottom	16b: Groundwater-Flushed Bottom + Watercourse Inputs	16c: Groundwater Overflow Bottom
Key character combination	Surfaces in GW-flushed valleyheads and troughs. Often similar to [14] but over aquitard and often with thinner peat. Marginal springs / seepages often evident.	The typical form, without an associated WC (other than endotelmic flows).	Adjoins exotelmic WC – often well below surface, but sometimes floods.	GW outflow over low permeability swamped surface, sometimes delivered by GW-sourced streams.
Example sites		Dersingham Bog, Hyde Bog, Thursley Common, Winfrith Heath	Cridmore Bog, Matley Bog, Morden Bog, Retire Common, Pont-y-Spig	Benacre Broad, Leighton Moss, Rhôs Gôch Common, Westwood Marsh (Walberswick)
Landscape context	Valleyheads, broad basins and troughs.			
Topography	Flat			
Summer water level and main source	Fed mainly by marginal springs and seepages. WT usually near surface ('dry' examples transitional to [8]).			Fed by flooding from springs or GW-sourced streams. WT often at or above surface.
Association with GW	Springs and seepages along margins			
Association with watercourse (WC)	Some adjoin watercourses. WC level usually well below wetland surface, but may help regulate WT and have an episodic supply function.	No adjoining watercourses (though may have endotelmic water-tracks or drains).	Adjoining streams or drains. WT of these mostly (well) below wetland surface.	
Association with upslope SW	May be some rain-generated run-off, but much infiltrates into ground above site, or intercepted by catchwater drains.			Adjoining streams or drains; fed in part from springs.
Surface flooding	Some experience periodic, shallow winter flooding.	Normally only associated with artificial barriers	Occasional flooding from WC in wet conditions in some sites.	Regular (sometimes more or less permanent) surface flow.
Water flow: within stand (IS); from stand (OS)	IS: None visible OS: Rarely visible			
Summer water outflow from (sub-)site	Sometimes visible.	Some have quite strong outflows.	Outflows often not very obvious	
Dept of PAL	Mostly fairly shallow.			Shallow, sometimes recent, peat over aquitard.
PAL 'permeability'	Usually permeable, fresh and spongy, but less permeable where drier and more consolidated.			Loose, sometimes quaking.
Basal substratum 'permeability'	Mainly low-permeability clay, silts and sandy clays.			

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 17	17: Groundwater-Flushed Slopes	17a: Groundwater-Flushed Slopes	17b: Weakly GW-Flushed Slopes	17c: Distributed GW- Flushed Slopes	17d: Groundwater-Flushed Flow Tracks
Key character combination	GW-flushed slopes (rarely flats) with thin peat over aquitard, below springs or seepage line (often narrow).	Summer-'wet' surface, sometimes with visible flow.	Summer-dry surface, without visible flow	Summer-dry surface distant from GW outflows where GW-sourced streams etc. may provide some recharge	GW-fed flow paths, often embedded in [17a/b] but occasionally alone. Unconsolidated or watery surface.
Example sites		Acres Down, Banc y Mwldan, Buckherd Bottom, Retire Common, Stoborough Heath, Ventongimps Moor, Widden Bottom	Ashculm Turbary, Cors Llyn Coethlyn, Dowrog Common, Great Candlestick Moss, Hense Moor, Retire Common,	Retire Common, The Moors (Bishop's Waltham)	Bicton Common, Buckherd Bottom, Landford Bog, Stoborough Heath, Tarn Moor, Sunbiggin, Ventongimps Moor
Landscape context	Valleyheads and hillslopes.				
Topography	Sloping (occasional pans).				Often quite strongly sloping.
Summer water level and main source	Mainly fed by (near-) surface GW flow. WT at surface when wet; can be seasonally dry.	At surface	Often undetectable	WT often well below surface	WT at, near or just above surface.
Association with GW	Usually visible springs or seepages above flush.		Seepages not always visible in dry conditions.	GW distributed by small streams which help recharge adjoining wetland. WT in streams may be well below wetland surface.	Collects near-surface flow of GW from springs or [17a/b].
Association with watercourse (WC)	May be watercourse in valley bottom, but usually well below stand surface.				WETMEC itself forms an endotelmic flow-path.
Association with upslope SW	May be rain-generated run-off.				
Surface flooding	None, but may be surface water in wetter examples in runnels etc.				
Water flow: within stand (IS);	IS: Sometimes visible	IS: Sometimes visible	IS: Not visible	IS: Not visible	IS: Usually visible where surface water occurs.
from stand (OS)	OS: Sometimes visible	OS: Visible in runnels	OS: Rarely visible	OS: Flow may be visible in streams or drains, which may either drain or recharge stand.	OS: Usually visible
Summer water outflow from (sub-)site	Often not visible in dry conditions.	Sometimes visible	Sometimes visible	Flow may be visible in outflow streams or drains.	Usually visible.
Dept of PAL	Very shallow, skeletal.				
PAL 'permeability'	Amorphous peat or clay, silts and sandy clays. Permeability correspondingly variable.				Vegetation rooted onto 'solid' material, or quaking, soft or buoyant.
Basal substratum 'permeability'	Low-permeability clay, silts and sandy clays.				

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 18	18: Percolation Troughs	WETMEC:19: Flow Tracks
Key character combination	Like [14] but fed mainly by RGR or streams, or importance of GW not clear. May be some GW outflow from a minor, superficial aquifer.	Like [15] but fed mainly by RGR or streams, or importance of GW not clear. May be some GW outflow from a minor, superficial aquifer.
Example sites	Birk Bank Moss, Cliburn Moss, Cors Graianog, Cors Gyfelog (Gyfelog Farm and NW arm), Eycott Hill, Knott End Moss, Silver Tarn, Stable Harvey Moss	Birk Bank Moss, Bowscale Moss, Cliburn Moss, Cors Gyfelog , Cors y Llyn, Eycott Hill, Great Candlestick Moss, Knott End Moss, Stable Harvey Moss, Wybunbury Moss
Landscape context	Valleyheads, occasionally in troughs.	Mainly valleyheads, but in all (semi-) topogenous contexts.
Topography	Trough	Trough. Often embedded within [18] but can be with other WETMECs or (rarely) alone.
Summer water level and main source	Mainly SW fed, or importance of GW not clear. WT at or near surface.	Mainly SW fed, or importance of GW not clear. WT at or above surface (this, plus greater flow rates is main distinction from [18].
Association with GW	Lateral springs, and flushes sometimes visible. Minor superficial aquifer or none.	May be associated with minor superficial aquifer, or none; sometimes lateral springs and seepages visible.
Association with watercourse (WC)	No water course, or remote and well below surface (may be endotelmic water-track or stream within [18]).	No water course, or remote and well below surface (WETMEC is itself an endotelmic flowpath).
Association with upslope SW	RGR and land-drainage inflows; may contain a component of GW outflow, usually sourced (well) upslope.	RGR and land-drainage inflows; may contain a component of GW outflow, usually sourced (well) upslope.
Surface flooding	Flooding under extreme conditions, especially adjoining [19].	Normally with surface water.
Water flow: within stand (IS);	IS: Occasionally visible, but not normally OS: Often visible	IS: Usually visible, sometimes strong
from stand (OS)		OS: Visible, sometimes strong
Summer water outflow from (sub-)site	Often strong outflow.	Visible, often strong.
Dept of PAL	Shallow to deep.	Shallow to deep, depending on topographical context.
PAL 'permeability'	Spongy to strongly quaking, of quite high permeability.	Highly permeable, unconsolidated; sometimes semi-floating.
Basal substratum 'permeability'	Mostly over clays and silts, or presumed low-permeability bedrock.	Mostly over clays and silts, or presumed low-permeability bedrock.

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

WETMEC 20	20: Percolation Basins	20a: Percolation Quag	20b: Percolation Water Fringe
Key character combination	Like [13] but fed mainly by RGR or streams, or importance of GW not clear. Some inflows may be sourced from GW outflows above the site.	The typical form of [20], in basins, mostly fed by water inflow from upslope	Adjoining open water and receiving water from this, which may have different provenance to upslope sources
Example sites		Cors Gyfelog , Dowrog Common, Emer Bog, Eycott Hill, Hollas Moss, Llyn y Fawnog, St. David's Airfield Heaths, Trefeiddan Moor	Betley Mere, Dowrog Common, Cors Llyn Coethlyn
Landscape context	Basins		
Topography	Flat		
Summer water level and main source	WT at or near surface, fed mainly by SR, some of which may be sourced by GW outflow.		
Association with GW	More or less confined or v. minor aquifer, or none; sometimes springs and seepages visible, usually well upslope.		
Association with watercourse (WC)	Mostly not associated with water courses.		Water body irrigates stand. Provenance of water in this may be different to any upslope sources
Association with upslope SW	RGR and land-drainage inflows. May be partly sourced by GW outflow (well) upslope.	Mostly fed from upslope telluric sources	May also receive water from upslope telluric sources
Surface flooding	Surface sometimes flooded.		Normally with surface water
Water flow: within stand (IS);	IS: Not visible		
from stand (OS)	OS: Sometimes visible		
Summer water outflow from (sub-)site	Sometimes visible		
Dept of PAL	Shallow to deep		
PAL ‘permeability’	Often highly permeable, unconsolidated, quaking or semi-floating.		Typically very unconsolidated and unstable, but may be rooted swamp rather than buoyant surface
Basal substratum ‘permeability’	Mostly over clays and silts, or presumed low-permeability bedrock.		

Abbreviations: GW = groundwater; K = hydraulic conductivity; SW = surface water; RGR = rain-generated runoff; WC = water course; WT = water table

Table 6.3 Percentage occurrence of the main herbaceous wetland NVC community types in individual WETMECs

WETMEC	Domed Ombrogenous Surfaces	Buoyant Ombrogenous Surfaces	Buoyant, Weakly Minerotrophic Surfaces	Drained Ombrotrophic Surfaces (bogs and fens)	Summer-Dry Floodplains	Surface-Water Percolation Floodplains	Groundwater Floodplains	Groundwater-Fed Bottoms with Aquitard	Groundwater-Fed Bottoms	Permanent Seepage Slopes	Intermittent And Part-Drained Seepages	Fluctuating Seepage Basins	Seepage Percolation Basins	Seepage Percolation Troughs	Seepage Flow Tracks	Groundwater- Flushed Bottoms	Groundwater-Flushed Slopes	Percolation Troughs	Flow Tracks	Percolation Basins
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NVC																				
M04			45									9		9		9	9			18
M05						6					6	6	38	6		6		6		25
M09							3	3	2	3			44	2	6			17	14	6
M10										57					10		29		5	
M13									6	49	7	1	29		2		5			
M14										24	4		4		48		16		4	
M18	65	35																		
M21		1								24	4		4	22	19	13	11	2	1	
M22					5	3	4	4	6	22	30	6	6	2	1	5	8			
M24				6	3		10	8	19	3	42					2	6			
M29										6					56		6		25	6
S01												60	40							
S02						9						36	55							
S24					46	41	3	1					6		1	2				1
S27			5	3	5	15						5	21	3		8		10		21

WETMECs have been colour-coded by group as in the cluster dendrogram in Figure 6.1*.*

6.3 Content of WETMEC accounts

The following information is presented for each WETMEC:

Outline	Summary statement of the character of the WETMEC.
Occurrence	Summary of distribution in England and Wales (with map), with lists of sites sampled for this project.
Summary characteristics	Main distinctive features. Illustrated by schematic sections across the WETMEC.
Concept and description	Main features of the unit, with particular reference to hydrological mechanisms. Includes points of difference and similarity to other WETMECs. Details of the 'CLUSTAN clusters' on which it is based (and their derivation) are given in Chapter 4 and Appendix 2.
Origins and development	Details of how each WETMEC is thought to have formed and developed over time.
Situation and surface relief	A description of the main topographical situations in which each WETMEC occurs.
Substratum	Details of the main substratum types, including wetland infills (such as peat, lake muds) and basal substratum (drift/solid geology).
Water supply mechanisms	Main water sources and an assessment of the mechanism of water supply.
WETMEC sub-types	Major variations (usually equating to a separate CLUSTAN cluster) on the main water supply mechanism.
Ecological characteristics	A brief account of the ecological characteristics of each WETMEC, with particular focus on features specifically associated with them.
Ecological types	A summary of the main ecological types found in examples of the WETMEC based on permutations of three base-richness and three fertility categories. Only the main permutations are presented.
Naturalness	The 'naturalness' of each WETMEC is identified: its natural status within the landscape and any major modifications to this that have occurred frequently.
Conservation value	Main features of recognised conservation importance, including the main herbaceous wetland vegetation types, EU Habitats and uncommon species associated with each WETMEC. This material is not comprehensive.
Vulnerability	Some of the key threats to each WETMEC are identified.

Table 6.4 EU SAC-habitat types thought to be supported by the WETMECs at the sites included in this study

WETMEC *SAC feature*	1 Domed Ombrogenous Surfaces	2 Buoyant Ombrogenous Surfaces	3 Buoyant Weakly Min. Surf.	4 Drained Ombrogenous Surfaces	5 Summer-Dry Floodplain	6 SW Percolation Floodplain	7 GW Floodplain	8 GW-Fed Bottoms + Aquitard	9 GW-Fed Bottoms	10 Permanent Seepage Slopes
Active raised bogs	✓	✓								
Alkaline fens						✓		✓	✓	✓
Calcareous fen					✓	✓	✓	✓	✓	?
***Molinia* meadows**				?	✓		✓	✓	✓	✓
Depressions on peat substrates										?
Transition mire and quaking bogs		✓	✓		✓	✓				?

	11 Intermittent and Part-Dr. Seepages	12 Fluctuating Seepage Basins	13 Seepage Percolation Basins	14 Seepage Percolation Troughs	15 Seepage Flow Tracks	16 Groundwater-Flushed Bottoms	17 Groundwater-Flushed Slopes	18 Percolation Troughs	19 Flow Tracks	20 Percolation Basins
Active raised bogs										
Alkaline fens	✓	✓	✓		✓		✓			
Calcareous fen		✓	✓							
***Molinia* meadows**	✓					✓	✓			
Depressions on peat substrates	✓		✓	✓	✓	✓	✓	✓	?	

	11 Intermittent and Part-Dr. Seepages	12 Fluctuating Seepage Basins	13 Seepage Percolation Basins	14 Seepage Percolation Troughs	15 Seepage Flow Tracks	16 Groundwater-Flushed Bottoms	17 Groundwater-Flushed Slopes	18 Percolation Troughs	19 Flow Tracks	20 Percolation Basins
Transition mire and quaking bogs			?		✓	✓	✓	✓	✓	✓

Note: this table is not necessarily exhaustive, and there are uncertainties in the scope and occurrence of some types.
Full names of WETMECs can be found in Table 6.1. Full names of the SAC interest features and their representation in the study sites are given in Table 3.3.

6.4 WETMEC 1: Domed Ombrogenous Surfaces ('raised bog' sensu stricto)

6.4.1 Outline

This unit includes spongy peat surfaces that have developed under the exclusive influence of precipitation upon a deep, and typically domed, deposit of ombrogenous peat, mostly elevated well above the regional water table, or adjoining surface water sources, and little influenced by these, if at all. A schematic section is provided in Figure 6.4.

6.4.2 Occurrence

Example sites: Bowness Common, Bowscale Moss, Fenns Whixall and Bettisfield Mosses, Flaxmere Moss, Great Ludderburn Moss, Tarn Moss (Malham), Meathop Moss, Nichols Moss, Rhôs Gôch Common, Walton Moss, Wedholme Flow

Outlier sites: Cliburn Moss

Most of the samples clustered within this WETMEC were from the large raised bogs in the North and North-West of England, with the exception of Rhôs Gôch (mid-Wales) (Figure 6.3).

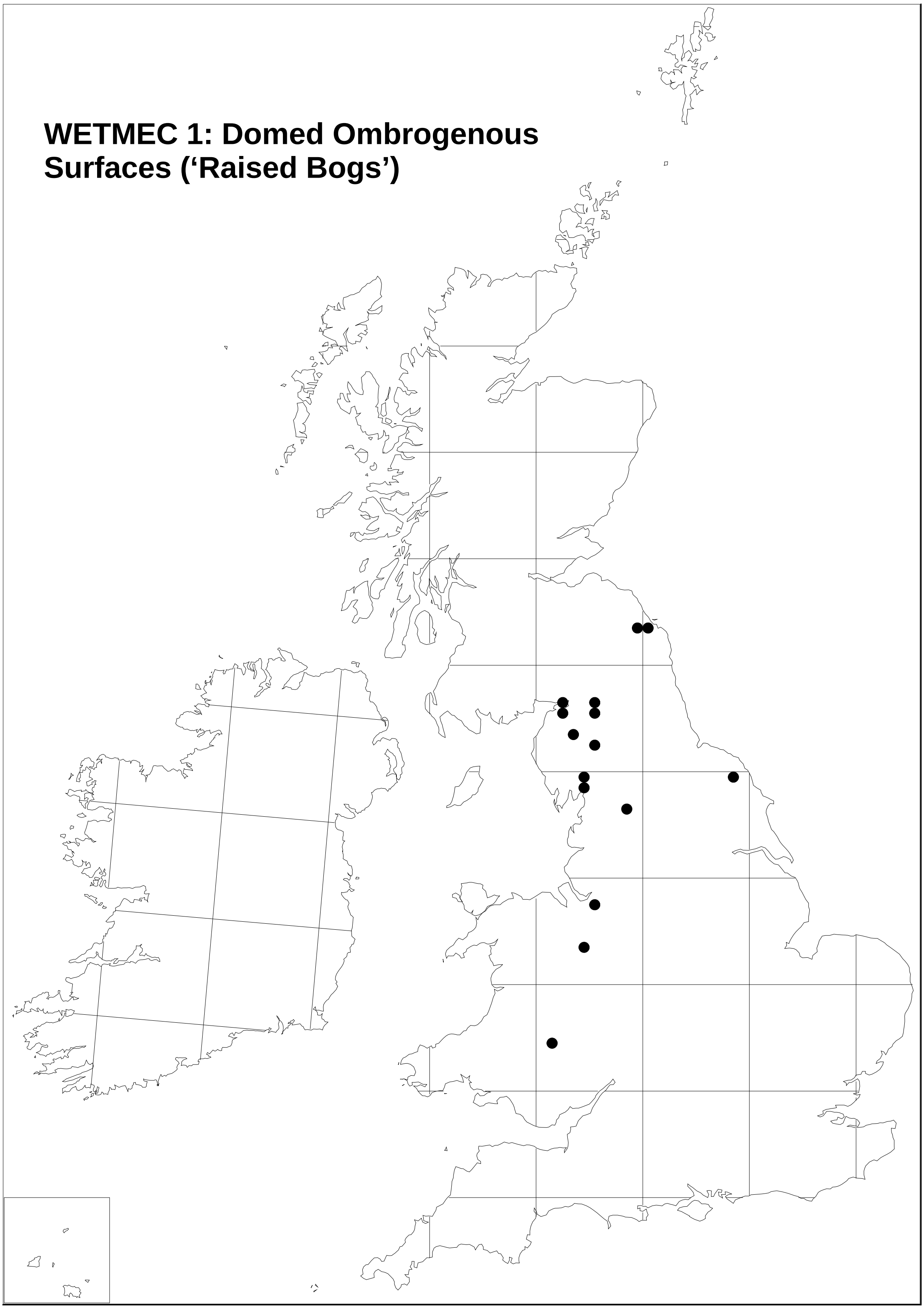


Figure 6.3 Distribution of examples of WETMEC 1 in sites sampled in England and Wales

6.4.3 Summary characteristics

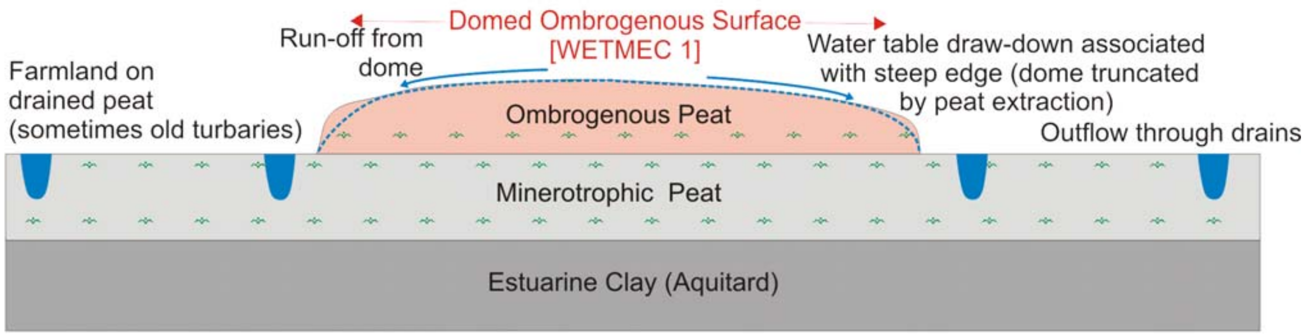
Situation		Basins, floodplains and flats
Size		Often large (for example, above 100 ha).
Location		Mostly sampled from North and West.
Surface relief		More or less domed, locally with quite steep slopes, especially near the periphery (rand); shallow pools, lawns and hummocks may provide a locally well-developed micro-topography; undulations are often associated with drainage or peat removal.
Hydrotopography		Ombrogenous.
Water:	***supply***	Precipitation (perhaps supported by regional water table).
	regime	Water levels naturally vary across the surface and with time, especially with rainfall patterns, but are typically relatively stable, and near-surface.
	distribution	Lateral flow to margins through surface layer; some vertical flow downwards into main peat deposit.
	superficial	Shallow pools, occasional soakways; sometimes drains.
Substratum		Ombrogenous peat often upon fen peat. Underlain by clays, fluvio-glacial deposits and so on.
	peat depth	Typically 2–12 m.
	peat humification	Usually with a shallow (0.5 m) spongy surface (acrotelm); underlying catotelm more humified and often solid, especially lower down, though some fresh horizons may occur.
	peat composition	Ombrogenous peat (with *Sphagnum* spp., *Eriophorum* spp. and ericaceous shrubs) upon fen peat.
	permeability	Surface layer (acrotelm) typically fairly permeable, much more so than lower layer (catotelm). Basal substratum variable, but usually low permeability.
Ecological types		Oligotrophic, acidic.
Associated WETMECs		Some examples can form a complex with various other WETMECs, especially in the peripheral lagg (if present) (such as WETMECs 15 and 19). Sometimes juxtaposed with WETMEC 2 (the latter in turf ponds).
Natural status		Natural successional state formed by both terrestrialisation and paludification. Appears to form a self-maintaining climax condition (but all examples damaged to some degree by drainage/peat cutting and so on).
Use		Conservation. Some examples provide rough grazing. More remunerative use is associated with damage and conversion to a degraded state (such as WETMEC 4).
Conservation value		Supports examples of EU priority habitat (active raised bog). Vascular plant species diversity is generally low (sometimes enhanced by damage).
Vulnerability		Direct drainage and peat extraction. Drainage of the surroundings may be detrimental in some circumstances.

WETMEC 1: DOMED OMBROGENOUS SURFACES

No WETMEC sub-types have been identified for WETMEC 1, but examples vary considerably in their topographical context. Examples of this are illustrated here. The two contexts shown on this page represent the two most characteristic situations in which WETMEC 1 occurs in lowland England and Wales. The two basin contexts on the next page are quite widespread, but are less good examples of WETMEC 1 in that they have some affinities with WETMEC 2, differing mainly in the stability of the surface and solidity of the underlying infill. Some such samples of WETMEC 1 in small basins may represent partly drained examples of WETMEC 2.

WETMEC 1: ombrogenous dome on flood-plain or coastal plain
(*e.g.* Meathop Moss)

- WETMEC 1 surface is fed ± exclusively by precipitation and drains radially; shape of dome is independent of underlying topography
- dome has been truncated by turbary, creating steep dry edges and water drawdown around the periphery of the bog
- bog is surrounded by drained (minerotrophic) peat, some of which was once covered by bog peat, and which now forms farmland
- water levels in the drains can potentially affect the bog water table, but the extent to which this is the case depends on local factors (especially peat hydraulic conductivity and topography)



WETMEC 1: ombrogenous dome within drumlin field
(*e.g.* Bowness Common, Wedholme Flow)

- WETMEC 1 surface is fed ± exclusively by precipitation and drains radially to a narrow peripheral lagg
- mire was initiated in two basins, but has coalesced by growth of ombrogenous peat over the separating ridge
- dome of bog is not fully independent of underlying topography; it is not known if this represents the natural condition or is a product of subsidence and local reconformation consequent upon surface drainage

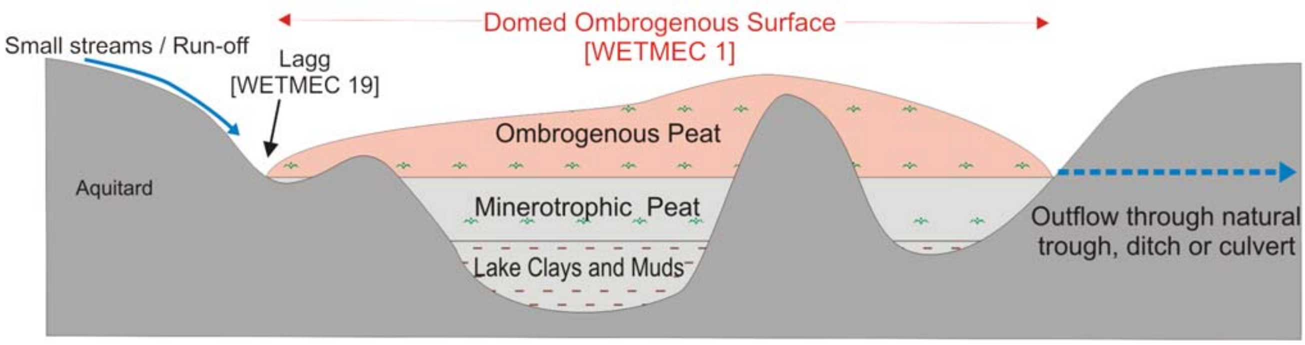


Figure 6.4 Schematic sections of a Domed Ombrogenous Surface (WETMEC 1)

6.4.4 Concept and description

CLUSTER: 1

This WETMEC encompasses peat surfaces which have become isolated (by long-term peat accumulation) from telluric water influences and which are fed directly and exclusively by precipitation. Impeded drainage of precipitation inputs produces a perched mound of stored rainwater within the peat, elevated above the regional groundwater table and surface water sources. The accumulation of the ombrogenous peat deposit and its associated rainwater mound proceed hand-in-hand. In flattish topogenous situations (such as floodplains or basins), it results typically in the development of a hemi-elliptical deposit of ombrogenous peat, often referred to as a 'raised bog' ('topogenous bog' *sensu* Wheeler and Shaw, 1995a).

The typically domed conformation of a raised bog presents a range of topographical conditions for individual stands, ranging from virtually flat surfaces to quite steep slopes. The latter are particularly found at the edge of the deposit, and can be part of a natural edge structure known as a *rand.* However, the steep edges of many ombrogenous deposits found nowadays are not natural, but a product of peripheral peat extraction. At Tarn Moss (Malham, Yorkshire) there is a particularly prominent, steep rand along much of the northern margin of the bog, which appears to be a product of truncation, or even erosion, of the bog peat by the adjoining Tarn Beck. In the 'classic' concept of a raised bog, as described by Weber (1908), the dome of ombrogenous peat is surrounded by a peripheral moat of fen known as a *lagg*. In some cases, this represents a minerotrophic habitat similar to that from which the ombrogenous dome originally developed. Although often informally incorporated within the concept of a 'raised bog', the lagg is not considered here to be an integral part of this concept because it has different, and independent, water supply mechanisms (such as WETMECs 3, 15 and 19), and because it is not clear that a lagg is a necessary associate of an ombrogenous dome (except in the trivial sense that minerotrophic conditions always occur at the junction between ombrogenous peat and adjoining minerotrophic peat or mineral ground). As with the rand, assessment of the natural status of the lagg can be difficult, because the natural margins of many candidate ombrogenous deposits have been destroyed or modified by peat extraction or agricultural conversion.

The surface of ombrogenous bogs is variably patterned, mainly in relation to variation in water conditions (Lindsay *et al*., 1988). In the range of examples considered here, most of the main surface features can be categorised into hummocks, lawns, hollows and small pools. These microtopographical elements undoubtedly experience their own water regimes but they are all essentially rain-fed and as they frequently occur as a mosaic, they are often interdependent and not easily separated.

Sites allocated to this WETMEC include some of the largest remaining raised bogs in England and Wales. These can have thick accumulations of ombrogenous peat, sometimes forming a dome several metres above the surrounding land (and regional water table). However, a few bogs in small basins are also allocated here, with a much shallower ombrogenous dome. These sometimes have affinities to the semi-floating ombrogenous surfaces of WETMEC 2, and some examples occupy the same basins. They differ mainly in that their surface is generally drier and their substratum more solid, in some instances probably as a consequence of drainage. At Flaxmere and Moorthwaite Moss, samples from the more solid ombrogenous peat clustered within WETMEC 1 whilst samples with strongly quaking surfaces, thought to be old turf ponds, clustered with WETMEC 2.

Affinities and recognition

The samples allocated to this unit formed a distinctive cluster (Figure 6.1) with little internal variability (all samples were allocated to the same, single cluster at the 72-cluster stage of the analysis as well as at the 36-cluster stage). The key diagnostic features are the occurrence of a deposit of relatively firm peat elevated well above the level of any adjoining sources of telluric water and with a fairly high summer water table (thereby distinguishing samples from the drier surfaces of the drained sites referred to WETMEC 4 (Drained Ombrotrophic Surfaces in bogs and fens)). In many cases, the ombrogenous surface is some two metres or more above telluric water sources, though in others the height difference is less.

The main difference between WETMECs 1 and 2 is that the peat in WETMEC 1 is mostly solid, sometimes with a spongy surface, whereas in WETMEC 2 (Buoyant Ombrogenous Surfaces) the deposit is much less consolidated and the surface is buoyant or quaking. Water table fluctuations in WETMEC 1 are dominated by the effects of atmospheric exchanges (precipitation and evapotranspiration), coupled with the hydroregulatory properties of the acrotelm, whereas those in WETMEC 2 are much more influenced by fluctuations in the level of the – often telluric – water table of the wetland basin as a whole, frequently coupled with raft-based hydroregulation in which the surface of the peat raft to some extent moves with the rise and fall of the underlying water table. The majority of WETMEC 2 sites occupy small basins, have only a shallow ombrogenous layer, and correspond to what have sometimes been called ‘basin bogs’, whereas many WETMEC 1 sites are less obviously associated with basins and correspond to what have often been called ‘raised bogs’. However, a number of WETMEC 1 sites do occupy some type of basin and the split between WETMECs 1 and 2 does not correspond exactly to the split between basin and non-basin sites. A few examples of WETMEC 1 occur in parts of small basins, where there are firm, sometimes rather dry, ombrogenous surfaces. In some instances (such as Flaxmere, Great Ludderburn Moss, Moorthwaite Moss), samples from solid surfaces that have not been dug for peat (or perhaps, dug less deeply) have clustered within WETMEC 1, whereas samples from recolonised turf ponds have clustered within WETMEC 2. Hence, whilst there appears to be a fundamental ecohydrological distinction between WETMECs 1 and 2, it is not possible to make a similarly clear distinction between ‘raised bogs’ and ‘basin bogs’.

With more samples in the analyses, it might be possible to make a clearer distinction between variations subsumed within WETMEC 1.

6.4.5 Origins and development

Ombrogenous surfaces referable to WETMEC 1 have developed in a variety of topographical contexts, including basins, troughs and floodplains. This has resulted in a series of rather different, and distinctive, developmental sequences (Table 6.5) all of which have led to the same essential WETMEC and which can be used for an ontogenic subdivision of the type.

Table 6.5 Ontogenic categorisation of ombrogenous bogs in lowland England and Wales

Note that only Ontogenic Types 1, 2 and 4 relate directly to WETMEC 1; Type 3 relates more directly to WETMEC 2, but this can be a precursor of WETMEC 1.

Ontogenic Type 1: Bogs of coastal, near-coastal and inland floodplains
- 1a: Bog development associated with coastal submergence
- 1b: Bog development associated with coastal emergence
- 1c: Bog development in other coastal and near-coastal contexts
- 1d: Bogs of inland floodplains and valley-bottom troughs

Ontogenic Type 2: Raised bogs in basins and valleyhead troughs
- 2a: Terrestrialisation basins
- 2b: Paludification basins

Ontogenic Type 3: Buoyant bogs in basins and valleyhead troughs
- 3a: Terrestrialisation basins
- 3b: Subsidence basins

Ontogenic Type 4: Bogs on irregular terrain

Ontogenic Type 1: Bogs of coastal, near-coastal and inland floodplains

Many of the large raised bogs considered here are associated with coastal or near-coastal plains, whereas few are associated with inland floodplains – Cors Caron (Ceredigion) (not included in this study) is perhaps the best example of a raised bog on an inland floodplain in England and Wales. Derelict raised bogs such as Holme Fen (Cambridgeshire) and Shapwick Heath (Somerset) are ostensibly inland, but they are actually parts of submergent floodplains that have been coastal during some periods of their post-glacial history. [Likewise some of the large inland raised bogs of the Forth valley (Scotland) have developed upon emergent, former coastal plains.]

Development of WETMEC 1 on coastal plains, floodplains and valley-bottom troughs (Type 1) is illustrated in Figure 6.5. In the floodplain and coastal plain context, the maximum extent of the ombrogenous dome appears to be fixed by constraints on lateral expansion created by episodic flooding of the margins with telluric water, so that the dome is separated from rivers (and so on) by a band of fen. In some circumstances, tributary watercourses crossing the floodplains laterally may also delimit, or separate, ombrogenous domes along the valley. In these circumstances, although the bog dome may be flanked or surrounded by fen, this lagg – if that is what it is called – is more a feature imposed upon the bog by independent hydrological events in its surroundings than a feature of the bog itself.

The distinction made here between bogs on inland floodplains and valley-bottom troughs is perhaps rather tenuous, but is intended to reflect differences between sites such as Cors Caron, where the bog domes flank a clear river floodplain, and those such as Bowscale Common (Cumbria) on a valley bottom drained by a rather small stream where the epithet of ‘floodplain’ is, perhaps, less appropriate. Nonetheless, the differences between the two types are only of degree, and in both cases the extent of the bogs is determined, at least in part, by axial and lateral watercourses.

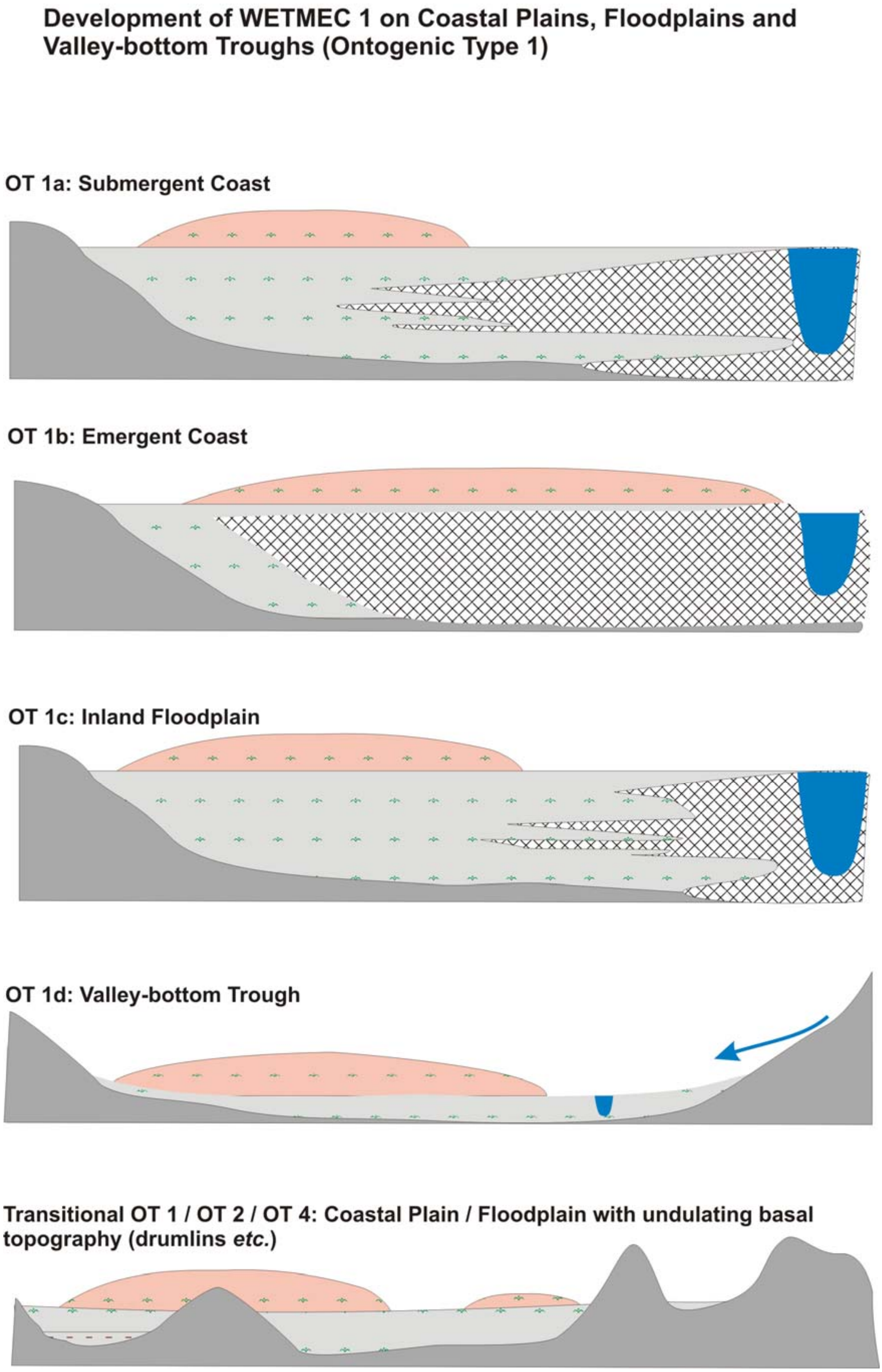


Figure 6.5 Development of WETMEC 1 on coastal plains, floodplains and valley-bottom troughs (Ontogenic type 1)

Ontogenic Type 2: Raised bogs in basins and valleyhead troughs

The wide variety of shapes and sizes of basins and troughs means that bogs developed within them also have a considerable range of forms, ranging from narrow, elongate mires (such as Esgyrn Bottom, Pembs.), to much broader and larger sites (such as Ford Moss, Northumberland; Red Moss, Greater Manchester). All, however, share the common feature of the mire being largely confined within a topographical basin, sometimes very obviously so (Figure 6.6).

Raised bogs in basins sometimes occur over more or less flat underlying deposits, especially where they have developed over former lake sediments or fen peat. However, the underlying topography of the basin can often be irregular, and peat accumulation across internal ridges and mounds, and on sloping surfaces, is a known feature of some mires allocated to this category, giving them some obvious similarities with the development of bogs on irregular terrain (Ontogenic Type 4). The difference between the two types is not in the height of the ridges over which coalescence has occurred, but whether the resulting mire surface remains topographically confined within a basin. The basin structure can also supervene other topographical features. For example, Danes Moss (Cheshire) is developed over a shallow interfluve and potentially drains in two directions, but the mire appears largely to be confined within a topographical basin and, for that reason, has been allocated to this category. Likewise, some mires in sloping troughs can have considerable developmental affinities with bogs on irregular terrain (Type 4). For example, the Fenn's and Whixall Moss complex has formed in an elongate, large trough. "*It is likely that peat formation began in the deeper hollows and then coalesced over intervening ridges to form more extensive deposits. The base of North East Fenn's Moss lies at a distinctly higher level and peat formation may have started later there when drainage to the south was impeded by the accumulation of peat in the centre of Fenn's Moss and in Whixall Moss*" (Berry *et al.*, 1996). The Fenn's and Whixall complex is larger than most examples of basin-like troughs, and has undoubted affinities with bogs on irregular terrain (Type 4), but it does occupy a 'macro-trough' and, on balance, we consider that Type 2 provides the most appropriate categorisation of this site. Such considerations highlight the intergradations that occur within raised bogs and the difficulty of extracting meaningful sub-categories of this type of mire.

The only consistent distinction to emerge within Ontogenic Type 2, on the basis of available data, is between examples that have developed primarily by terrestrialisation and those that have developed primarily by paludification, and even in this respect intermediates undoubtedly occur.

Bog development by terrestrialisation – serally from open water and through intermediate phases of swamp and fen – corresponds to the classic concept of raised bog as described by Weber (1908). Most such basins in lowland England and Wales have largely completely terrestrialised, but in a few instances open water persists lateral to the raised bog (such as Tarn Moss, Malham). Also, although lake sediments of varying character can be found beneath a number of raised bog sites, they do not necessarily form part of a continuous autogenic hydrosere that has progressed directly from open water to raised bog. This is perhaps most obviously the case at Thorne Moors (Humberside), much of which is underlain by the infilled glacial Lake Humber, but where raised mire development seems to have been uncoupled from this, occurring only when wet conditions had re-established after the lake deposits had become naturally partly drained and part-covered by alluvial and estuarine deposits. Some examples of this category which appear to be located more in troughs than in true basins occur over lake sediments that have infilled an underlying basin topography (such as Rhôs Gôch Common, Radnor).

Paludification basins represent troughs and basins in which there has been little or no terrestrialisation of open water, but where bog development has occurred as a consequence of deteriorating drainage. In some cases, only a thin layer of minerotrophic peat separates the ombrogenous peat from the underlying mineral soil, except perhaps in depressions in the basin bottom where deeper deposits of fen peat occur locally. In others, specific topographical and water supply circumstances have permitted the accumulation of thick deposits of minerotrophic peat before ombrotrophication has occurred (such as Esgyrn Bottom, Pembs).

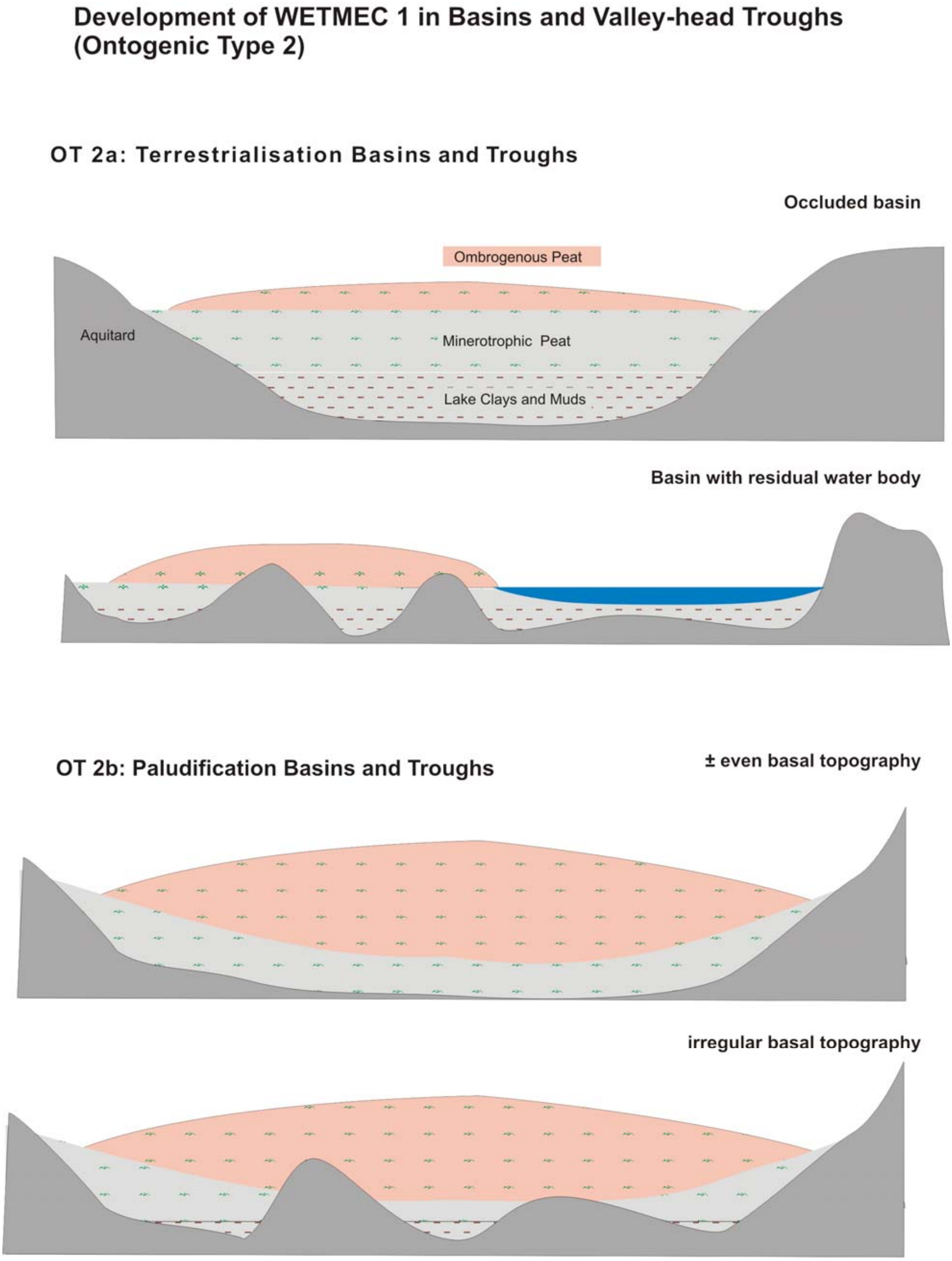


Figure 6.6 Development of WETMEC 1 on basins and valleyhead troughs (Ontogenic Type 2)

Ontogenic Type 4: Bogs on irregular terrain

This category contains some of the largest extant (and archaic) ombrogenous bogs in England. Its most distinctive feature is that peat formation appears to have been initiated in one or more hollows or depressions but has subsequently spread, as a minerotrophic or ombrogenous surface, across the flats, ridges and mounds separating these (Figure 6.7). A similar process has occurred in some Type 2 basins (such as Tarn Moss, Malham), but the distinctive feature of the Type 4 sites is that the ombrogenous surface has become partly or wholly unconfined (where its limits are not controlled by a high water table maintained within a macro-basin, as is the case at Tarn Moss, Malham).

This type of bog is strongly associated with an irregular underlying topography. It can occur in a variety of geomorphological contexts, but is particularly associated with extensive, undulating plains of Till and morainic material, shallow interfluves, undulating drumlin fields and sometimes kame and kettle complexes. The topography of the underlying ground is often masked by the accumulation of peat, and may become evident only on stratigraphical investigation. The most characteristic landscape type for this category is plateau–plains or, sometimes, hillslopes, but the basin–mound topography which dominates this bog category can be superimposed upon, or intergrade into, a range of landscape types.

Patterns of mire development vary considerably, but typically mire has been initiated, and initially contained, within shallow depressions by the terrestrialisation of shallow open water or – perhaps more frequently – by the gradual paludification of poorly drained hollows. The initial habitat was usually a form of minerotrophic mire, and in some topographical and water supply circumstances this persisted for quite a long period before being replaced by ombrogenous bog. This process was not substantially different from that described for bogs in basins (Type 2), and has shown much of the same variation, but the distinctive feature of this type of bog development is that subsequent accumulation of ombrogenous peat has expanded from one basin to the next, often leading to the formation of an extensive ombrogenous surface by coalescence. The precise mechanism of paludification in bogs on irregular surfaces may vary from site to site. In some it appears to have been polytopic in origin, with ombrogenous peat spreading from a number of initiation centres, though data on this are sparse.

Examples of bogs that have developed across ridges and mounds are provided by some of the large mosses bordering the Solway estuary, Cumbria (Bowness Common, Glasson Moss, Wedholme Flow) and may partly account for the slightly sloping, almost blanket-bog appearance presented by some of these (though Meade and Mawby (1998) present evidence that at Wedholme Flow former doming may have been lost or reduced as a consequence of past drainage). Many of the large mosses on the Till plains of West Lancashire have also developed by this process, along with others on fluvioglacial sands and gravels (such as Rixton and Risley Mosses). The precise character of the underlying topography varies considerably between and within sites. In some instances the sub-peat topography is rather subdued; in some, the underlying surface may have an overall slope to varying degrees (such as Rixton and Risley Mosses) (Leah *et al.,* 1997); in yet others, peat expansion has occurred from within deep depressions embedded within the plains (such as Chat Moss) (Birks, 1965; Hall *et al.*, 1995).

It is clear that bogs on irregular terrain can represent an ontogenically composite type of mire and can encompass variations which, if they occurred individually, would be allocated to one of the other categories (especially Type 2). As the extent to which spreading has occurred from bog initiation centres is strongly determined by the surrounding topography, examples of Type 4 bogs can occur in the same area as Type 2 bogs depending on their topographical circumstance. In this situation there may be little real difference between the two types, and it can be difficult to decide to which category certain sites belong – a difficulty frequently enhanced by removal or modification of peat from the vicinity around some apparent Type 2 bogs.

The development of bogs on irregular terrain is essentially comparable to the mechanism described by Moore and Bellamy (1974) as leading to the development of 'ridge-raised mires' (or 'intermediate mires' *sensu* Lindsay (1995)). It is possible that the capacity of ombrogenous peat to expand from initiation basins (the height of ridges and mounds that can be crossed) is partly dependent upon climatic circumstances, and one might expect that in wetter, cooler regions Type 4 bogs can form over greater irregularities in terrain. However, we are unable to make any consistent or sensible developmental distinction between examples of Type 4 bogs from Lancashire, Cumbria and parts of Central Scotland.

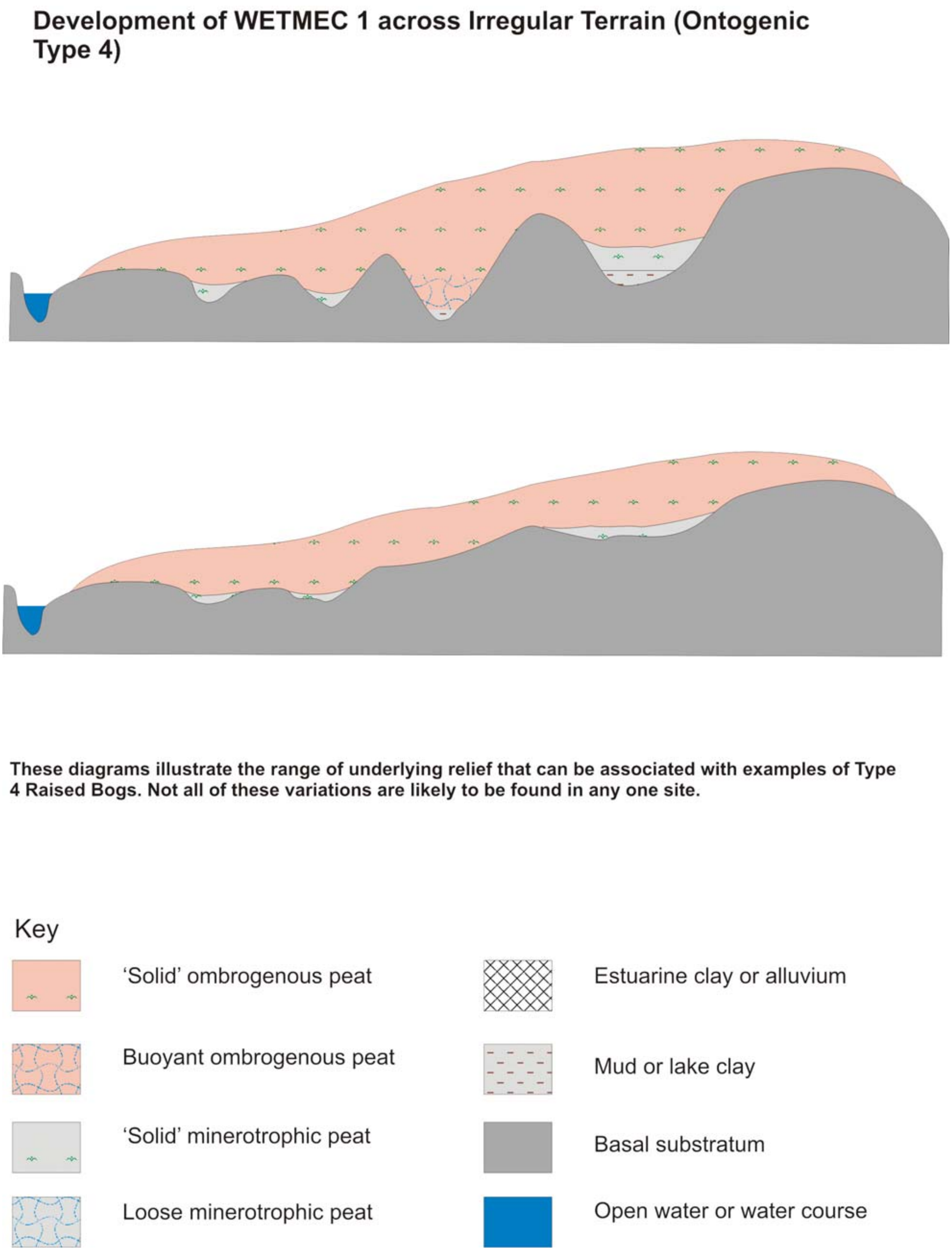


Figure 6.7 Development of WETMEC 1 across irregular terrain (Ontogenic Type 4)

Initiation and accumulation of ombrogenous peat

In most – perhaps all – instances, the ombrogenous conditions of WETMEC 1 have developed serally from a preceding minerotrophic phase of fen or wet woodland, though in some cases this has been rather short-lived and, probably often, not very base-rich (though a number of examples of WETMEC 1 have formed serally over calcareous deposits, as at Malham Tarn). The development of an ombrogenous surface is sometimes considered to represent the climax of the hydrosere, in climatically appropriate regions (such as Walker, 1970). However, in certain circumstances hydrological changes within the vicinity of ombrogenous deposits has led to their subsequent inundation with telluric water and a seral reversal resulting in the re-establishment of fen. Such 'flooding horizons' have been reported from the Somerset Levels (Godwin, 1941) and some other sites (such as Crymlyn Bog (Hughes and Dumayne-Peaty, 2002)).

Surface acidification and ombrotrophication can occur readily and rapidly in some terrestrialisation sequences upon a buoyant mat of vegetation, which neither much dries out nor becomes flooded by telluric water, thereby providing ideal conditions for the establishment of some species of *Sphagnum* (Tratt, 1998). This is more directly applicable to the establishment of WETMECs 2 (quag bogs) and 3 (transition bogs) than to WETMEC 1, but it is relevant for some examples of the latter which seem to have developed in the sequence WETMEC 3 > WETMEC 2 > WETMEC 1.

Most examples of WETMEC 1 appear to have originated from relatively solid peat surfaces, where the process of acidification and *Sphagnum* establishment may have been a more protracted process than in buoyant contexts, especially in the drier climatic range of WETMEC 1. The process seems generally to be envisaged as resulting from the accumulation of tumps of peat or tussocks of vegetation above the normal influence of telluric water, and a concomitant switch to an exclusively precipitation-fed surface on which the accumulation of – now ombrogenous – peat is able to continue. At the present time, rain-fed (ombrotrophic) surfaces in fens can be produced by drainage or disruption of the telluric water supply (WETMEC 4), but these are relatively dry, do not appear to accumulate peat, and are not examples of WETMEC 1. However, Hughes (2000) has pointed out that the fen-bog transition in stratigraphical sequences of some raised bogs is marked by a horizon suggestive of comparatively dry conditions, and he has speculated that ombrotrophication could have been initiated in response to a drop of the mire water table. This possibility cannot be discounted, but nor does it need to be invoked to account for the observed stratigraphical features: in non-buoyant contexts the fen–bog transition may normally, and perhaps necessarily, proceed *via* a phase of water table instability and autogenically induced low summer water tables, during the hydrological inter-regnum as the mire surfaces switches from a telluric water-based to a *Sphagnum* acrotelm-based hydroregulation.

The water mound in raised bogs is primarily a product of impeded drainage of precipitation and in a natural state the water table surface largely conforms to the peat surface. The hemi-elliptical dome is nominally independent of the underlying topography, as is well illustrated in examples of raised bogs which have developed over extensive horizontal surfaces of fen peat or estuarine deposits and so on. However, many bogs have developed in more irregular topographical circumstances and many stratigraphic sections show that the current shape of the bog surface broadly parallels the underlying mineral ground. However, Meade and Mawby (1998) have suggested that at Wedholme Flow this is a consequence of partial drainage and that the original dome was more independent of the underlying topographical features than is now the case.

6.4.6 Situation and surface relief

Of the sites sampled, some 75 per cent were in, or spilling out from, more or less discrete basins and were hydroseral. Others were on coastal flats (examples around the head of Morecambe Bay) or on broad valley bottoms (Bowscale Moss). No examples were recorded from true floodplain locations, but Cors Caron (not sampled) occupies part of the floodplain of the River Teifi, with ombrogenous domes on either side of the river, where it crosses a former lake basin.

The surface is more or less domed, locally with quite steep slopes, especially near the periphery (rand); shallow pools, lawns and hummocks may provide a locally well-developed micro-topography; undulations are often associated with drainage or peat removal. The majority of samples were taken from flat or gently sloping locations, but a small number occupied steeper slopes (mostly in a rand location) (Table 6.6).

Table 6.6 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 1

	Mean	1	2	3	4	5	6	7
Surface layer permeability	4.2			33	19	43	5	
Lower layer permeability	4.1		29	38	24	10		
Basal substratum permeability	1.6	48	48		4			
Slope	1.6	63	30	5		1	X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.4.7 Substratum

Most WETMEC 1 samples occured on deep peat (mean: six-metre depth). This usually consisted of ombrotrophic peat superimposed upon minerotrophic peat, reflecting the development of the mire, though the proportions of the two varied considerably. The very thin peat depths (< 2 m) recorded came from parts of Cliburn Moss, where peat may have been dug away. The top (acrotelm) layer was generally fairly loose, and apparently more permeable than the lower substrata (Table 6.6).

The basal substratum was also variable. Most sites occurred upon low permeability, thick clays and silts, in some coastal and other contexts, but a few were on fluvio-glacial deposits. It cannot be assumed that the latter were necessarily in free hydraulic connection with the peat deposit.

6.4.8 Water supply

As the ombrogenous surface is raised above the surrounding water table, water supply to this WETMEC is directly, and exclusively, from precipitation, although it may be supported by an underlying telluric water table. However, the latter – where present – may often be relatively unimportant in influencing short-term fluctuations in the water table (*cf.* WETMEC 2, *q.v.*)

The mean value of precipitation in sites with WETMEC 1 is, at 1,073 mm, the highest of any WETMEC, whereas mean potential evaporation is only about half of this value (537 mm). However, whilst a feature of the wetter climates of the North and West of Britain, ombrogenous surfaces once occurred extensively within floodplains and coastal plains in eastern England (such as Whittlesea Mere), where values are currently 547 mm (ppt) and 627 mm (PE). Of the sites sampled here, Fenns, Whixall and Bettisfield Mosses occupied the driest conditions: 710 mm (ppt) and 582 mm (PE). The capacity of wetland species to survive upon a dome of peat containing a perched, rain-dependent water table in a region prone to periodic (and sometimes protracted) droughts has been attributed to characteristics of the thin unsaturated surface layer (or *acrotelm*). The acrotelm, at least when it supports a spongy *Sphagnum* surface, appears to have some hydroregulatory properties (Joosten, 1993; Money and Wheeler, 1999), some of which are similar to those associated with rafting structures in telluric systems (Wheeler, 1999a). Damage to, or destruction of, the acrotelm can lead to a loss of hydroregulatory function and concomitant difficulties of rewetting in restoration initiatives (Wheeler and Shaw, 1995d).

The acrotelm is underlain by the *catotelm* deposit, the top of which is usually defined as the limit of permanent saturation. The hydraulic conductivity of the catotelm is generally an order of magnitude lower than that of the acrotelm and the deposit constrains vertical water seepage through the peat, though in some situations fissures, ‘pipes’, tree roots and so on may provide localised preferential flow paths. It is also clear that the catotelm deposits can vary considerably in their character, and this may possibly influence surface conditions. For example, the best remaining areas of Fenns, Whixall and Bettisfield Moss appear to be located over a deep, relatively fresh catotelm deposit, which is more reminiscent of a quag bog deposit than of a typical raised bog catotelm. However, little seems to be known about the hydraulic conductivity of this type of catotelm material, and in the absence of such data its possible significance to the vegetation surface remains uncertain.

All of the examples of WETMEC 1 examined have been subject to varying degrees of deliberate surface drainage, where drains provide a potentially important mechanism of water loss and drying. Although hydrometric data are few, drains are likely to have a substantial and pervasive impact upon the water table within the acrotelm. Drains have often been blocked as a conservation measure to restore water levels, and natural occlusion also occurs in the absence of ditch management, but abandoned drains can still act as a major pathway for rapid flow of water away from the mire dome.

Some data are available for evapotranspirative losses from raised bog surfaces (such as Ingram, 1983). Losses from *Sphagnum* carpets vary with their state of hydration: rates may be equal to or more than PE in wet conditions, but may fall to less than half of PE in dry conditions. *Sphagnum* carpets are often interrupted by hummocks and other microforms, and in most cases support a range of vascular plant species, of which graminoids and dwarf shrubs are normally quantitatively the most important. A number of the vascular plant species found in bogs are xeromorphs: they have morphological features which are normally interpreted as adaptations to growth in dry conditions, especially by reduction of transpirative water loss. However, bog surfaces in which graminoids are prominent may lose water more rapidly than *Sphagnum* carpets (Ingram, 1987; Spieksma *et al.,* 1997), and whilst surfaces in which ericoids are prominent may have low rates of transpirative water loss, interception losses may be high (Wallace *et al.*, 1982). Grazed surfaces (such as Walton Moss) can have lower total evapotranspirative loss than ungrazed surfaces with a similar water table, but few reliable data are available to support such generalisations.

In most WETMEC 1 sites, telluric water sources are either largely absent or are well isolated from the ombrogenous surface by either vertical or horizontal distance. However, in some instances the ombrogenous surface is only some 30 to 50 cm above peripheral telluric water, possibly due to past peat removal. Minerotrophic conditions frequently occur around the ombrogenous deposit, and may sometimes feed into, or across, the deposit along drains cut through this. A marginal lagg sometimes occurs, fed both by run-off from the bog and from any adjoining mineral slopes, but even along ‘intact’ edges of bogs a lagg is not necessarily well developed (for example, around parts of Walton Moss (Cumbria) apparently ombrotrophic vegetation extends to within about 10 m of the mineral edge). In some sites, such as where bog peat has accumulated within a drumlin or kame-and-kettle field, residual peaks of mineral material protruding above the ombrogenous surface can introduce minerotrophic conditions into the middle of the moss. For example, towards the eastern edge of Bowness Common (Cumbria) a small island of agricultural land on a drumlin (Rogersceugh) may introduce more base-rich surface run-off into some of the drainage channels around and within the SSSI. Likewise at Malham Tarn Moss, a small island within the bog (Spiggot Hill) is surrounded by a band of minerotrophic peat and telluric water spreads out from this along channels across parts of the bog. In this case the source of the minerotrophic water is not really known: Pigott and Pigott (1959) interpreted the hill as a drumlin, in which case the telluric water is likely to be surface run-off, but it now seems more likely that it is a fluvio-glacial deposit comparable with the low hills to the south, and possibly in hydraulic connection with these.

Other bog sites also occur over permeable deposits, but the degree of connectivity between the peat, and especially the bog surface, and any underlying aquifer is generally not known. It is possible that in many cases, much of the basin is separated from the mineral aquifer by a layer of clay (the peat-covered fluvio-glacial deposits at Malham appear to be extensively clay-smeared) or other impedance layer (see also discussion on water supply for WETMEC 2). There is no evidence for any substantial ingress of groundwater into any of the WETMEC 1 sites considered here, except for Tarn Moss (Malham).

6.4.9 WETMEC sub-types

No sub-types have been recognised within the samples available, but inclusion of comparable ombrogenous mires from other parts of Britain would almost certainly result in the recognition of sub-types.

6.4.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 1 are summarised in Table 6.7. The primary feature of ombrogenous surfaces is that they are fed directly and exclusively by precipitation. They are oligotrophic and acidic in character (pH typically 3.5–3.8), and based on peat which often contains remains of ‘bog-building’ *Sphagnum* species (*S. imbricatum, S. magellanicum* and *S. papillosum*) as major constituents. WETMEC 1 samples have the lowest mean fertility of all WETMECS, the lowest soil pH, and they share the lowest water pH with WETMEC 2. The lowest soil pH was recorded from a slightly elevated peat surface at the margin of Cliburn Moss. Note that some calculated values of K_{corr} were negative, indicating that in some samples, the measured water pH value was too high for the measured conductivity.

Water levels relative to the surface are naturally variable in this WETMEC because of microtopographical variation (hummocks, hollows and lawns) and variation across the dome of the bog. Pools can occur within WETMEC 1, but were not specifically sampled, which helps to account for the relatively low maximum water level. In addition, several of the sites in Cumbria were sampled at the end of a summer drought period, when water tables were probably atypically low.

Table 6.7 WETMEC 1: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	6.1	0.4	12.0

Summer water table (cm)	–10.3	–22.2	0
Rainfall (mm a^{-1})	1,021	710	1,480
PE (mm a^{-1})	535	474	610
Water pH	3.6	3.4	3.8
Soil pH	3.6	2.8	3.9
Conductivity (µS cm^{-1})	98	67	131
K_{corr} (µS cm^{-1})	11.7	–30	67
HCO_3 (mg l^{-1})	0	0	0
$Fertility_{Phal}$ (mg)	3.0	1	5
Eh^{10} (mV)	234	107	331

See list of abbreviations in Appendix 1

6.4.11 Ecological types

All examples of WETMEC 1 have acidic or base-poor peat and water, and are oligotrophic (Table 6.8).

Table 6.8 Percentage distribution of samples of WETMEC 1 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base rich			
Sub neutral			
Base poor	10		
Acidic	90		

6.4.12 Naturalness

Ombrogenous surfaces are a natural successional development within wetlands, developing either hydroserally or by paludification processes, and often replacing preceding fen in whole or part. In relatively dry climates (such as Eastern England), their development is restricted to topogenous situations (floodplains and basins), but in wetter conditions they can overgrow ridges or spread out onto sloping surfaces. They are considered to represent the climax wetland state in many situations, though in dynamic wetland complexes, ombrogenous surfaces can sometimes become flooded with telluric water leading to a reversal in the normal successional sequence. Although some present-day wetlands consist almost exclusively of ombrogenous surfaces, in their natural state these more usually occur as a complex with other wetland types: ombrogenous surfaces may over-run much of their progenitor fen, but often some peripheral fen remains.

As the surface water conditions of domed ombrogenous deposits are critically dependent both upon climate and the topography of the accumulating peat mass, both of which can vary over time, a raised bog surface can experience considerable natural variation in the long-term position of the water table and dry heathy surfaces can sometimes become extensive, even in the absence of drainage. This has sometimes been recognised as a so-called ‘still-stand complex’, and in some cases has led to natural afforestation of the drying surfaces. One of the best examples of the influence of interactions between climatic change and mire development on the character of a raised bog complex has been elucidated by Casparie (1972) by stratigraphical investigations on the Bourtanger Moor in the Netherlands.

6.4.13 Conservation value

The vegetation of little-damaged ombrogenous surfaces, especially those rich in 'bog-building' Sphagna, forms a priority EC Habitats Directive interest feature (active raised bogs) (see Tables 3.3 and 6.4). The most characteristic community of the samples allocated to WETMEC 1 is *Erica tetralix–Sphagnum papillosum* raised and blanket mire (M18[1]) (71 per cent), though bog pools support *Sphagnum cuspidatum/recurvum* bog pool community (M2) (14 per cent). Some partly degraded examples (such as Tarn Moss, Malham) support rather impoverished vegetation which has been referred to *Scirpus cespitosus–Eriophorum vaginatum* blanket mire (M17) or *Calluna vulgaris–Eriophorum vaginatum* blanket mire (M19) (nine per cent) (though a recent examination of data from Tarn Moss (Malham) suggests greater affinities to M18 than M19). Part-drained examples can support a range of communities, from degraded M18 to heathy surfaces that are referable to *Scirpus cespitosus–Erica tetralix* wet heath (M15) (four per cent). However, even a little-damaged raised bog is not necessarily covered with wall-to-wall M18. The topographical variation means that some surfaces may be naturally quite well drained and heathy, especially – but not exclusively – the rand, whilst others may be wet and support bog pool vegetation (Lindsay *et al.,* 1988).

Partly because relatively few plant species are well adapted to growth in strongly acidic, oligotrophic and waterlogged conditions, ombrogenous surfaces typically support a small, but distinctive, cohort of plant species capable of growing in these difficult conditions (a total of 30 was recorded in samples of WETMEC 1). Also, because ombrogenous surfaces of one type or another are rather extensive nationally, few of the plant species that grow on them are nationally rare (*Andromeda polifolia, Sphagnum molle, S. pulchrum*) though many of the species are local or rare regionally. These include such species as *Sphagnum magellanicum, S. papillosum* and *Vaccinium oxycoccos.* None of these is confined to WETMEC 1, or even to ombrogenous surfaces, and in some regions they are well represented in oligotrophic, base-poor mire fed by groundwater, such as those of the New Forest (particularly WETMECs 10, 14–19).

Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 1 is given in Table 6.3.

6.4.14 Vulnerability

Little-damaged ombrogenous surfaces are potentially vulnerable to direct drainage, drainage of their surroundings and to peat extraction. Surface drainage may be able to reduce the water table over quite large areas: although the low hydraulic conductivity of the catotelm peat may require intensive drainage to cause a widespread, deep reduction of the catotelm water table, drainage may have a more pervasive impact upon the higher K acrotelm – though data documenting this are generally rather sparse. Peripheral peat extraction can also lead to marginal water drawdown, though again its impact appears to be sometimes surprisingly localised, and wet M18 vegetation can sometimes persist within 20 to 30 m of peat diggings. This is especially the case in fairly high rainfall locations (such as Walton Common, Wedholme Flow) and may possibly be partly because of reconformation of the peat surface to the water table by subsidence and slumping. Most of the sites sampled here had been subject to some peripheral peat extraction and in some instances (Fenn's, Whixall and Bettisfield Mosses, Wedholme Flow) large parts of the site have been cut away in the twentieth century. The occurrence and scale of past turbary can be difficult both to appreciate and demonstrate. The curiously eccentric dome of ombrogenous peat at Rhôs

[1] See account for M18 in Part 3

Goch Common (Bartley, 1960b) may well represent a remnant of extensive past peat extraction which has completely removed bog peat from much of the site (see WETMEC 16). If this is correct, at this site peat removal has created a large area of wet fen and swamp on the exposed fen peat and lake deposits.

The impact of deep drainage of agricultural land in the surroundings of a raised bog is strongly context dependent. Where the bog has developed upon an aquitard (stiff clays and so on), drainage of the surroundings may have little if any hydrological impact upon the mire, except perhaps locally where the periphery has been oversteepened by drainage or other damage. Where the area of bog represents an undrained remnant, surrounded by drained or cut-over peat supporting agricultural land, the remnant is potentially more sensitive to deep drainage of the surroundings, but the impact of this is strongly influenced by variables such as the hydraulic conductivity of the drained peat and the topography of the remnant. For example at Meathop Moss (Cumbria), which comprises an upstanding remnant of ombrogenous peat surrounded by farmland on drained peat, Hess *et al.* (2002) concluded that surface flows were determined by the steep topographic gradients at the peripheries of the Mosses, and that these were insensitive to water levels in the arterial drainage network. They considered drainage maintenance activities in the farmland beyond the SSSI boundaries to have negligible effect on the rate of surface flows or seepage from the perimeter ditches and therefore on the hydrological status of the bog.

Where an ombrogenous deposit is located over, or forms part of, an aquifer, dewatering of this may have a pervasive impact upon the residual deposit, though this depends upon the degree of hydraulic connection between the two, and the hydraulic conductivity of the catotelm peat, neither of which is usually well known. Such uncertainties may in part account for contrasting estimates of the width of buffer zone required to protect a raised bog remnant from deep drainage of the surroundings.

Because of the topographical character of the WETMEC, enrichment with base-rich or nutrient-rich water is only a problem in exceptional circumstances, where there is little difference in the altitude of the surface and the telluric water table. This is most often the case where peat cutting has much reduced the original height of the bog surface, but occasionally occurs in other, more idiosyncratic, circumstances. For example, an unusual case of enrichment occurs at Tarn Moss (Malham) where soakways with telluric water cross the bog from Spiggot Hill. In this case, the water outflow onto the mire is both rather base-rich and nutrient-rich, the latter possibly as a consequence of a roosting colony of birds on Spiggot Hill; its impact seems to have been enhanced by attempts to dam the soakways, resulting in a wider spread of enriched water onto the ombrotrophic surface than would otherwise have been the case. Another curious example of base-enrichment, which appears to have been remedied, occurred at Fenn's, Whixall and Bettisfield Mosses, caused by leakage of telluric water from the Shropshire Union Canal, which was dug across part of the site at the start of the nineteenth century (Berry *et al*., 1996).

Ongoing growth of trees, especially those that are not deciduous, is likely to increase the dryness of any mire surfaces which depend on rainfall as a significant water source, due to increased interception and evapotranspiration losses.

6.5 WETMEC 2: Buoyant Ombrogenous Surfaces (quag bog)

6.5.1 Outline

This unit includes peat surfaces that have developed under the exclusive influence of precipitation. However, in contrast to most WETMEC 1 (Domed Ombrogenous Surfaces) bogs, the deposit of ombrogenous peat is not much elevated (around 0.5 m) above the regional water table, or adjoining surface water sources. This may be because the ombrogenous deposit is thin, because it has secondarily sunk into telluric conditions or because peat has been removed by turbary. These mires typically have a strongly quaking, often buoyant, surface which helps maintain vertical isolation of the ombrogenous surface from underlying telluric water. Thus, whilst the vegetation surface is thought to be fed directly and exclusively by precipitation, the hydrological status of the surface is closely linked to the dynamics of the (telluric) water table of the basin as a whole. Schematic sections are provided in Figure 6.9.

6.5.2 Occurrence

Example sites: Abbots Moss (South Moss and Shemmy Moss), Biglands Bog, Black Firs and Cranberry Bog, Chartley Moss, Cors y Llyn (Radnor), Flaxmere Moss, Hollas Moss, Lin Can Moss, Moorthwaite Moss, Tarn Moss, Wybunbury Moss

Outlier sites: Cliburn Moss, Tarn Moss (Malham)

Most of the samples clustered within this WETMEC were from small basin sites in the North and West of England, with one example (Cors y Llyn) from Wales (Figure 6.8). WETMEC 2 is almost certainly more widely represented in Wales.

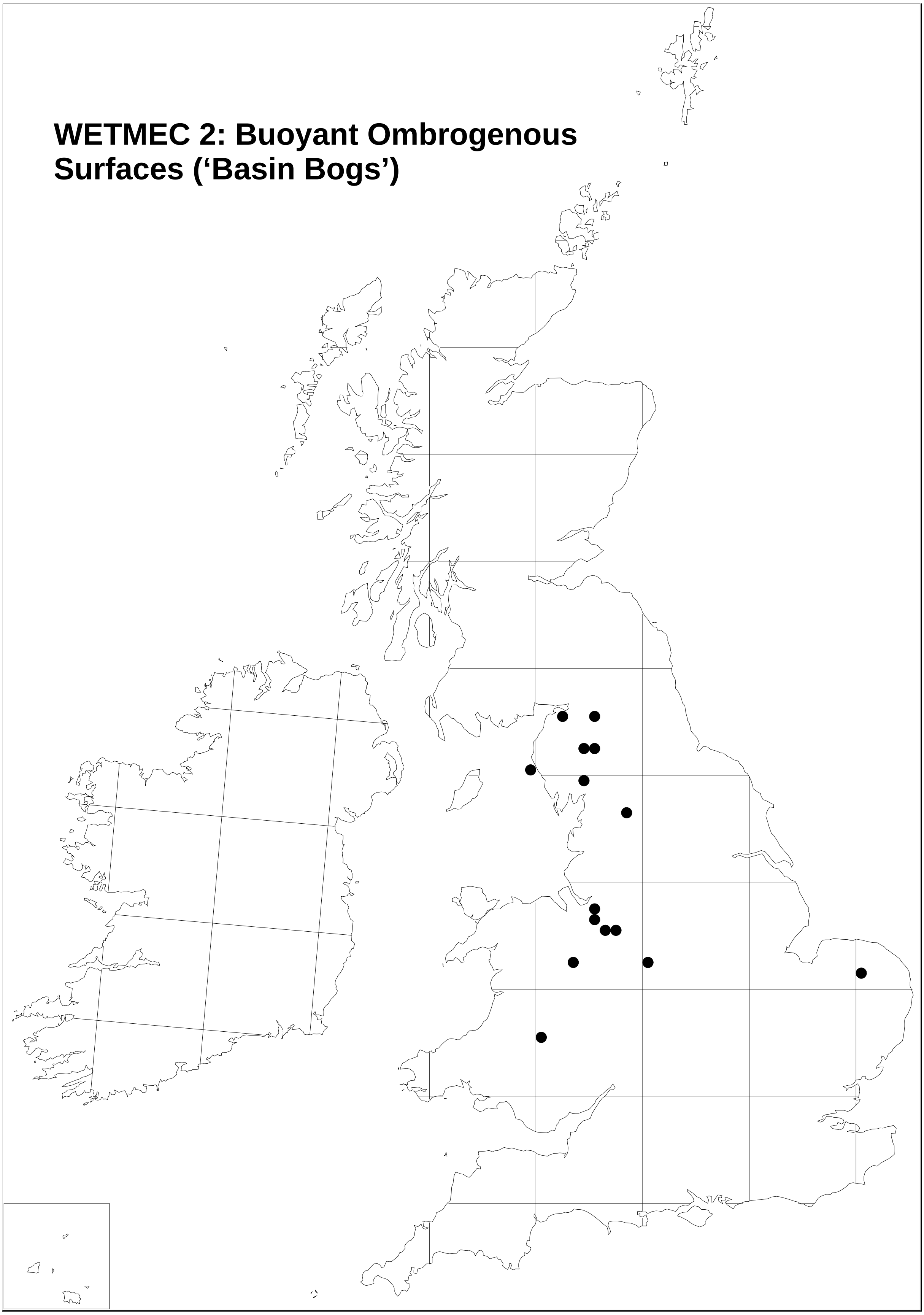


Figure 6.8 Distribution of examples of WETMEC 2 in sites sampled in England and Wales

6.5.3 Summary characteristics

Situation	Basins.
Size	Mostly small.
Location	Mainly North and West England (including the West Midlands) and Wales.
Surface relief	Shallow-domed, or more or less flat, often adjoined by a wet peripheral lagg; no real rand; shallow pools, lawns and hummocks may provide a locally well-developed micro-topography, but the surface is often largely planar, sometimes modified by peat diggings. Small examples of the WETMEC sometimes occupy peat workings within other (WETMEC 1) surfaces.
Hydrotopography	Ombrogenous.
Water: ***supply***	Precipitation, typically supported by telluric water.
regime	Water levels naturally vary to some extent across the surface and with time, especially with rainfall patterns, but are typically relatively stable and close to the surface, especially in examples with a buoyant surface.
distribution	Vertical flow downwards into peat and watery muds; possibly some lateral flow through acrotelm.
superficial	Shallow pools, occasional soakways; sometimes drains.
Substratum	Buoyant, loose ombrogenous surface upon fen peat or submerged ombrogenous peat, usually underlain by a watery mix of peat and/or muds. Often in fluvio-glacial deposits, but may be separated from these by low-permeability layers.
peat depth	Peat and/or muds typically 2 – 15 m.
peat humification	Usually with a shallow (0.5 m) spongy surface (acrotelm); underlying material often much less solid and less humified.
peat composition	Ombrogenous peat with *Sphagnum* spp., *Eriophorum* spp. and ericaceous shrubs upon fen peat, submerged ombrogenous peat or watery material.
permeability	Surface layer rather loose, but actual permeability little known; lower layers more variable but often very watery. Basin may have a low-permeability infill or clay lining separating it from underlying mineral deposit.
Ecological types	Oligotrophic, acidic.
Associated WETMECs	Some examples can form a complex with various other WETMECs, especially in the peripheral lagg (if present) (such as WETMECs 3, 15, 19). Occasionally in peat workings within, or adjoining, WETMEC 1.
Natural status	Natural successional state formed by terrestrialisation and paludification. May also occupy some turf ponds.
Use	Conservation. Usually too wet for any other use, though some sites may once have been turbaries.
Conservation value	Supports examples of EU SAC habitats ‘active raised bog’ and ‘transition mire and quaking bog’. Vascular plant species diversity is generally rather low (and sometimes increased by damage).

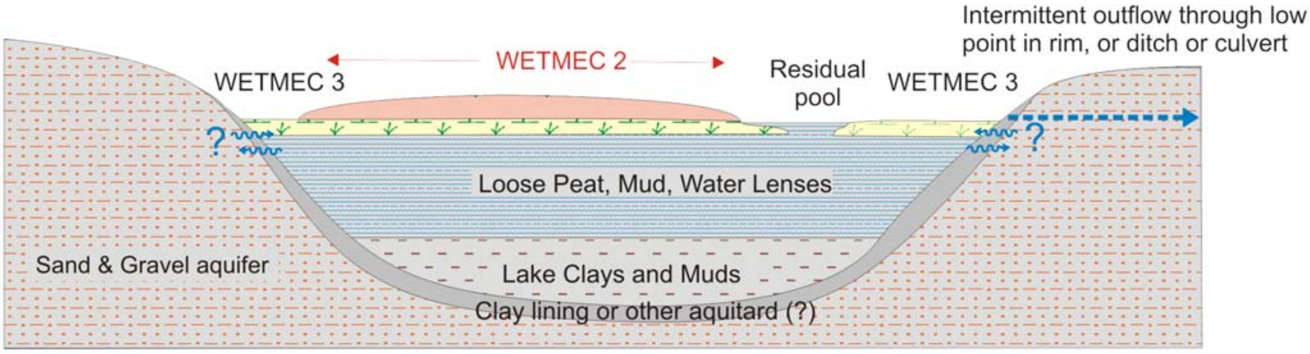
Vulnerability	Drainage and nutrient enrichment (from both telluric and meteoric sources)

WETMEC 2: BUOYANT, OMBROGENOUS SURFACES

[For other examples, see WETMEC 3]

WETMEC 2a: Ombrogenous quag
(*e.g.* Abbots Moss)

- WETMEC 2 surface is fed ± exclusively by precipitation
- basin may be ± 'sealed' from aquifer (but little documented)
- magnitude, and in some contexts direction, of any water exchange with mineral aquifer is uncertain (if connected some basins may recharge the aquifer)
- the WETMEC 2 surface is hydroseral, and typically developed over WETMEC 3. [This may persist in places, and can form a lagg or proto-lagg in peripheral locations.]



WETMEC 2b: Ombrogenous quag (groundwater-fed basin)
(*e.g.* Wybunbury Moss)

- WETMEC 2 surface is fed ± exclusively by precipitation
- visible groundwater outflow from mineral aquifer into lagg water-track around part of basin (other parts may be fed just by surface run-off)
- basin may have attributes of a Seepage Percolation Basin (WETMEC 13), at least near surface and where ditched
- lower basin may be ± 'sealed' from aquifer (but little documented)
- the WETMEC 2 surface is hydroseral, and typically developed over WETMEC 3.

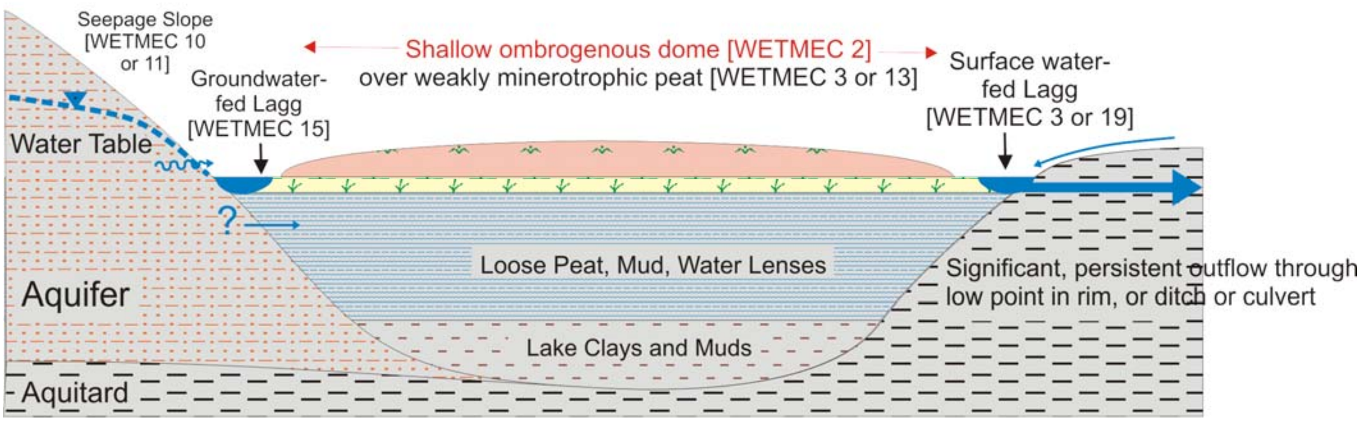


Figure 6.9 Schematic sections of Buoyant Ombrogenous Surfaces (WETMEC 2)

6.5.4 Concept and description

CLUSTER: 2

WETMEC 2 encompasses quaking or semi-floating peat surfaces which are completely or largely isolated from telluric water influences and which are fed directly and exclusively by precipitation. Unlike the raised bogs of WETMEC 1, these examples do not have a thick dome of ombrogenous peat, but generally consist of a rather thin layer of ombrogenous peat elevated some 0.5 to one metre above the level of the telluric water table[1]. This WETMEC mostly occurs in rather small basins, similar in topography to those which support small examples of WETMEC 1. The smaller thickness and elevation of ombrogenous peat compared to most WETMEC 1 stands may be because these examples are younger or because former ombrogenous peat has been removed by domestic peat digging. However, in some instances the thickness of ombrogenous peat is greater than it appears because some of it has sunk below the telluric water level. This can simply be a response to an accumulation of peat mass and concomitant depression of a buoyant surface, but in at least two instances (Chartley Moss and Wybunbury Moss) it can also be attributed to geological subsidence of the basin which contains the mire. Although the quag bogs do not have a conspicuous dome or rand, the Buoyant Ombrogenous Surface is often surrounded by a well-developed, and frequently very treacherous, lagg, but this latter is referable to a separate WETMEC (such as WETMECs 3, 15 or 19).

Affinities and recognition

The samples allocated to this unit formed a single cluster at the 36-cluster stage of the multivariate classification (Figure 6.1). At the 72-cluster stage, these were segregated into three sub-clusters, which correspond to the three WETMEC sub-types identified below. WETMEC 2 differs from WETMEC 1 in a number of significant respects, including proximity (both vertically and horizontally) to telluric water sources and the greater influence of the basin water table in determining the hydrodynamics of the surface. However, the key differences are that the dome of bog peat is generally considerable shallower than in most examples of WETMEC 1, and that the surface is buoyant and underlain by unconsolidated material (loose peat or watery muds) rather than by a solid catotelm. The majority of WETMEC 2 sites occupy small basins, and have only a shallow ombrogenous surface. They broadly correspond to what have sometimes been called ‘basin bogs’, whereas most WETMEC 1 sites are less obviously associated with basins and correspond to what have often been called ‘raised bogs’. However, the split between WETMECs 1 and 2 does not correspond exactly to the split between basin and non-basin sites, as some examples of WETMEC 1 occupy parts of small basins, where there are firm, sometimes rather dry, ombrogenous surfaces. In some small basin sites (such as Flaxmere, Great Ludderburn Moss, Moorthwaite Moss) samples from solid surfaces that had not been dug for peat (or perhaps, dug less deeply) clustered into WETMEC 1 (or WETMEC 4), whereas samples from recolonised turf ponds clustered into WETMEC 2.

The greatest practical difficulty in identifying WETMEC 2 is in separating it from WETMEC 3 (Buoyant, Weakly Minerotrophic Surfaces). Both WETMECs often occur in close juxtaposition in the same basin. In principle the defining difference is clear – the presence or absence of an ombrogenous surface – but in practice ombrotrophy is difficult to identify

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[1] Whilst many WETMEC 2 surfaces are clearly underlain by telluric water, in other cases the extent to which telluric water penetrates beneath the surface mat is not known, and the provenance of the the ‘basin water table’ is uncertain.

without detailed measurements. The allocation of samples to the clusters has been made primarily on the height difference between the surface of the peat and the telluric water table (which can be identified *inter alia* by measurements of pH and conductivity), but, reflecting their ontogenic relationship, there is often no clear distinction between WETMECs 2 and 3 at their point of contact.

6.5.5 Origins and development

The ontogenic patterns of WETMEC 2 are much less variable than WETMEC 1 (Table 6.5) and all the apparently natural examples examined (those not in obvious turf ponds) fall into a single ontogenic type, Ontogenic Type 3 (Figure 6.10). This is effectively the buoyant counterpart of Ontogenic Type 2. Unlike some of the latter, WETMEC 2 surfaces do not appear to have arisen directly as a consequence of paludification, though in some cases this process may have played an important part in the mire development of the basins as a whole (Tallis, 1973). Rather, as the buoyant character and often watery underlay of the surfaces suggest, they have often formed by terrestrialisation. However, the terrestrialisation sequences involved are potentially complex and not altogether well understood. Moreover, in a few cases the ombrogenous 'raft' appears to be more a consequence of subsidence of the underlying basin than of direct colonisation of a former water body.

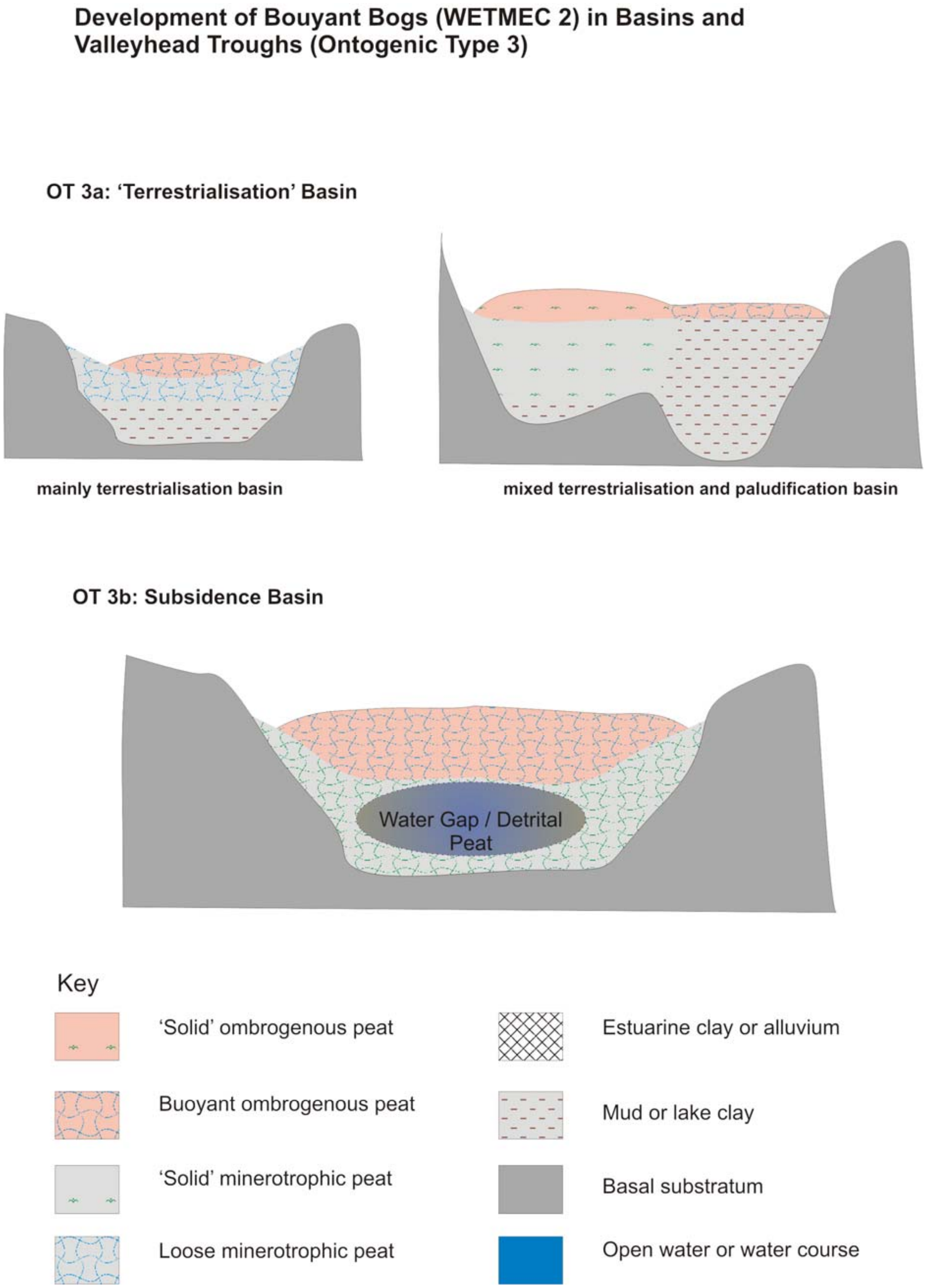

Figure 6.10 Development of Buoyant bogs (WETMEC 2) in basins and valleyhead troughs (Ontogenic Type 3)

Ontogenic Type 3: Buoyant bogs in basins and valleyhead troughs:
3a: Terrestrialisation basins

Quag bog surfaces (often in the guise of the broadly synonymous term *schwingmooren*) have frequently been envisaged as floating or semi-floating mats of vegetation that have encroached centripetally across quite deep water, usually in small, sheltered basins (such as Moore and Bellamy, 1974; Gore, 1983). However, whilst there can be no doubt that in many cases the surface has developed across former open water, sometimes apparently quite quickly (as reported from Lin Can Moss (Shropshire) by Sinker (1962)), it is much less certain to what extent this has occurred over *deep* water. Tallis (1973) reviewed various lines of evidence which suggested that *schwingmoor* development in Cheshire has occurred mainly over shallow water (less than two metres deep) and this proposition is compatible with the general absence of raft encroachment across deep pools observed in the present survey. For example, at Cranberry Bog (Staffs) the mire basin is occupied by a WETMEC 2 surface alongside a deep dystrophic pool (Black Mere), reported to be up to 18 m deep. Although this basin is very small and sheltered, there is an abrupt transition between the bog surface and the pool, both in surface conditions and stratigraphy, and the pool is remarkable mostly for the *absence* of an obvious centripetal terrestrialisation gradient. Nonetheless, it is not at all clear why rafting should be constrained by the depth of underlying water, especially in small, sheltered basins.

Some buoyant surfaces do not appear to be located over free water. For example, Abbots Moss (Cheshire) consists of a quite deep (8 m) basin covered by a buoyant, strongly quaking, surface, which can be described as *schwingmoor.* However, stratigraphical investigations suggest that this is underlain by a soft and sloppy *Sphagnum* peat, which although in some layers is sufficiently unconsolidated not to be retrievable by some designs of peat borer, is certainly not water. This has also been found in other sites, such as Biglands Bog (Cumbria) where there is a WETMEC 2 surface over a deep (> 15 m) basin of peat with alternating watery and firmer layers.

If rafting generally does not occur over deep water (except, perhaps, across very small areas), this implies that the basins currently supporting WETMEC 2 have not always contained deep water. Although data are sparse, there is supporting evidence for this proposition from at least two basin sites, Flaxmere (Tallis, 1973) (Box 6.1) and Cors y Llyn (Radnor) (Moore and Beckett, 1971; Moore, 1978; French and Moore, 1986) (Box 6.39).

From the perspective of WETMECs, it is notable that most of the surface of Flaxmere is quite solid and, although little domed, its samples cluster within WETMEC 1. WETMEC 2 is now apparently restricted to some peripheral peat diggings. The stratigraphical data suggest that WETMEC 1 can develop from WETMEC 2, but it is less clear to what extent this is part of a natural seral process or a consequence of (partial) drainage initiatives.

Although in a rather different topographical context, the development of Cors y Llyn shows some clear parallels with Flaxmere. An interesting conclusion from this site is that its developmental patterns, including the persistence of open water until recently, may reflect its late-Devensian topographical footprint. This explanation may also be appropriate for some similar contemporary juxtapositions of WETMEC 2 and open water, as at Cranberry Bog.

Box 6.1: Development of Flaxmere (Cheshire)

Flaxmere is a small mire in a basin in the Delamere Forest region of Cheshire. Tallis (1973) dated (by pollen analysis) specific horizons in the deposits and showed that the mire did not form by terrestrialisation of a basin that was brim-full of water; indeed, much of the peat infill seems not to have arisen by direct colonisation of open water. In the late-Devensian/early post-glacial period, water tables in the basin were quite low and lake muds occurred only as a shallow (1–2 m) thick deposit restricted to the deepest part of the hollow. These became covered by compacted poor-fen peat and the early basin infill was essentially concave, so that telluric inflows from the basin slopes would have drained across the accumulating peat to the centre of the basin. The pollen data suggest that a broadly concave vegetation surface was present during much of the development of this basin, though the gradient progressively decreased with time. However, in the deeper parts it was replaced by "*a much wetter and more fluid peat of similar character, but with more prominent Sphagnum remains*" (Tallis, 1973), apparently in response to a rising water table early in pollen zone VIIa. Whilst this deposit formed in the deeper parts of the basin, there was continued accumulation of more compacted peat on the more marginal slopes.

A "*second increase in surface wetness (probably bringing the water table up to present-day levels) apparently took place towards the end of Zone VIIb*" (Tallis, 1973), and Tallis considers that this marks the development of a *schwingmoor* which "*originated as a floating raft of Sphagnum cuspidatum (probably buoyed up by rhizomes of Eriophorum angustifolium and Scheuchzeria palustris) over open water … It is probable that open water conditions were widespread immediately prior to the accumulation of the S. cuspidatum peat, but that subsequently the open water was gradually filled in almost everywhere by settling down of the basal layers of the raft, or that it was drained off from below the raft when the drainage ditches were dug*". The *Sphagnum cuspidatum* raft subsequently developed into a more diverse surface with *S. papillosum* and *S. imbricatum* and may perhaps have once formed a shallow ombrogenous dome, though currently there is no evidence of a convex surface.

Tallis (1973) related the increase in water levels within the basin to post-glacial climate changes. In kettle-hole sites in North-East Germany, where a similar process seems to have occurred, Timmermann and Succow (2001) suggest (in translation) that "*the gradual sealing of the hollow by organic linings lets the mire water body rise gradually so that this can outgrow the influence of the regional water body*", but this explanation may be less applicable to Flaxmere, where the basin appears to be sealed by quite thick glacial silts and clays.

Box 6.2: Development of Cors y Llyn (Radnor)

Although ostensibly in a single basin, the Cors y Llyn site contains two topographical basins, which have become united by the overgrowth of peat. The south-eastern basin is the broadest and generally the deepest and contained the eponymous lake until fairly recently, whereas the northern basin has long supported mire, developed in its deepest part over an early post-glacial lake (Moore and Beckett, 1971; Moore, 1978; French and Moore, 1986). Although the stratigraphical horizons have not been dated, it is possible to interpret the stratigraphy along lines very similar to those reported from Flaxmere by Tallis. This suggests that the water level in the original lake was some five metres below the present-day surface of the mire (which now corresponds broadly with the level of the main outfall). In the northern basin the early post-glacial lake was mostly shallow and short-lived, becoming replaced by fen and fen woodland; much of the subsequent accumulation of (fairly firm) peat in the northern basin appears to relate to a progressive increase in water level and may have been more paludification than terrestrialisation.

By contrast, in the south-eastern basin, the deep late-glacial lake persisted as open water up until at least post-Medieval times accumulating some six metres depth of detrital muds. It is not known with certainty why the two basins had contrasting ontogenies, but he late-glacial lake of the south-eastern basin appears to have been both broader and, for the most part, deeper than that of the northern basin. A possible explanation is that the latter had terrestrialised before post-glacial increases in water level, whereas the southern basin was too large and deep for complete early seral colonisation by swamp and fen. These constraints on terrestrialisation persisted, or even increased, as the post-glacial increase in water level led to the perpetuation of an ever deeper (and probably increasingly dystrophic) lake. On this interpretation, the juxtaposition of lake and mire in this basin could be seen as a direct derivative of the late-Devensian topographical footprint of the depression.

The more recent development at Cors y Llyn is also of interest with respect to the development of WETMEC 2 surfaces. The former deep lake in the south-eastern basin became covered centripetally with a mat of vegetation sometime in the post-Medieval period, perhaps because the accumulation of detrital muds had shallowed it sufficiently for *schwingmoor* encroachment to occur. French and Moore (1986) present evidence which suggests that a trigger for overgrowth could have been nutrient inwash associated with deforestation around the basin, but such a stimulus may have only been effective because the lake was sufficiently shallow. By contrast, the peat accumulation in the northern basin is deep and much is consolidated and does not form a *schwingmoor* structure. However, the surface of the northern basin is pitted with recolonised turf ponds and these contain small, secondary peat rafts, some[1] of which have been clustered, along with the *schwingmoor* of the south-eastern basin, into WETMEC 2.

Ontogenic Type 3: Buoyant bogs in basins and valleyhead troughs: 3b: Subsidence basins

In some examples of WETMEC 2, a semi-floating mat *does* occur over deep watery deposits. In particular, Chartley Moss is reported to have a four to six metre layer of peat over water some
10 metres deep (Ahmad-Shah and Rieley (1989) (though this is apparently not a uniform reservoir of liquid material, but contains irregular layers of recoverable peat separated by water lenses). Likewise, at Wybunbury Moss there is a three to five metre thick *Sphagnum*-based raft upon some 10 metres of 'water' (Green and Pearson, 1977). However, neither of

[1] Other examples, closer to the lagg, appear to receive some telluric water influence and have been clustered into WETMEC 3.

these sites appears to have basal lake sediments (Bale, 1982; Green and Pearson, 1977) and both are reported to be subsidence hollows. It appears that the deep ‘water’ may have formed as a result of subsidence beneath an existing peat surface rather than that there has been rafting *de novo* across a deep body of open water.

6.5.6 Situation and surface relief

All of the non turf-pond samples of WETMEC 2 were from discrete basins, often kettle holes and mostly small and isodiametric (Chartley and Wybunbury Mosses were larger). Most basins were mostly closed, or had just a weak surface stream outflow, but some had strong outflows. One (Biglands Bog) had a throughflowing stream. The mire surface is typically shallow-domed or more or less flat, often adjoined by a wet peripheral lagg but with no real rand. Shallow pools, lawns and hummocks may provide a locally well-developed micro-topography, but the surface is often largely planar. All of the samples had more or less flat surfaces (Table 6.9). WETMEC 2 sometimes occurs within turf ponds, usually within or adjoining (former) examples of WETMEC 1.

Table 6.9 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 2

	Mean	1	2	3	4	5	6	7
Surface layer	6.1				5	18	41	36
Lower layer	6		5	5	5	18	9	60
Basal substratum	2	23	55	9	5		9	
Slope	1	100					X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.5.7 Substratum

All samples recorded were on quite deep peat and muds (mean: 7.6 m depth; range three to 15 metres), the mean depth being the greatest of all WETMECS. The surface peat is typically loose and buoyant but usually sufficiently consolidated to support access. It consists of a thin mat (0.5 m, occasionally more) of ombrotrophic peat upon a mat of peat that lies below the main basin water level. This latter may be either weakly minerotrophic peat or submerged ombrogenous peat. The thickness of the peat mat (as opposed to the thickness of ombrogenous peat) is variable, typically from about 0.2 to two metres but deeper in a few instances. It is underlain by a watery mix of material, with a total depth depending on the dimensions of the basin. This is often difficult to sample with standard peat borers, and is then sometimes described as ‘water’ or ‘mud slurry’, but in most cases probably contains a loose mixture of plant material. It is thus potentially more permeable than the surface layer (Table 6.9) and provides the least consolidated mid-layer deposit of all WETMECs. In a few cases (such as Biglands Bog, Cumbria), the peat infill consists of alternating layers of sloppy and more consolidated material.

Many basins examined were located within fluvio-glacial deposits, but the basin infill was often partly or wholly separated from these by lake sediments. Some basins appear to be clay-lined and in others, there may be other layers that function as aquitards (see below).

6.5.8 Water supply

As the ombrogenous surface is raised somewhat above the surrounding water table, water supply to this WETMEC is thought to be directly and exclusively from precipitation. However, unlike WETMEC 1, the mire surface is rather close to the telluric level and whereas, because of the buoyancy of the mat, this may have but a limited water *supply* function, it is probably important in supporting the water balance of the mat.

Neither the hydrodynamics nor the ontogenesis of the buoyant bog mats is well understood. It seems likely that the buoyancy is in large measure a product of entrapped bubbles of methane. This may result in rather small *K* values for the raft and lead to rather small rates of recharge from below, especially in conditions dominated by evapotranspirative losses in summer. This may help explain the tendency of the more mature, thicker rafts readily to become colonised by trees (especially pine).

Little is known in detail about evapotranspiration losses from surfaces referable to WETMEC 2, though there may be broad similarities with WETMEC 1. Losses are likely to depend upon the precise character of the surface and the nature of the surroundings, with the likelihood of an 'oasis effect' in sheltered basins, especially those surrounded by forest. Gilman (2002) has suggested that shallow, sheltered pools with open water in sites such as Cors y Llyn may lose water at about 80 per cent of the Penman open water rate. Wet, *Sphagnum*-dominated hollows are likely to lose water at rates similar to, or perhaps somewhat above, those from open water in the same context, whereas *Sphagnum* lawns – which are often more extensive in WETMEC 2 than in WETMEC 1 – may be expected to lose water at rates above open water in wet conditions, but less than half this rate in dry circumstances. And whilst immature, unstable buoyant surfaces may show little tendency to dry out, the surface hydration of thicker rafts may vary considerably in response to precipitation episodes.

For sites such as Cors y Llyn, Gilman (2002) suggests that an open, *Sphagnum*-dominated surface may lose water at about 70 per cent of PE. When – as is frequently the case – these surfaces become invaded by pines, the effect upon evapotranspirative loss is likely to be dependent *inter alia* upon the density of the trees. Gilman (2002) points out that mature, closed canopy coniferous woodland may have evapotranspirative losses of about 180 per cent of PE, much of which is a consequence of interception losses. However, when trees are sparse they may lead to a net reduction of evapotranspiration from bog surfaces because of their sheltering effect (Spieksma *et al.*, 1997), and total losses from a sparsely treed surface may be similar to, or even slightly less than, those of an open mire. However, ongoing growth of trees, especially nondeciduous ones, is likely to increase the dryness of any mire surfaces which depend on rainfall as a significant water source, which is the case *par excellence* in ombrotrophic contexts. At Cors y Llyn, it seems likely that an important contribution to the progressive decline in the mire water table since – and probably before – 1985 may be increased evapotranspiration losses caused by the expansion and maturation of pine trees across much of the surface (Gilman, 1998); many of the trees have now been removed. Stratigraphical data (Moore and Beckett, 1971) suggest that some form of woody vegetation has occurred widely – and presumably naturally – over parts of the site in the past, with considerable portions in the northern basin, raising interesting questions about the natural state of the mire surfaces in such contexts.

The source of telluric water to WETMEC 2 basins is also a matter of considerable uncertainty. Many of the basins occupy ground hollows in fluvio-glacial deposits which are generally water bearing and, as minor aquifer units, might be expected to supply groundwater to the basins. In some cases, there is evidence that clay layers extend beneath and line the basin (such as Flaxmere: Tallis, 1973; ECUS, 2001), but many sites have not been thoroughly examined. Many basins are partly infilled with gyttja, or have some clay lining, but it is often not known how continuous this is; nor is the likely role of other impedance layers well recognised or understood. With reference to some North-East German kettle-hole mires, Timmermann and Succow (2001) comment (in translation) that "*it* *is generally accepted that loamy and silty–fine-sandy substrates of late-glacial origin, and especially organic linings, seal the hollow to a large extent*". Hence, in the absence of evident groundwater outflows into the basin, neither hydraulic continuity nor separation between the basins and the drift aquifers can be assumed and there is a need for hydrometric data from within the basins themselves – dipwell or piezometric records from the closely adjoining Drift do not necessarily reflect the behaviour of the water table within the mire.

A feature of WETMEC 2 sites is that there is little evidence of visible surface water outflow from many of the basins, certainly in summer and sometimes in winter, though only a few examples (Lin Can Moss and Cranberry Bog) occupy what appear to be closed basins. The absence of summer water outflows suggests either that the basins are isolated from groundwater outflows, or that they are in free connection with them, effectively forming a local expression of, and perhaps providing recharge to, the groundwater table. Both Lin Can Moss and Cranberry Bog occupy quite deep hollows within the surrounding Drift and, although little is known about the water table within the Drift, both would seem to be candidate discharge basins, but there is no surface evidence for this (Box 6.3).

Box 6.3: Lin Can Moss (Shropshire)

Lin Can Moss occupies a very small, and apparently closed, basin within glacial sands and gravels which overlie the Wilmslow Sandstone Formation of the Sherwood Sandstone (Bunter) Group (with which they are thought to have hydraulic continuity (Aspinwall and Co., 1994)). However, data from Harding (1996, cited by ESI (2003)) and Environmental Simulations International (2003) suggest that clay layers within the Drift in the vicinity of the basin may effectively isolate the basin from groundwater inputs, leaving it supplied only by precipitation and rain-generated run-off from the quite steep adjoining slopes.

Some WETMEC 2 basins in the Delamere Forest area are potentially in hydraulic connection with the sandsheet aquifer, but the extent to which there is water exchange between the two is much less clear (Box 6.4; see also WETMEC 3).

Box 6.4: Delamere Forest Mosses (Cheshire)

The Delamere Forest area has numerous, small mire-filled basins, some of which support WETMEC 2 and are potentially in hydraulic connection with the Delamere sandsheet aquifer. However, the actual relationship between the moss basins and the regional groundwater table has been little investigated and is opaque. WMC (2003) provide evidence which suggests that Oakmere (not sampled here), located on the crest of the groundwater divide and subject to large fluctuations in water levels, is in good hydraulic connection with the sandsheet aquifer. In their site account for Abbots Moss, Labadz and Butcher (2005) have also pointed to the coincidence between the elevation of Lily Pond and the groundwater levels as evidence for likely hydraulic continuity, but its status and that of the nearby Abbots Moss is uncertain, in the absence of appropriate topographical and piezometric data. None of these sites normally has a surface water outflow, and this could be taken as evidence of either good or poor hydraulic connection with the aquifer. There is little ecological reason to suspect significant groundwater outflows into many of these basins, though of course they could function primarily as recharge basins.

A small number of basins (such as Chartley Moss, Wybunbury Moss) are fed in part by visible groundwater inflows. However, the importance of groundwater to the hydrodynamics of the basin in general, and the WETMEC 2 stands in particular, is often far from clear. For example, at Wybunbury Moss, whilst there is visible groundwater inflow into the northern lagg, it is not known to what extent this penetrates directly into the basin and beneath WETMEC 2 – though it is clear that it is dispersed quite well along open and occluded ditches both into and around parts of the basin. On the south side, the water beneath the peat raft is thought likely to be in hydraulic continuity with the aquifer of the Wilkersley Halite Formation (which effectively forms the bottom of the basin on the south side and is confined by a cap of Boulder Clay). However, the piezometric head within the Halite in a borehole about 100 m south of the southern edge of the mire is some 10 m above the surface of the Moss, suggesting that there are considerable barriers to outflow into the mire basin.

Probably all basins supporting WETMEC 2 receive some rain-generated run-off, but in most cases this is derived from their immediate slopes and the catchment is often very small. Run-off appears generally to be intercepted by the lagg and it may contribute more to the water balance of the basin as a whole than to the WETMEC 2 areas. A few sites have land drainage inflows which may have more nuisance value as a source of nutrients than importance as water sources. For example, a field drain into Moorthwaite Moss leads to local enrichment within the mire; Flaxmere has various surface inflows, but these mostly flow through the site in ditches rather than enrich the ombrogenous areas, and the same is largely true for Cliburn Moss (Cumbria). The lagg at Cors y Llyn is enriched by field drainage and whilst most of this is intercepted by the lagg, there is in places a slight enrichment gradient extending towards, or into, WETMEC 2 surfaces. At Tarn Moss (Cumbria), some water inflows are effectively captured by peripheral ditches or flow paths; it is likely that before a stream inflow into the south-west part of the basin was diverted into a marginal drain it fed a soakway through the basin, with ombrogenous surfaces developed laterally to this. Perhaps the most remarkable example of interaction between WETMEC 2 and surface water inflow occurs at Biglands Bog (Cumbria) (Box 6.5).

Box 6.5: Biglands Bog (Cumbria)

Biglands Bog occupies a trough-like basin in North Cumbria. In places the basin is at least 15 m deep and, partly because of this, has not been comprehensively cored. However, Wheeler and Wells (1989) found a loose peat infill to a depth of 4.5 m over much of the surface, though the upper layers were much impregnated, apparently secondarily, with silt. The silt appears to be derived from the eutrophicated Bampton Beck which flows through the mire, so that the basin for the most part functions as a small floodplain rather than as a basin mire. Much of the loose infill alongside the Beck has been allocated to WETMEC 6, but at the north end, where the silt forms a thick deposit over consolidated peat, there is WETMEC 5. Much of the site is eutrophic and covered by beds of *Phalaris arundinacea* (S28), but a patch of WETMEC 2 occurs at the south end, alongside the Bampton Beck The persistence of this more or less ombrogenous surface alongside a eutrophic, flashy stream is remarkable and is almost certainly due to the buoyancy of the *Sphagnum* area, which is reported to move up and down by some 0.5 m in response to flooding and never to be inundated (F. Mawby, unpublished data). At this site, the ombrotrophic ‘raft’ is formed over more than 7.5 m depth of *Sphagnum* peat banded with unsampleable watery layers, and it may well be water penetration into the latter during flooding episodes which results in elevation of the *Sphagnum* surface, and the freedom from the deposition of alluvium that has occurred across most of the basin. Stratigraphical data (Wheeler and Wells, 1989) indicate that *Sphagnum*-rich peat strata, which may represent a former ombrogenous surface, at the north end of the mire are now covered by eutrophic vegetation, suggesting that the capacity of WETMEC 2 to persist in this context is partly determined by local circumstances.

6.5.9 WETMEC sub-types

Cluster 2 is segregated into three sub-clusters at the 72-cluster level. These appear to be based on the presence or absence of summer water outflow from the basins in which the stand is located and, in the case of examples with visible outflow, on the telluric water source. It should be noted that this refers to the presence of absence or telluric sources proximate to WETMEC 2 and it should not be concluded that the telluric supply necessarily influences WETMEC 2. To that extent, the sub-types are descriptive categorisations of the basins as a whole rather than of specific, necessary relevance to the functioning of WETMEC 2 surface.

WETMEC 2a: Ombrogenous Quag

CLUSTER: 2.1 (72-cluster level)

Examples at: Abbots Moss, Brown Moss, Cranberry Bog, Lin Can Moss, Moorthwaite Moss

This sub-cluster includes examples of WETMEC 2 in basins from which there is no normal summer outflow or visible inflow. It includes basins which appear to be completely closed (such as Cranberry Bog, Lin Can Moss) and basins which may outflow in particularly wet conditions (such as Abbots Moss, Brown Moss, Moorthwaite Moss). In some examples, attempts have been made to impound water in the basins by sluices in the outflow drains, but in summer the drains themselves appear normally to be dry.

WETMEC 2b: Ombrogenous Quag (GW-Fed Basin)

CLUSTER: 2.2 (72-cluster level)

Examples at: Chartley Moss, Wybunbury Moss

This sub-cluster includes examples of WETMEC 2 in basins with visible groundwater inflows and outflows, though in both Chartley and Wybunbury Mosses the relationship of the WETMEC 2 surface to the groundwater is not clear. Water chemical analyses from both mosses show slightly higher concentrations of some elements than might have been expected from precipitation sources alone (Proctor, 1992), especially at Chartley Moss, though this does not necessarily mean that the WETMEC 2 surfaces are not, to all intents and purposes, currently ombrotrophic. Both basins have various structural features in common in addition to groundwater supply (thick peat raft over a deep basin) and their clear clustering into Type 2.2 probably reflects these features as well as groundwater supply. Wybunbury has a particularly strong outflow through some drains, even in dry summer conditions.

Whereas drains dug into or across the mire surface can provide a conduit for water sourced from groundwater outflow, it is less clear to what extent peripheral telluric water sources normally penetrate into or beneath the WETMEC 2 surface. At Wybunbury Moss, despite its gross stratigraphical character with layers of unconsolidated watery material, the peat raft may offer significant resistance to near-surface lateral flow of telluric water from groundwater inflows along the northern edge. There is undoubtedly flow of telluric water in and alongside some ditches, but the seepages on the northern side, apparently slightly above the level of peat, result in considerable ponding of relatively base-rich surface water in the northern lagg. There is little clear evidence for a general, pervasive ingress of base-rich water from the northern margin through the whole peat raft (though Rieley and Page (1989) reported an increase in electrical conductivity in parts of the oligotrophic raft between 1981 and 1985; they also reported some evidence for coliform contamination of surface water from parts of the oligotrophic surface). Lack of penetration of telluric water could be a consequence of resistance to flow (the watery layers may not be laterally persistent) or of the hydraulic gradient, but relevant data are not available.

Bog pools in a quaking surface within the part groundwater-fed soakway north of Spiggot Hill on Tarn Moss (Malham) are also grouped in the sub-type, to which they are conceptually similar but structurally very different. They form an outlier to the main cluster.

WETMEC 2c: Ombrogenous Quag (SW-Fed Basin)

CLUSTER: 2.3 (72-cluster level)

Examples at: Biglands Bog, Cliburn Moss, Cors y Llyn, Flaxmere

Includes ombrogenous surfaces lateral to surface-water fed soakways (Cliburn Moss, Tarn Moss), laggs (Cors y Llyn), streams (Biglands Bog) and ditches (Flaxmere). At Flaxmere, most of the solid ombrogenous surface is clustered into WETMEC 1; the stand allocated to WETMEC 2c is a quaking surface over old turf ponds in the south-west corner of the site.

6.5.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 2 are summarised in Table 6.9. The primary feature of ombrogenous surfaces is that they are fed directly and exclusively by precipitation, though assessment of this status is usually based on topographical relationships and vegetation composition rather than hydrological studies. They are oligotrophic and acidic in character and based on peat which often has bog-building *Sphagnum* species. Some of the WETMEC 2 surfaces do support *S. magellanicum* and *S. papillosum*, but these are often not major constituents, and many examples are lawns of *Sphagnum recurvum*. WETMEC 2 surfaces have much thinner surface layers of ombrogenous peat than do most examples of WETMEC 1 and the surface is in closer proximity to telluric water. Water and peat samples taken from the surface layers may therefore include a component of underlying, weakly minerotrophic, material. The mean water pH value was slightly more than for WETMEC 1, and mean EC was somewhat lower (interestingly, mean K_{corr} values were also significantly smaller than from WETMEC 1), suggesting that the disparity between measured pH and conductivity was greater in WETMEC 2, though the reason for this is not clear. The highest pH values were associated with Great Ludderburn Moss (Cumbria), which has quite base-rich inflows into part of the mire, and with Hollas Moss (Cumbria) and Lin Can Moss (Salop). The last two sites are both small and in basins adjoined by farmland, where it is perhaps particularly likely that near-surface conditions will be weakly minerotrophic. Nonetheless, many of the surfaces allocated to WETMEC 2 had pH values similar to those of WETMEC 1.

The mean fertility of WETMEC 2 was also slightly, but significantly ($p < 0.05$) greater than in WETMEC 1, with some samples being at or just above the oligotrophic/mesotrophic boundary. Again, these include samples from Great Ludderburn Moss, but Lin Can Moss was at the low end of the oligotrophic category. Some samples from Abbots Moss (Cheshire) were also weakly mesotrophic. This enrichment could again perhaps represent some telluric influence, but the possibility of greater atmospheric inputs of nutrients, particularly N, cannot be discounted. Tallis (1973) has provided evidence for some chemical enrichment of *Sphagnum* surfaces in some Cheshire examples of WETMEC 2.Table 6.10 WETMEC 2: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	7.1	3	15
Summer water table (cm)	–5.8	–22.5	0
Rainfall (mm a^{-1})	907	692	1,480
PE (mm a^{-1})	568	462	614
Water pH	3.7	3.3	4.5
Soil pH	3.7	3.2	4.4
Conductivity (µS cm^{-1})	81	50	167
K_{corr} (µS cm^{-1})	3	–40	129
HCO_3 (mg l^{-1})	0	0	0
$Fertility_{Phal}$ (mg)	4.7	2	11
Eh^{10} (mV)	98	–29	286

See list of abbreviations in Appendix 1

Water levels relative to the surface are variable in some examples of this WETMEC because of microtopographical variation (hummocks, hollows and lawns), but other examples consist of extensive *Sphagnum* lawns. Pools sometimes occur, but are generally scarce compared to WETMEC 1; they were not sampled as part of the unit, which helps account for its relatively low maximum water level. In view of their lawn-like and buoyant surface character, it is perhaps not surprising than mean water tables were higher (and mean Eh values lower) than in examples of WETMEC 1. However, some of the more consolidated surfaces were well above the measured water table.

6.5.11 Ecological types

All examples of WETMEC 2 have acidic or base-poor peat and water. Most are oligotrophic, but a few are weakly mesotrophic (Table 6.11). The differences are generally small and do not obviously correspond with floristic differences, so the existing dataset does not commend the identification of separate ecological types.

Table 6.11 Percentage distribution of samples of WETMEC 2 in pH and fertility categories

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich			
Sub-neutral			
Base-poor	24	4	
Acidic	68	4	

6.5.12 Naturalness

Ombrogenous surfaces form by natural successional processes within wetlands, either hydroserally or by paludification, and often replace preceding fen in whole or part. They are considered to represent the climax wetland state in many situations, though in some dynamic wetland complexes, ombrogenous surfaces can sometimes become flooded with telluric water leading to a reversal in the normal successional sequence.

All the examples of WETMEC 2 surfaces examined here appear to have developed at least in part hydroserally within their basins (see 6.5.5). In all cases ‘doming’ is weak (or absent) and the ombrogenous peat is mostly thin, suggesting that these surfaces may represent immature bogs which may eventually develop domed surfaces more akin to those of

WETMEC 1. However, in some sites the ombrogenous peat is deeper than it appears, as it extends below the level of the telluric water table, apparently because of sinking of the buoyant raft. At Chartley and Wybunbury Mosses, this process has apparently been promoted by subsidence of the basin which contains the mire.

As well as occupying whole basins, some turf ponds dug within WETMEC 1, with buoyant surfaces, have become clustered within WETMEC 2 (such as the north basin of Cors y Llyn). At Moorthwaite Moss (Cumbria), WETMEC 2 occupies a sump-like depression which has been interpreted as an old peat working (Walker, 1966), close to a platform of solid, part-drained peat (WETMEC 4). The sump supports an example of *Erica tetralix–Sphagnum papillosum* raised and blanket mire (M18) vegetation similar to that which occurs in intact buoyant quag bogs, and if it had occupied most of the basin might well be considered unambiguously to be natural. However, Walker (1966) thinks it likely that the Moorthwaite basin once supported an ombrogenous bog "considerably above its present surface level", which has since been largely removed by peat digging. If correct, this raises the question of the degree to which the WETMEC 2 surfaces in other quag bogs are also a product, or residue, of past turbary, but little relevant information is available. A note filed by D.J. Bellamy in 1973 shows that he thought at least some of the surface of Abbots Moss has been cut over[1]. At Wybunbury Moss, there is manorial evidence for peat cutting rights from the sixteenth and seventeenth centuries and the 1845 Tithe Map shows much of the moss to be crossed by a series of (mostly narrow) strips, some of which are continuous with croft holdings in the field north of the moss. Leah *et al.* (1997) claim that "these strips were undoubtedly cut for peat", but it is not clear what evidence exists for this. Anecdotal information suggests that nineteenth century peat extraction was particularly focussed upon the drier, more consolidated drained peats at the eastern end of the mire (A and V Green, personal communication), though this does not preclude the possibility of earlier turbary elsewhere.

The main difficulties with the notion that the entire WETMEC 2 surface of basins in which it occurs is a product of past peat removal are: (a) the technical difficulties of extracting peat if the foundation was similar to the treacherous surface found today; and (b) the low value of the peats, if they were similar to the present-day surface peats. Of course, if the present-day surface represents the uncut residue, any peat extracted may have been much more consolidated, in which case the natural surfaces some of the quag bogs could have been once more akin to WETMEC 1 raised bog. Such suggestions are, of course, largely speculative and there is no known evidence that some examples of WETMEC 2 (such as Cors y Llyn, south basin) have ever been the subject, let alone the product, of past turbary.

WETMEC 2 surfaces show a strong tendency to colonisation by trees (mainly pines, but also birch and *Rhododendron ponticum*), except in the wettest locations. On unstable wet rafts, saplings may establish on elevated microsites, and the growing trees can become too heavy for the raft and sink into it, becoming either moribund or dead; but even so, unchecked this process can lead to an inexorable development of open woodland, often more readily than appears to be the case on WETMEC 1 surfaces. Such woodland is often perceived as undesirable, partly on the basis that in Britain ombrogenous surfaces are thought naturally to be treeless. However, it is far from certain that bog woodland vegetation is not a natural condition of WETMEC 2.

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[1] "It appears that the south and south-west margins of the bog have been cut, questionably for peat, but there are certainly depressions too regular in outline to be natural. Open pine wood occupies much of the southern region of the bog, some of the larger trees growing on the peat ridges that separate the old cuts, the depressions themselves being filled with actively-growing carpets of *Sphagnum.*"

6.5.13 Conservation value

As with WETMEC 1, little-damaged ombrogenous surfaces, especially those rich in bog-building Sphagna support a priority EC Habitats Directive interest feature (active raised bogs) (see Tables 3.3 and 6.4). They also support the “transition mire and quaking bog” interest feature. M18 (*Erica tetralix–Sphagnum papillosum* raised and blanket mire) occurs in WETMEC 2, but only in 40 per cent of the samples. Many surfaces (56 per cent), especially in the agricultural lowlands, are dominated strongly by *Sphagnum recurvum*, often forming a rather impoverished lawn-like vegetation in which some typical M18 species (such as *Andromeda polifolia*) are either sparse or absent. This vegetation is perhaps best referred to M2, though in this context the epithet ‘bog pool’ is inappropriate (and Rodwell (1991b) appears to consider such vegetation an impoverished form of M18; see account of M18 for further discussion). Tallis (1973) has shown that in some Cheshire examples, the *S. recurvum* surface is a recent replacement for a more diverse *Sphagnum*-based vegetation (which would probably have been referable to M18). Some of the (usually drier) surfaces can become colonised by birch, to form a bog woodland community with strongest affinities to *Betula pubescens–Molinia caerulea* woodland (W4).

WETMEC 2 supports only a rather small range of plant species probably because, as with WETMEC 1, the typically base-poor, waterlogged, mostly oligotrophic surfaces provide a difficult environment for the growth of most plant species. Thirty-six species were recorded in the samples referred to WETMEC 2. These include most of the species recorded from WETMEC 1, supplemented by a small range of species which may be indicative of, or a legacy from, weakly minerotrophic conditions. These include such widespread species as *Juncus effusus* and *Typha latifolia*, along with two nationally rare species (*Carex lasiocarpa* and *C. limosa*). *Andromeda polifolia*, also nationally rare, occurred in some samples, and some local or regionally rare species, such as *S. magellanicum* and *S. papillosum*, were also recorded – but not as frequently as in WETMEC 1.

Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 2 is given in Table 6.3.

6.5.14 Vulnerability

The topographical context and wetness of WETMEC 2 surfaces means that they are less vulnerable to some forms of damage than those of WETMEC 1. In most cases, peat extraction would be both difficult and unrewarding. Some basins could be drained, but the benefits of this are limited, though in some cases afforestation might be practicable. Past drainage has occurred in some basins (in some instances in preparation for forestry), but the partial drainage of certain wet basins may have increased the extent of WETMEC 2 at the expense of WETMEC 3 and open water (Lind, 1949; Tallis, 1973).

As many of the basins are embedded within permeable Drift deposits, lowering of groundwater tables could be detrimental to this WETMEC. However, the buoyancy of the mat suggests that in the wetter examples at least, a reduction of water levels would not necessarily be associated with surface drying. Moreover, as discussed above, the degree of hydraulic connection between the peat aquifer and the mineral aquifer may be constrained by low-permeability layers.

The buoyant character of WETMEC 2 may mean that it has only limited susceptibility to nutrient enrichment of any telluric inflows, unless these are directed onto its surface. Nonetheless, Tallis (1973) suggests that in some sites, the recent development of *Sphagnum recurvum* surfaces could be associated with some degree of enrichment. However, it is not clear if this is likely to be a function of changes in the character of telluric water inflows, or if it is a response to greater rates of dry and wet atmospheric deposition of nutrients over the last 100 to 200 years.

The fairly close relationship between the ombrotrophic surface and underlying telluric water means that water management initiatives (drainage and so on) can lead to ingress of telluric water into this WETMEC more readily than is the case with WETMEC 1. This effect can be particularly significant in contexts where the hydraulic gradient encourages telluric water flow (WETMEC sub-types 2b and 2c). This can be seen particularly well at Wybunbury Moss (sub-type 2b), where occluded drains leading from the northern (groundwater-fed) edge towards the centre of the mire are associated with tongues of minerotrophic conditions (and vegetation). In places inflow of septic tank discharge, apparently initially focussed on ditch lines, appears to have led to pervasive decomposition and deconsolidation of the peat (Rieley and Page, 1989). This may well have resulted in a feedback increase in permeability of the upper peat raft, enhancing further the spread of minerotrophic conditions across the site into parts of the former *Sphagnum* area. The pervasiveness of this effect at Wybunbury is almost certainly a consequence of the strong groundwater sources along the northern edge of the ombrotrophic part of the mire, and of drainage flow across it.

Ongoing growth of trees, especially those that are not deciduous, is likely to increase the dryness of any mire surfaces which depend on rainfall as a significant water source, due to increased interception and evapotranspiration losses.

6.6 WETMEC 3: Buoyant, Weakly Minerotrophic, Surfaces (transition bogs)

6.6.1 Outline

Many examples of this unit are weakly minerotrophic surfaces in basins which also support WETMEC 2 bogs (Buoyant Ombrogenous Surfaces). They sometimes form quite large stands in which ombrogenous surfaces are embedded, or form the lagg or soakways in basins that are primarily occupied by bog. The unit thus shares many of the characteristics of WETMEC 2, the primary difference being that stands of WETMEC 3 have surfaces which are more nearly level with the telluric water table, and hence often wetter and potentially more influenced by this than is the case with WETMEC 2. WETMEC 3 also includes, as outliers to the main cluster, similar surfaces in locations which do not support ombrogenous stands, including some isolated weakly minerotrophic rafts in Broadland. Schematic sections are provided in Figure 6.12.

6.6.2 Occurrence

Example sites: Abbots Moss, Bowscale Moss, Cors y Llyn (Radnor), Eycott Hill, Forest Camp, Hollas Moss, Lin Can Moss, Tarn Moss, Wybunbury Moss

Outlier sites: Catfield and Irstead Fens, Loynton Moss

Most of the samples clustered within this WETMEC were from basin mires in the North and West of England, with only a few examples from elsewhere (Figure 6.11).

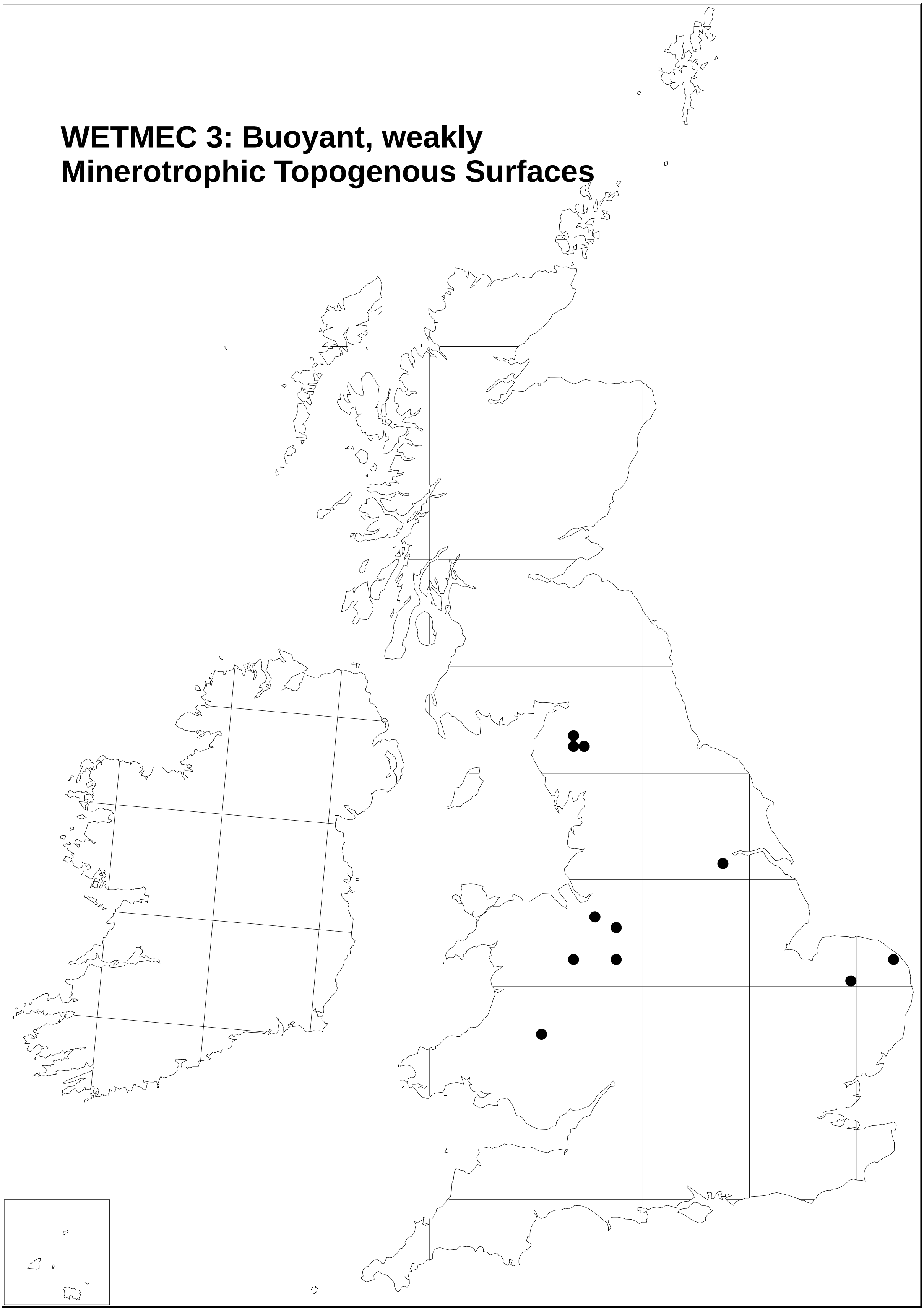


Figure 6.11 Distribution of examples of WETMEC 3 in sites sampled in England and Wales

6.6.3 Summary characteristics

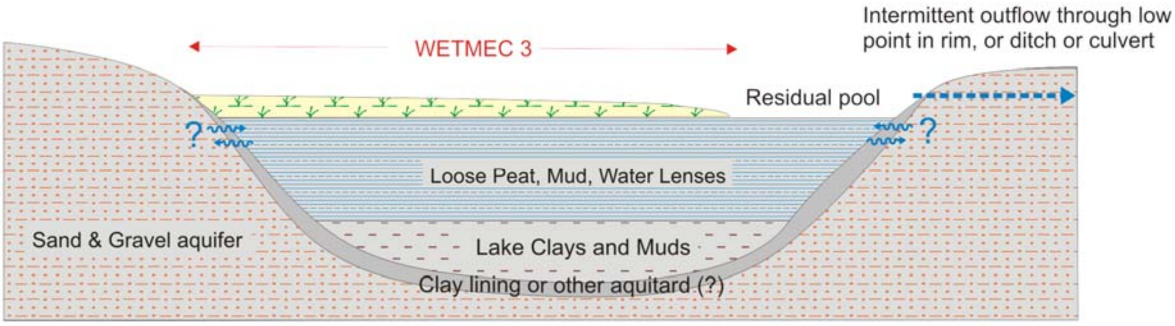
Situation		Basins. Sometimes sumps in other wetland types or within peat workings.
Size		Mostly small (sometimes very small).
Location		Mostly sampled from North and West, including the West Midland basins.
Surface relief		Typically lawns on more or less flat surfaces, sometimes grading into (often fairly deep) pools, sometimes forming swamps with 'swimming' *Sphagnum.* Can have localised, mostly low hummocks (which may provide the nuclei for development in WETMEC 2).
Hydrotopography		Weakly minerotrophic.
Water:	***supply***	Precipitation with some telluric water influence.
	regime	Water table generally high (mostly just sub-surface).
	distribution	Uncertain. Receives some telluric water inflows but water exchange is probably generally small.
	superficial	Shallow pools; sometimes inflow or outflow soakways.
Substratum		Buoyant, loose surface, usually underlain by a watery mix of peat and muds. May be underlain by lake muds. Examples in kettle holes are often in fluvio-glacial deposits but may be separated from these by low-permeability layers.
	peat depth	Typically 2 – 15 m of peat and/or muds.
	peat humification	Usually with a shallow spongy surface; underlying material often less solid and less humified.
	peat composition	Typically dominated by *Sphagnum* spp., *Eriophorum* spp. upon loose peat or watery material.
	permeability	In most sites the surface peat is loose and buoyant but actual permeability little known; lower layers more variable but often very watery. Basin may have a low-permeability infill or clay lining separating it from underlying mineral deposit.
Ecological types		Oligotrophic, acidic.
Associated WETMECs		Some examples can form a complex with various other WETMECs, especially WETMEC 2. Can form a lagg around WETMEC 2 with limited flow of telluric water.
Natural status		Natural successional state formed by terrestrialisation. May also occupy some turf ponds.
Use		Conservation. Usually too wet for any other use, though some sites were once turbaries.
Conservation value		Supports EU SAC habitat ('transition mire and quaking bog'), though species diversity is generally low (sometimes increased by damage).
Vulnerability		Drainage and nutrient enrichment (from both telluric and meteoric sources).

WETMEC 3: BUOYANT, WEAKLY MINEROTROPHIC SURFACES

[For other examples, see WETMEC 2]

WETMEC 3a: Bog-transition quag (± closed basin)
(*e.g.* Forest Camp)

- WETMEC surface is probably fed primarily by precipitation
- basin may be ± 'sealed' from aquifer (but little documented)
- magnitude and in some contexts direction of any water exchange with mineral aquifer is uncertain (if connected some basins may recharge the aquifer)
- the buoyant surface is hydroseral, over either a natural pool or reflooded turbaries



WETMEC 3b: Bog-transition quag (± open basin)
(*e.g.* Tarn Moss)

- WETMEC surface is probably fed primarily by precipitation
- streams and rain-generated run-off make a significant contribution to the water balance, though this supply may sometimes be channelled through WETMEC 3 as a soakway (WETMEC 19) (not illustrated)
- may be minor, local groundwater outflow into basin from sand lenses in Till
- the buoyant surface is hydroseral, over either a natural pool or reflooded turbaries

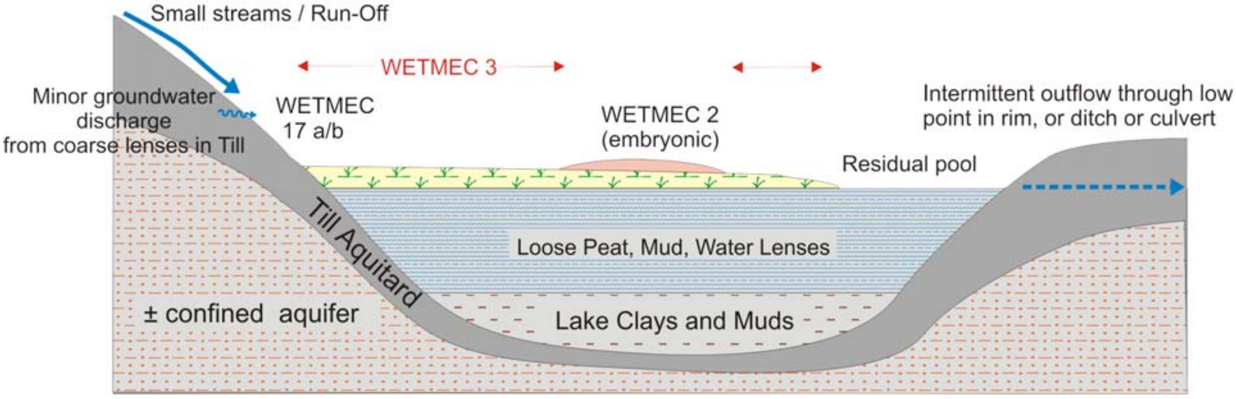


Figure 6.12 Schematic sections of Buoyant, Weakly Minerotrophic, Topogenous Surfaces (WETMEC 3)

6.6.4 Concept and description

CLUSTER: 3

WETMEC 3 mostly contains examples of buoyant, wet surfaces in deep basins which have little or no known groundwater supply but are fed primarily by precipitation, supplemented at least during wet periods by some surface water inflows, either rain-generated run-off, field drainage or stream inflow. Many such basins support ombrogenous surfaces (WETMEC 2) and examples of WETMEC 3 typically occur intermixed with these, or form a peripheral surface water-fed lagg (note that laggs with a substantial groundwater input are clustered elsewhere). WETMEC 3 also occupies some (usually small) basins which do not support WETMEC 2 (such as Forest Camp).

Like WETMEC 2, the surface of WETMEC 3 is usually buoyant, or strongly quaking, but is mostly more so, and often more treacherous. In some systems (such as Abbots Moss) WETMEC 2 may gradually expand over WETMEC 3 surfaces, except in locations (such as around the margins of the basin or along soakways) where the regular ingress of telluric water prevents the development of ombrogenous conditions. The WETMEC appears always to have developed hydroserally, most frequently in ground ice depressions in which it may once have occupied the entire basin, but also in sumps within some other types of mire (such as Eycott Hill) or sometimes in turf ponds within more solid ombrogenous deposits, in (mostly marginal) locations where there is some (small) influence of inflowing telluric water (such as Bowscale Moss, Cliburn Moss, Flaxmere, Cors y Llyn).

Affinities and recognition

The samples allocated to this unit formed a distinctive cluster in the multivariate classification (see Figure 6.1), with rather little internal variability, but two sub-clusters were distinguished at the 72-cluster stage of the analysis. The key diagnostic features are the occurrence of a buoyant vegetation surface at more or less the same level as the telluric water table. WETMEC 3 is distinguished from WETMEC 2 (which often occupies the same basins) by the surface of the latter being some 20 to 50 cm above the telluric level. WETMEC 2 is also usually somewhat more consolidated, as well as being drier, whereas examples of WETMEC 3 typically form a buoyant or semi-floating surface, and in some particularly unconsolidated examples, plants of *Sphagnum* are 'swimming' in telluric water, with or without the binding rhizomes of such species as *Carex rostrata* and *Eriophorum angustifolium.*

Basins supporting WETMEC 3 typically do not have obvious surface water or groundwater inflows and outflows. It appears that although the surface is essentially minerotrophic, precipitation is an important water source, to the extent that in some circumstances it can form a lens of rainfall-sourced water perched upon telluric water. In some instances, the present-day conditions appear to be a consequence of deliberate water management, including the diversion of former surface inflows around the basin (such as Tarn Moss, Cumbria). Some buoyant mats of vegetation that are remote from telluric water inflows in other contexts are also clustered here.

Lagg fens that are fed by significant groundwater inflow are classified elsewhere. However, samples of the southern lagg of Wybunbury Moss were clustered here, reflecting the fact that although this basin as a whole is undoubtedly strongly groundwater-fed, groundwater inflow appears to be primarily into the northern lagg: the southern lagg is sandwiched between the main ombrogenous deposit and a steeply rising slope of boulder clay and is not known to have a significant groundwater supply.

Some samples from Loynton Moss (Staffs) have also been clustered here, though they are strikingly different from the others. They form outliers and appear to have been placed here because they have no other better location. Summary data values for the WETMEC (Table 6.13) have been calculated both with and without the Loynton Moss samples.

6.6.5 Origins and development

There is little information available about the development of WETMEC 3 stands. Where they occur in ground ice depressions, the ontogenic considerations discussed for WETMEC 2 are probably equally valid for WETMEC 3, and the two types may form a successional sequence, in the direction WETMEC 3 > WETMEC 2. However, local reversals of this process can be observed, as in places where the establishment of scrub (most usually *Pinus*) on a WETMEC 2 surface has resulted in it sinking below the level of the telluric water table.

Some insights into the development of WETMEC 3 can be obtained from studies on the Delamere basin mires, where WETMEC 3 is widespread (Box 6.6). Some information is also available on the development and history of Loynton Moss (Staffs), though this is an outlier site with an idiosyncratic history (Box 6.39).

Box 6.6: WETMEC 3 in the Delamere Basin Mires

WETMEC 3 is widespread in the small basins embedded within the Delamere sandsheet. There is documented evidence of the recent encroachment of *Sphagnum recurvum*-dominated examples of WETMEC 3 over former open water. For example, Tallis (1973) reported that spread of the *Sphagnum* surface in the Forest Camp basins was in response to a lowering of the water table as a consequence of drainage operations some 40 years previously. In one basin, this apparently resulted in the complete terrestrialisation of former open water. Lind (1949) also reported rapid terrestrialisation of ‘Blackmere’ (= Black Lake), resulting in the loss of open water in favour of *Sphagnum* dominance, which may also have been related to some attempted drainage. She also observed that the development of a *S. recurvum* raft along part of the western side of Hatchmere was consequent upon a fall in the water level of the lake. Tallis (1973) used these observations to suggest that “*it is probable that the development of a Sphagnum-dominated vegetation was dependent upon the establishment of shallow water conditions (with a water depth of perhaps less than two metres*)”. The encroachment of Hatchmere was of particular interest in view of the relatively base-rich character of the water in this lake, which has a quite strong inflow and outflow of surface water, compared with the more weakly minerotrophic conditions found in the more closed basins[1].

[1] Hatchmere was not included in the Framework survey. The particular hydrological circumstances in which the *Sphagnum* raft has developed here suggest that, had samples been available, they would *not* have been clustered into WETMEC 3, but it is mentioned here because of its relevance to WETMEC 3 sites.

Box 6.7: Loynton Moss (Blakemere Pool, Staffs.)

An anomalous stand included within WETMEC 3 occupies the eastern end of Loynton Moss, Staffs. This has various similarities with other members in that it represents a quaking hydroseral surface developed over a residual pool (Blakemere Pool) within a glacial basin, but differs in being much more base rich and fertile. Blakemere was once naturally fed by a stream draining a large agricultural catchment to the east of the site. The basin is immediately west of the deep Grub Street Cutting of the Shropshire Union Canal, dug in the 1830s. The canal has probably influenced components of the natural water supply to the basin, but the stream input was maintained until recently by an aqueduct across the canal. However, concerns about the quality of this water, and water damage to the aqueduct, resulted in the re-routing of this supply north-westwards along the eastern side of the canal and there now appear to be few significant surface water inflow drains into the moss. Hence, the Clustan classification reflects rather accurately the *current* water supply mechanisms to this site, and its ecological differences from other examples of WETMEC 3 are a legacy of a former, different supply mechanism. Interestingly, there is evidence of surface acidification in some hydroseral locations around the former Blake Mere, perhaps partly in response to the reduction of surface water inflow.

In its former (non-WETMEC 3) state, Blakemere is notable for providing one of the first known descriptions of raft-based terrestrialisation of a shallow pool: in the seventeenth century marginal vegetation "*doe yearly grow forward upon the surface of the water, three or four yards in seven years, the water standing under them*" (Plot, 1686). Such overgrowth was apparently constrained, to prevent the loss of cattle, by cutting away the margins – which provides a salutary reminder that interference in natural ecohydrological processes (*i.e.* 'management') is of long standing!

6.6.6 Situation and surface relief

Most (72 per cent) of the samples were from parts of discrete hydroseral basins, often kettle holes and mostly small and isodiametric. Most basins were mainly closed, or had just a weak surface inflow and/or outflow. Some examples were in peat workings within ombrogenous peat, which receive some leakage of telluric water from peripheral sources (such as Cors y Llyn, north basin). Others occurred in peat workings in some other contexts including troughs (17 per cent) (such as Bowscale Moss) and floodplains (11 per cent) (such as Broadland floodplains) that are well isolated from telluric water inflows.

The surface is typically comprised of lawns on more or less flat surfaces (Table 6.12), sometimes grading into (often fairly deep) pools, and sometimes forming swamps with 'swimming' *Sphagnum.* It can support localised, mostly low hummocks (which may provide the nuclei for development in WETMEC 2), and sometimes occurs within turf ponds.

Table 6.12 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 3

	Mean	1	2	3	4	5	6	7
Surface layer	5.8			17		11	28	44
Lower layer	3.3	6	33	28	17		6	11
Basal substratum	2	2	89	9	5		9	
Slope	1	100					X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.6.7 Substratum

Most samples were on quite deep peat (mean: 3.9 m depth; range 0.7 – 8 m). The samples on shallow peat were all from Cliburn Moss, from where it is possible that much peat has been removed. In most sites the surface peat is loose and buoyant, and perhaps more permeable than some, but not necessarily all, of the lower substrata layers (Table 6.12). It is often sufficiently consolidated to support access, but in some swampy pools and at the interface with open water access is not normally possible. In some cases the buoyant surface is underlain by a deep deposit of watery material, similar to that in WETMEC 2, but in others (especially in turf ponds) deep solid peat occurs only a short distance (0.5 – 0.8 m) below the surface, and at Cliburn Moss the loose deposit referable to this WETMEC rests almost directly upon a thin layer of basal peat. Basin examples are often located in fluvio-glacial deposits, but the basin infill is often partly or wholly separated from these by lake sediments.

Some basins appear to be clay-lined and in others, other layers may function as aquitards (see details of Water Supply for WETMEC 2 (page 173)). In the Broadland sites, the peat infill of the floodplain is thought to be separated from the underlying Crag aquifer by a clay layer; Cliburn Moss appears to be underlain by Till (clay or sandy-clay).

6.6.8 Water supply

The basin examples of WETMEC 3 occur in situations similar to those supporting WETMEC 2 and the considerations, and uncertainties, about water supply discussed for WETMEC 2 apply equally here. Particular uncertainties relate to connectivity to aquifers within which some basins are embedded, as in the Delamere Forest (Box 6.4). In some locations (such as the Lily Pond basin, Forest Camp), the water table in WETMEC 3 is thought to be at about the same level as the regional aquifer in this vicinity (Labadz and Butcher, 2005), which may suggest hydraulic connectivity. However, in the absence of studies on the hydraulic interactions, this remains uncertain. In general, there is little ecological reason to suppose significant inflows from a minerotrophic aquifer, though it is possible that in some circumstances the mire basins may help recharge a connected mineral aquifer, rather than receive inflows from it.

Some basins with WETMEC 3 have been noted for their apparent fluctuations in water level. For example, at Black Lake (not sampled in the current project but referable to WETMEC 3), Lind (1949) reported that the basin was covered with a *Sphagnum*-dominated vegetation whereas “twenty years ago there was a good area of open water”. However, Tallis (1973) stated that in 1969 “even after a prolonged dry spell there was considerable open water”. The ecohydrological significance of these observations is uncertain.

In some basin sites WETMEC 3 occurs in the marginal lagg, in contexts where this represents the interface between the central WETMEC 2 and the rising upland slopes rather than a lagg stream with significant water flow. At Wybunbury Moss it occupies the lagg along the southern edge of the mire, where there is thought to be little groundwater inflow and little flow through the lagg (the groundwater-fed lagg along the northern edge of Wybunbury has been clustered into WETMEC 19).

The Broadland examples of this WETMEC all occur in terrestrialised turf ponds and the water supply considerations described for WETMEC 6 (to which the Broadland WETMEC 3 samples are transitional) largely also apply to these surfaces, except that telluric water has little direct impact upon surface conditions, but appears to support a rainwater lens. Loynton Moss is anomalous and appears currently to be fed only by precipitation (Box 6.39).

Little is known about evapotranspirative losses from this WETMEC, but the observations made for WETMEC 2 (6.5.8) probably apply equally here. In some of the immature examples, where the surface is inundated or only slightly above the water table for much of the year, evapotranspiration losses may be similar to, or somewhat above, losses from open water. In some of the examples in turf ponds in Broadland, the *Sphagnum*-dominated surface is variably over-topped by tall helophytes (rooted in more base-rich peat and telluric water beneath the surface). It is quite possible that these may increase evapotranspirative losses from the stand as a whole, but their effect upon the *Sphagnum* surfaces is much less clear, especially when they are sufficiently sparse to result in minimal interception losses; it is possible that they may have little effect upon, or even increase, the hydration of the WETMEC 3 surfaces. The same is almost certainly not the case when the surfaces become colonised by closed-canopy scrub, which may significantly reduce rainwater supply to the buoyant surface.

6.6.9 WETMEC sub-types

Samples in Cluster 3 have been allocated into two main sub-clusters, which appear to relate to the degree of water throughflow. These are broadly comparable with two of the sub-clusters recognised for WETMEC 2, but there is not a comparable groundwater-fed sub-cluster.

WETMEC 3a: Bog-Transition Quag (± closed basin)

CLUSTER: 3.1 (72-cluster level)

> *Examples at*: Abbots Moss, Bowscale Moss, Cors y Llyn, Forest Camp, Hollas Moss
> *Outliers at:* Loynton Moss

This includes examples of WETMEC 3 in basins which have little obvious inflow (such as Hollas Moss) or outflow, except in particularly wet conditions (such as Abbots Moss, Forest Camp). It also includes examples in peripheral turf ponds in ombrogenous deposits, where the telluric influence appears to be maintained by episodic flow of minerotrophic water *into* the ombrogenous deposit (such as Bowscale Moss, Cors y Llyn). Some of these basins have artificial inflow and outflow channels which appear not to carry water for much of the year. Hollas Moss can drain at high water levels through a pipe to the nearby terrestrialised Silver Tarn.

WETMEC 3b: Bog-Transition Quag (± open basin)

CLUSTER: 3.2 (72-cluster level)

> *Examples at*: Cors y Llyn (lagg fen), Eycott Hill, Tarn Moss
> *Outliers at:* Catfield and Irstead Fens

This includes examples of WETMEC 3 in or near laggs or soakways which receive some drainage inflows. Throughflow is likely to include outflow from adjoining ombrogenous deposits as well as land drainage inputs.

6.6.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 3 are summarised in Table 6.13. The primary feature of WETMEC 3 surfaces is that they are fed by telluric water, but there is often little evidence for significant groundwater or surface water inflows. The surfaces are thus perhaps best seen as being fed primarily by precipitation, with some enrichment by contact with, and perhaps supply from, proximate minerotrophic sources. In consequence, many examples are oligotrophic or mesotrophic and acidic or base-poor. In general, the least fertile and most base-poor examples are sub-type 3a, which occupy the same basins as WETMEC 2. The example with the lowest pH (3.6) and conductivity (59 µS cm^{-1}) was from the Lily Pond in the Forest Camp near Abbots Moss. These values are more typical of WETMEC 2, but the sample here was undoubtedly from a telluric location. Whilst limited, such hydrochemical data reinforce the suggestion that these basins may receive little groundwater influence. The most fertile and base-rich examples are those which receive some inflows from enriched sources (Bowscale Moss, Cliburn Moss, Cors y Llyn) or which formerly received significant surface water inflows (Loynton Moss, Tarn Moss). One sample from Cors y Llyn, which appears to receive some enriched run-off from farmland, was eutrophic. Interestingly, the examples from turf ponds in Broadland were not very fertile (around 7–9 mg *Phalaris*) though they did tend to be amongst the most base-rich.

The water table was generally high (mostly just sub-surface) but some examples had shallow surface water (max: 4.4 cm agl), whereas the anomalous samples from Loynton Moss had very low water tables.

Table 6.13 WETMEC 3: values of selected ecohydrological variables

Values in parentheses refer to all WETMEC 3 samples excluding those from Loynton Moss.

Variable	Mean	Minimum	Maximum
PAL depth (m)	4.4 (4.2)	0.7	8
Summer water table (cm)	–6.7 (–3.2)	–38 (–12)	4.4
Rainfall (mm a^{-1})	1,062 (1,109)	613	1,484
PE (mm a^{-1})	547 (51)	454	625
Water pH	4.7	3.6	5.7
Soil pH	4.8	3.7	5.7
Conductivity (µS cm^{-1})	152	59	444
K_{corr} (µS cm^{-1})	136 (136)	–20	443
HCO_3 (mg l^{-1})	23 (14.6)	0	117 (53)
$Fertility_{Phal}$ (mg)	13 (10.3)	6	21
Eh^{10} (mV)	203 (208)	–29	306

See list of abbreviations in Appendix 1

6.6.11 Ecological types

Examples of WETMEC 3 occupy a quite wide range of pH and fertility conditions (Table 6.14), but no base-rich examples were recorded and the majority were either mesotrophic or oligotrophic. Eutrophic examples are largely atypical of the unit, and occur in particular situations in response to local enrichment sources.

Table 6.14 Percentage distribution of samples of WETMEC 3 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich			
Sub-neutral		22	2
Base-poor	22	39	6
Acidic		6	

Oligotrophic/mesotrophic, acidic/base-poor

These samples all came from examples of WETMEC sub-type 3a, from more or less closed basins, or basins with little or no surface inflow–outflow.

Mesotrophic, sub-neutral

These samples all came from examples of WETMEC sub-type 3b, from locations with some surface water inflow–outflow, and from some lowland base-rich locations (Broadland). In some of these cases, the high pH values measured may reflect the character of the water and peat beneath the buoyant raft rather than that feeding the raft. They include samples from locations in Tarn Moss (Cumbria) where some of the enrichment may be a legacy of former surface water flow into the basin.

Eutrophic, base-poor

This includes samples from near the edge of the north basin of Cors y Llyn, at the transition between the ombrotrophic centre and the run-off fed marginal lagg.

Eutrophic, sub-neutral

This includes two samples from the former Blakemere area of Loynton Moss, and represents a situation which was formerly surface-water fed. It is not known to what extent the eutrophic conditions are a legacy of former surface water inflows, or a product of nutrient release from peat drying in the basin in response to a reduction of the water table.

6.6.12 Naturalness

All the examples of WETMEC 3 surfaces have developed hydroserally. They occur either within basins where they may be natural or in peat cuttings where reflooded turf ponds provide a comparable habitat. It is possible that some of the apparently undisturbed surfaces in some small basins may also have been cut-over (see section in WETMEC 2). Whilst all examples of WETMEC 3 are hydroseral, in some basins their expansion over open water is recent, and may be in response to partial drainage (Lind, 1949; Tallis, 1973).

Many examples of WETMEC 3 are not stable; for many, a successional trend of sub-type 3a towards WETMEC 2 is expected, except in locations where there is a persistent telluric water influence (as in marginal laggs such as Abbot's Moss). Some examples of sub-type 3b may also ultimately progress to WETMEC 2 (such as Tarn Moss), but the successional development of this sub-type in peat pits is uncertain. There is little reason to suspect that examples in Broadland will progress to WETMEC 2; as with some of the other turf pond WETMECs, succession to WETMEC 5 (Summer-Dry Floodplains) may be more likely.

6.6.13 Conservation value

Samples of WETMEC 3 support a range of (mostly acidic) plant communities, and examples may support the "transition mire and quaking bog" EU SAC interest feature (see Tables 3.3 and 6.4). Communities sampled were: M4: (22%); BDC: (16%); M2: (11%); M21: (11%); S27: (11%); M6: (5%); M17: (5%); S12: (5%); W1: (5%); W4: (5%). One of the units listed here is a non-NVC unit, which has been described by Wheeler (1980c): BDC: *Betulo-Dryopteridetum* *cristatae.* In Broadland, all samples of WETMEC 3 support examples of the *Betulo-Dryopteridetum cristatae*, which contains the nationally rare fern *Dryopteris cristata.* This distinctive community does not clearly fit any NVC type, but its greatest affinities appear to be with M5 (*Carex rostrata–Sphagnum squarrosum* mire). The *Betulo-Dryopteridetum* contains a number of uncommon species that appear to be relict from an earlier, more base-rich, seral phase, in addition to acidophilous taxa, and it accounts for 23 of the 78 species found in samples allocated to WETMEC 3, and for about half of the 12 nationally rare species recorded. These latter include: *Andromeda polifolia, Calamagrostis canescens, Carex lasiocarpa, Carex magellanica, Carex pauciflora, Cladium mariscus, Dryopteris cristata, Osmunda regalis, Peucedanum palustre, Ranunculus lingua, Sphagnum teres, Thelypteris palustris.* Some examples of WETMEC 3 in lowland England are particularly important in supporting a number of species that are locally uncommon. For example, in Cheshire the only known locality for *Eleocharis multicaulis* and some of the small number of sites for *Rhynchospora alba* are all in WETMEC 3. Likewise, species such as *Sphagnum magellanicum* and *S. papillosum* are rare in, or absent from, some parts of lowland England and Wales and WETMEC 3 can provide an important locale for these.

Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 3 is given in Table 6.3.

6.6.14 Vulnerability

The topographical context and wetness of WETMEC 3 surfaces in deep basins means that they may have limited vulnerability to direct damage. Some basins could perhaps be drained, but the benefits of this are generally likely to be limited. Past drainage has occurred in some basins, but in some instances it seems to have increased the extent of WETMEC 3 at the expense of open water (Lind, 1949; Tallis, 1973). As many of the WETMEC 3 basins are embedded within permeable Drift deposits, lowering of groundwater tables could be detrimental to this WETMEC. However, the buoyancy of the mat suggests that in the wetter examples at least, a reduction of water levels would not necessarily be associated with surface drying. Moreover, as discussed elsewhere, hydraulic connection between the peat aquifer and the mineral aquifer is not well understood and may be constrained by low-permeability layers.

Perhaps the main threat to examples of WETMEC 3 in basins is successional change into WETMEC 2. Successional change is perhaps an even greater issue for examples of WETMEC 3 in turf ponds, because progressive consolidation of the peat infill is likely to lead to loss of the buoyant surface that is a defining feature of this WETMEC. The successional outcome of grounding is likely to be strongly context dependent. In Broadland, it could mean that surfaces which have hitherto stayed above any flooding episodes could become periodically inundated with base-rich water, and change in character, but at present the only indications are that as the slightly elevated surfaces thicken, they become more prone to drying in summer and colonisation by birch.

Some examples of this WETMEC that border enriched sources, and receive enriched run-off or land drainage, show evidence of nutrient enrichment. Whilst this is not necessarily prejudicial to the WETMEC *per se*, it is likely to result in changes to the vegetation in, and possibly adjoining, the WETMEC.

6.7 WETMEC 4: Drained Ombrotrophic Surfaces (in bogs and fens)

6.7.1 Outline

WETMEC 4 includes a rather heterogeneous range of sites united by the twin features of a surface that is consistently well above the summer water table and which is currently supplied directly only by precipitation. It includes both ombrogenous and non-ombrogenous sites. The latter are now apparently ombrotrophic as a result of disruption of their natural water supply mechanisms, usually because of drainage. However, they retain minerotrophic peat and can be quite base rich, though there is sometimes evidence of some surface acidification. Schematic sections are provided in Figure 6.14.

6.7.2 Occurrence

*Example sites***:** Barnby Broad and North Cove, Cornard Mere, Cors Erddreiniog, Cors Nantisaf, Holme Fen, Lakenheath Poor's Fen, The Moors (Bishop's Waltham), Woodwalton Fen

This type of wetland is widespread and has undoubtedly been undersampled in this project, partly because many sites and samples that could be assigned to it do not really support mire vegetation. The distribution of examples of WETMEC 4 in sites sampled is shown in Figure 6.13. They represent some of the wetter examples of this type of habitat, and retain a number of mire species, though this may sometimes be partly due to inertia. The only deeply drained bog included in this project is Holme Fen, though numerous others exist: the FENBASE database identifies some 166 drained bog sites in England which, in whole or part, have surfaces that are referable to this WETMEC. Comprehensive resource data are not available for drained fen sites, but they are likely to be equally numerous.

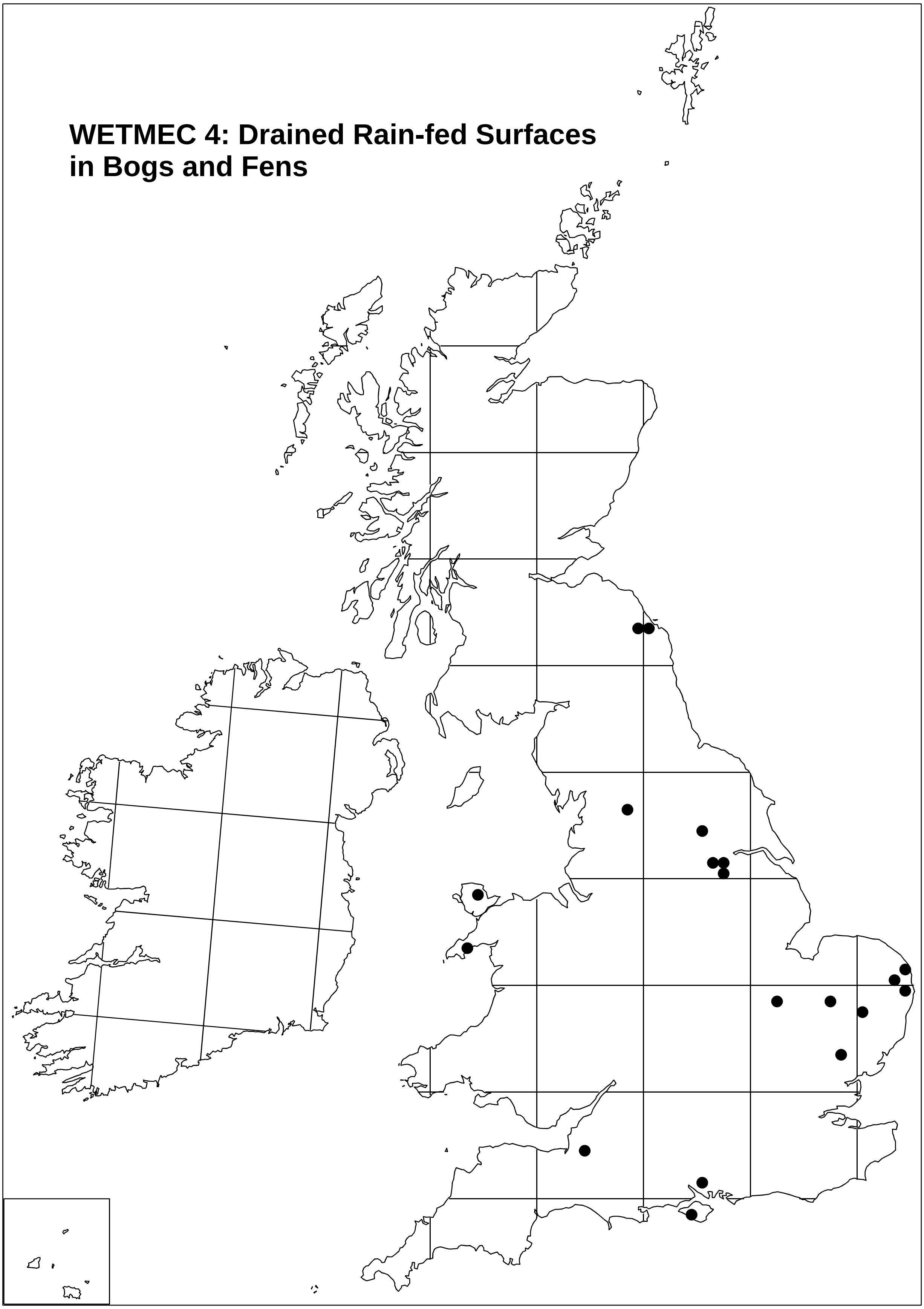


Figure 6.13 Distribution of examples of WETMEC 4 in sites sampled in England and Wales

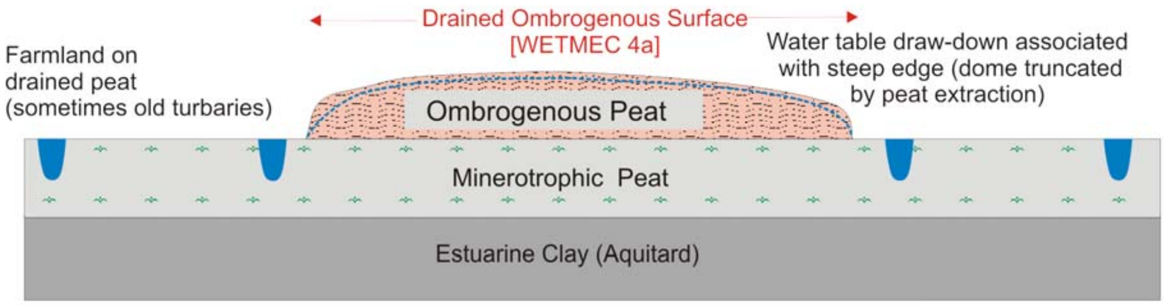
6.7.3 Summary characteristics

Situation	Mostly in topogenous locations, mainly sampled from floodplains.
Size	Large to small.
Location	Widespread, but mainly sampled from East Anglia.
Surface relief	Flat to gently sloping, but with some undulations associated with drainage.
Hydrotopography	Ombrotrophic.
Water: ***supply***	Precipitation (perhaps supported by regional water table).
regime	Summer water table deep below surface. Likely to fluctuate according to rainfall and efficiency of drainage.
distribution	Vertical flow downwards into peat; some lateral flow.
superficial	None, other than in drains
Substratum	Ombrogenous peat upon fen peat, or fen peat now fed only by rainfall.
peat depth	0.7 – 5 m in examples examined.
peat humification	Surface strongly decomposed and well humified, May be less humified below this, with some fresh horizons, but basal peats often rather solid and humified, or replaced by lake deposits.
peat composition	Ombrogenous peat with *Sphagnum* spp., *Eriophorum* spp. and ericaceous shrubs upon fen peat, or fen peat composed of brushwood, *Cladium mariscus* and so on.
permeability	Wetland and basal substrata probably generally of low permeability.
Ecological types	Base-poor, oligotrophic to base-rich, eutrophic.
Associated WETMECs	None.
Natural status	A much-drained surface but retaining some form of semi-natural habitat. [Many drained peatlands elsewhere have disappeared through past peat extraction and conversion to farmland or forest].
Use	Conservation and amenity.
Conservation value	Ombrogenous surface is usually highly impoverished, and may support birch wood rather than bog plants. Insome cases (such as Holme Fen) the birch wood may have some conservation and amenity value, but not as a wetland. Some former fen surfaces support a wide range of plant species, especially wet-grassland types.
Vulnerability	Some examples could be drained more effectively, or converted more comprehensively to agriculture and so on. Spontaneous colonisation by trees, which can occur readily, can accentuate the low summer water tables by increasing interception and evapotranspiration losses.

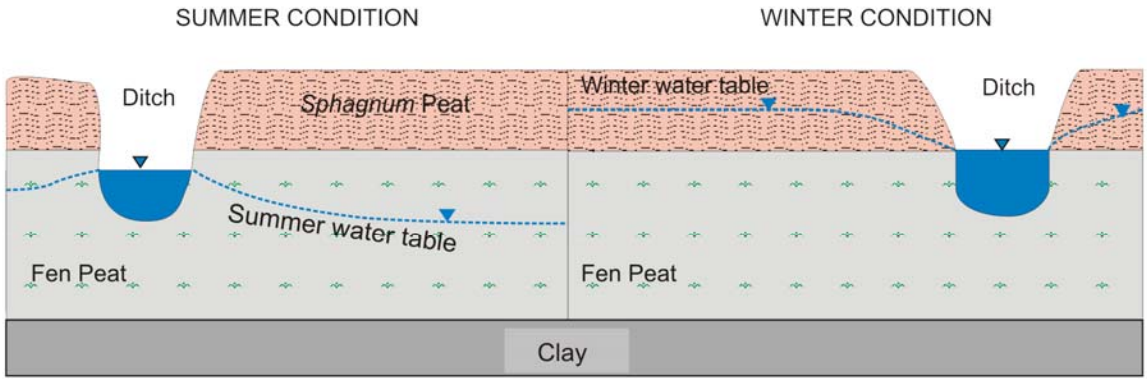
WETMEC 4: DRAINED OMBROTROPHIC SURFACES (IN BOGS & FENS)

WETMEC 4a: Drained ombrogenous bog
(*e.g.* Holme Fen)

- surface of remnant bog is elevated above surrounding drained peatland
- surface is fed exclusively by precipitation
- residual dome may be directly drained (not shown), but even without surface drainage the summer water table may be consistently well below the surface; this may be caused by draw-down associated with the margins and because the uppermost peat has impaired hydroregulation function (especially low specific yield)



WETMEC 4a: Drained ombrogenous bog - seasonal relationship to water table



WETMEC 4b: Drained ombrotrophic fen
(*e.g.* Woodwalton Fen)

- surface of residual wetland is slightly elevated above the surrounding drained and subsided peat
- no groundwater source. Surface water may be maintained at quite high level in adjoining dykes, but these generally have limited influence in lateral recharge of the adjoining peat, which is often well humified and dense, and WETMEC 4 surface is fed mostly only by precipitation
- flooding with surface water may occur occasionally, but is not a consistent component of the annual water budget and may have nuisance value (a) by import of nutrients and silt; (b) by creating unusually wet conditions (especially in contexts where evacuation of the flood water is slow)
- bog is surrounded by drained (minerotrophic) peat, some of which was once covered by bog peat, and which now forms farmland
- water levels in the drains can potentially affect the bog water table, but the extent to which this is the case depends on local factors (especially peat hydraulic conductivity and topography)

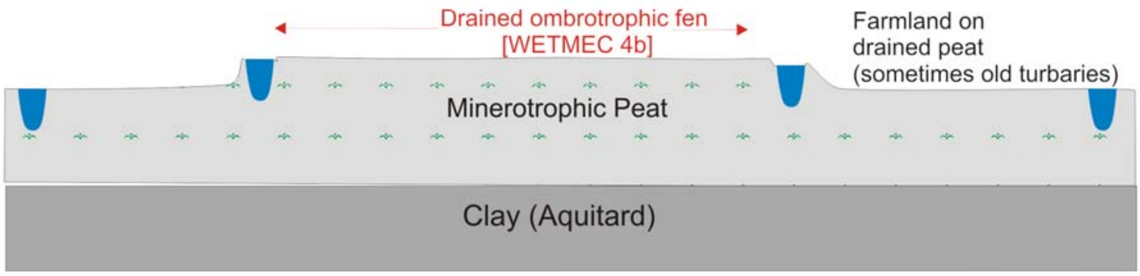


Figure 6.14 Schematic sections of Drained Ombrotrophic Surfaces (in bogs and fens) (WETMEC 4)

6.7.4 Concept and description

CLUSTER*: 4*

WETMEC 4 essentially contains a number of peatland sites which share the feature of being quite well drained but which still posses at least some vestiges of wetland habitat (as opposed to those which support an essentially dryland habitat, or which have been converted to farmland). The only water source to the surface is thought to be precipitation, but in some cases this is because drainage has disrupted the natural water supply mechanisms which would once have fed the surface with telluric water. Thus, whilst all sites in WETMEC 4 are *ombrotrophic* (mostly exclusively rain-fed) only some are also *ombrogenous* ('rain made', where their surface was formed in ombrotrophic conditions).

In some cases WETMEC 4 covers entire sites; in others, it represents a drained portion of an otherwise wetter site. Both circumstances have been much undersampled in the present project.

Most of the samples clustered within WETMEC 4 were from (partly) drained fens. Some are in floodplains, and the cluster is clearly related to the stands from Summer-Dry Floodplains (WETMEC 5). The examples from Eastern England were all in partly drained locations where the surface appears not normally to receive telluric water inputs. In some instances, these sites occupy pump-drained floodplains, and have potential for ready re-instatement to a telluric-supplied surface.

Some samples from Corsydd Erddreiniog and especially Nantisaf have also been allocated to WETMEC 4. These contiguous sites have been part-drained (though in recent years, water management measures have elevated the water table across parts of them). The samples that were clustered into WETMEC 4 were from fairly central locations in the compartments, elevated well above the water level in the ditches on a shallow dome of peat. They have low summer water tables (for example, 80 cm bgl) and their surfaces appear now to be exclusively fed by precipitation. At these sites, surfaces closer to the drains have higher water tables and have been clustered as 'Groundwater-Fed Bottoms with Aquitard' (WETMEC 8), and further consideration of their water supply is discussed in the section for that WETMEC. It is possible that in these sites the surfaces distant from groundwater sources were once naturally ombrotrophic, but no stratigraphic evidence for this proposition has been found (peat-winning could have removed former ombrogenous surfaces).

Numerous examples of part-drained ombrogenous peatland surfaces occur in Britain, some with vestigial mire vegetation. All could probably be allocated to WETMEC 4, but only two have been included in this project (Holme Fen and Woodwalton Fen); these wetland relicts within drained floodplain near the north-west edge of the Fenland Basin, are scarcely similar to the drained raised bogs of North and West England.

Affinities and recognition

Many of the stands included in WETMEC 4 are from Eastern England and were sampled and analysed in Phase 1 of this project (Wheeler and Shaw, 2000a). However, with that smaller dataset these samples did not form a cohesive cluster, but were allocated to dry versions of other WETMECs; for example, the samples from Holme Fen were clustered with some of the drier, more acidic, examples of 'Summer-Dry Floodplains'. However, in the present analysis a discrete cluster of dry, drained, rain-fed fens and bogs on deep peat has emerged. Its nomination of 'Drained Ombrotrophic Surfaces' reflects the fact that the surfaces are now more or less exclusively rain-fed. Note, however, that the surfaces of some of the drier examples of WETMEC 5 may be also mainly rain-fed, and the difference between the drained fens in WETMEC 4 and the drier WETMEC 5 examples is essentially one of degree – the latter usually having higher summer water tables than the former. Some samples from both Wicken Fen and Woodwalton Fen were transitional between WETMEC 4 and WETMEC 5, but these samples were not generally as dry as those allocated to WETMEC 4, and in the case of Woodwalton Fen at least, receive episodic winter flooding from an adjoining watercourse. These stands were generally allocated to WETMEC 5, though a sample from the unflooded acidic area at the south end of Woodwalton Fen was clustered unambiguously within WETMEC 4.

The grouping of former bog and fen sites within the same water supply cluster may seem surprising, but the only real difference between the Holme Fen (former bog) stands and the other stands in WETMEC 4 is that Holme Fen has a surface layer of ombrogenous peat. They are thus essentially ‘rain-fed legacy ombrogenous’ rather than ‘rain-fed legacy telluric’. Moreover, some of the ‘rain-fed legacy telluric’ stands may represent sites where a former ombrogenous layer has been removed by peat extraction to expose the underlying fen peat. This appears to be the case at Woodwalton Fen where remnant patches of more acidic soils may represent thin, residual ombrogenous deposits (Poore, 1956).

The amalgamation of samples into WETMEC 4 reflects the dominance of drainage and dry rain-fed surface conditions, and may obscure differences in underlying telluric water supply mechanisms. It is likely that WETMEC 4 surfaces can be formed by drainage of a number of progenitor WETMECs, but this is not reflected in the current clustering solution. It is possible that acquisition of more data for this type of wetland could lead to a segregation of WETMEC 4 into units that better reflect any underlying telluric water supply.

6.7.5 Origins and development

Like the sites allocated to this WETMEC, developmental patterns are quite variable. They can be illustrated by examples (Box 6.39). Others, in Broadland, have developmental sequences broadly similar to those of WETMEC 5 (see 6.8.5). Those at Corsydd Erddreiniog and Nantisaf are similar to those described for WETMEC 8 (see 6.11.6).

6.7.6 Situation and surface relief

WETMEC 4 samples were all from topogenous situations: 29 per cent in basins, 43 per cent on floodplains and seven per cent in valley-bottom troughs. Twenty-one per cent occur in topogenous valleyhead locations. The surface is generally flat to gently sloping but with some undulations, often associated with drainage structures (Table 6.15).

Table 6.15 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 4

	Mean	1	2	3	4	5	6	7
Surface layer permeability	2.3		72	29				
Lower layer permeability	2.6	7	36	50	7			
Basal substratum permeability	1.8	29	64	7			9	
Slope	1.1	86	14				X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

Box 6.8: WETMEC 4, development case studies

1. Holme Fen (Cambridgeshire)

Holme Fen represents an example of a raised bog remnant in Fenland. An example of its gross stratigraphy has been recorded by Money, Wheeler and James (1998):

Depth (cm bgl)	Peat Type	Macrofossils
0 – 150	Ombrogenous peat	*Sphagnum*
150 – 250	Herbaceous fen peat	*Cladium, Phragmites, Menyanthes, Scorpidium*
250 – 300	Brushwood peat	
300 +	Clay (presumed Oxford Clay)	

The ombrogenous peat at Holme Fen has developed serally from a phase of herbaceous fen. The relative freshness of the preceding herbaceous fen peat, and the occurrence of hypnoid mosses within it, suggests that it formed in a wet fen environment. Although conjectural, the characteristics of the herbaceous fen peat and location of the site suggest that it may represent a former natural example of a surface water percolation floodplain (WETMEC 6). As is currently the case in parts of Broadland, the buoyant surfaces associated with WETMEC 6 can provide a suitable *locus* for *Sphagnum* establishment, and may well have been appropriate for the initiation of raised bog in Fenland (by providing a consistently wet, but not much flooded, fen surface).

The start of ombrogenous peat formation in the Holme Fen area predates the Neolithic marine transgression. The accumulating dome of bog peat was not overwhelmed by the transgression, and may have helped restrict the landward deposition of buttery clay during this phase. During the subsequent marine regression, ombrogenous bog subsequently expanded seawards, over some of the clays. However, the eastern parts of the ombrogenous deposit later became flooded by calcareous water, associated with the formation of Whittlesey Mere and reducing the area of ombrogenous surface. Whittlesey Mere and the adjoining fen was eventually drained (1851), leaving some of the remaining ombrogenous surface as a wetland remnant which, although part-drained, was not reclaimed.

2. Cornard Mere (Suffolk)

Shaw (1991) reported four peat cores, taken from various points in the Cornard Mere basin. Only one reached the bottom of the wetland infill. This consisted of a rather uniform profile of a very dry, stiff, crumbly, amorphous peat overlying a layer of stiff clay at 1.8 m depth. The others, taken down to 4.5 m depth, revealed that much of the site was originally a deep, open water, marl-precipitating lake which had gradually terrestrialised. The lower layers of peat were often quite wet and composed of swamp species such as *Equisetum fluviatile*, in places with marl. In the wettest central area, wet fen/swamp peat continued almost to the surface, though the uppermost horizons were still strongly oxidised. The oxidised nature of many of the horizons is probably a result of the drying out of the site. It is not known if the clay found at the western bridge extends beneath the whole basin, but existing evidence does point to widespread lake marl deposits.

6.7.7 Substratum

Most examples of WETMEC 4 occur on a quite deep wetland infill (which may include both peat and lake sediments) (mean depth of 3.4 m). The substrata are generally likely to have low-permeability characteristics (Table 6.15). The surface layer of peat was typically very dense, consolidated and humified, and the mean value for assessed surface layer permeability was the lowest of all WETMECs. Lower in the profile the peat was sometimes rather less solid, but it was still mostly consolidated (or, in some sites, was composed of silts or lake muds). The basal substratum also typically had low-permeability characteristics, often consisting of a silt or clay – either Till or an estuarine deposit.

6.7.8 Water supply

Little is known about the hydrodynamics of WETMEC 4 surfaces. Most samples allocated to this WETMEC had very low summer water tables. The peat surface was mostly elevated well above the telluric water level, and there can be little doubt that the surface is now fed exclusively by precipitation. The presence of dense peat, lake deposits and/or clay at depth, may help to isolate the surface from any groundwater upflow. Some surface water inflow may occur from adjoining ditches, but the magnitude of any water exchange is not known. In many cases, the ditches are more likely to act as drains than as water sources, and in those instances where high water levels are maintained within adjoining dykes (such as Woodwalton Fen), water exchange in either direction may be constrained by low hydraulic conductivity wetland deposits (Poore, 1956).

Some systems (such as Holme Fen) have long been ombrotrophic, but most others appear to represent minerotrophic surfaces that are now exclusively rain-fed, on account of disruption to their natural mechanisms of telluric water supply.

6.7.9 WETMEC sub-types

WETMEC 4 has not been segregated into coherent sub-clusters below the 36-cluster level. The following two WETMEC sub-types have been identified informally, based on the former character of water supply to the surface (based on the composition of the surface peat).

WETMEC 4a: Drained Ombrogenous Bog

CLUSTER: 4 (informal sub-cluster)

Examples at: Holme Fen, Woodwalton Fen

This includes former raised bog surfaces, sampled at Holme Fen and at parts of Woodwalton Fen (the remnant surface ombrogenous peat at Woodwalton Fen is mostly very thin, on account of former turbary). Many other part-drained raised bog sites could be allocated to this unit.

WETMEC 4b: Drained Ombrotrophic Fen

CLUSTER: 4 (informal sub-cluster)

Examples at: Barnby Broad, Cornard Mere, Corsydd Erddreiniog and Nantisaf, Lakenheath Fen, Woodwalton Fen

This includes surfaces formed from minerotrophic (fen) peat. In some instances (as in parts of Woodwalton Fen), these represent locations from which the former cover of ombrogenous peat has been removed by turbary.

6.7.10 Ecological characteristics

WETMEC 4 has the lowest mean summer water table of all WETMECs. Highest values (higher than 20 cm bgl) were recorded from parts of Cors Nantisaf and the grazing levels at

Barnby Broad, but deeper water tables were also found in other samples from these sites, pointing to the continuous variation and intergradation into other WETMECs that occurs. A low value of 80 cm bgl was also recorded at Cors Nantisaf, and very low values (deeper than 1 m bgl) were recorded in various locations at Cornard Mere.

In some respects the WETMEC is rather variable (Table 6.16), reflecting the wide range of contexts in which it occurs. Drained ombrogenous surfaces such as Holme Fen typically have low pH and fertility, whereas drained legacy-telluric surfaces are often much more base-rich (though some samples from Cors Nantisaf were base-poor, more comparable with drained raised bogs, with pH 4.5, K_{corr} 80 µS cm^{-1}). Very high EC values (> 2,000 µS cm^{-1}) were measured in some samples from Cornard Mere, but the cause of this was not obvious. However, whilst some surfaces were eutrophic, hypertrophic conditions were not recorded, possibly because these locations are no longer inundated with enriched surface water. It is suspected that in some sites nutrient release associated with drying-induced mineralisation may create somewhat higher fertilities that would have occurred in a wet state, but few data are available on this.

Table 6.16 WETMEC 4: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	3.4	0.7	5.0
Summer water table (cm)	–59	–180	–9
Rainfall (mm a^{-1})	689	547	994
PE (mm a^{-1})	611	590	627
Water pH	6.3	3.2	6.9
Soil pH	5.7	3.8	7.2
Conductivity (µS cm^{-1})	918	85	2,150
K_{corr} (µS cm^{-1})	917	80	2,150
HCO_3 (mg l^{-1})	197	24	371
Fertility$_{Phal}$ (mg)	10	4	23
Eh^{10} (mV)	146	47	245

See list of abbreviations in Appendix 1

6.7.11 Ecological types

Samples in WETMEC 4 are united primarily in being drained and rather dry, with precipitation as the primary water source to the surface. Former ombrogenous surfaces generally remain oligotrophic and base-poor when drained (and may become even more acidic than their undrained counterparts because of oxidative processes). Former telluric surfaces can also show a tendency to acidify, especially when the undrained peat was rich in reduced forms of sulphur, but examples can often remain in a base-rich state, presumably as a legacy of residual bases. Examples of WETMEC 4 thus occupy a wide range of base-richness and fertility conditions (Table 6.17).

Table 6.17 Percentage distribution of samples of WETMEC 4 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich		38	23
Sub-neutral		15	2
Base-poor	20		
Acidic	3		

Oligotrophic, acidic/base-poor

This category includes surfaces of drained raised bogs (such as Holme Fen), residual patches of dry, acidic peat in cut-over fens (such as Woodwalton Fen) and elevated acidic surfaces of uncertain origin but isolated from telluric water sources, at Corsydd Erddreiniog and Nantisaf. This type is probably widespread amongst raised bog remnants throughout England and Wales, but was little sampled in the present survey, partly because many such remnants are scarcely mire, or are heavily wooded (as at much of Holme Fen). The vegetation supported is variable, but *Molinia* is typically an important constituent as part of M16, M25 and the *Cladio-Molinietum ericetosum* of Wheeler (1980a) – a unit which does not fit neatly into the NVC scheme, but which is closest to M25. Some samples from Cors Nantisaf have closest NVC affinities with M21, but this is a poor match and the vegetation is best regarded as having uncertain affinities

Mesotrophic, sub-neutral/base-rich

The majority of samples in this category also tended to be dominated by *Molinia*, but usually as M24. One example (Lakenheath Poor's Fen) had closest affinities with S24c, though it was a poor match, and some others were referable to a version of M22 (grazing levels at Barnby Broad).

Eutrophic, base-rich/sub-neutral

The samples of vegetation associated with this type were all rank and species poor, and were referable to NVC communities S5, S25a and S26. They are exemplified by many of the stands at Cornard Mere. The reasons for the eutrophic conditions are not known, but nutrient release by mineralisation at the dry surface of the deep peat may provide a contributory explanation.

6.7.12 Naturalness

The surfaces represented by WETMEC 4 samples are highly modified. All have been drained and some (perhaps many) have had peat removed. Examples of WETMEC 4a, which retain some of the former ombrogenous peat, are arguably somewhat more 'natural' than any surfaces of WETMEC 4b from which this layer has been stripped. Raised bogs were once widespread in parts of England, especially in the North and West, as their numerous drained remnants demonstrate. The former distribution of raised bog in Eastern England is less easy to establish, not least because peat cutting has removed all trace of it from some areas and drained remnants do not necessarily persist. Raised bog was undoubtedly extensively developed in parts of Fenland (Godwin, 1978), but there is no evidence for it in Broadland, possibly because in their natural state the Broadland fens were too frequently flooded by river water to permit any substantial accumulation of *Sphagnum* peat. The present 'islands' of *Sphagnum* in some Broadland turf ponds are not raised bogs, even in miniature, and it is doubtful they will become so. It seems more likely that as the turf pond peats progressively consolidate, their surfaces may lose the characteristics that permit the survival of *Sphagnum* on a base-rich floodplain (see WETMECs 3 and 6). It is possible that raised bogs may once have occurred as a late-hydroseral phase in some basins in Eastern England. For example, Burton and Hodgson (1987) report that at Cranberry Rough (Hockham Mere) "*on five hectares of the land there is up to 80 cm of oligotrophic raised moss peat (Turbary Moor series)*".

Whilst some of the WETMEC 4b samples represent minerotrophic surfaces that were once covered by ombrogenous peat, others may always have been minerotrophic. In these instances, the natural water supply mechanism may have been similar to that of WETMEC 5, of which in a sense they represent an extreme example. However, Cornard Mere represents a terrestrialised lake, apparently formerly fed by stream and probably groundwater inputs, which is now rather dry because of diversion of stream input, drainage and groundwater abstraction.

6.7.13 Conservation value

The drained mire surfaces included in WETMEC 4 have variable species interest, and this is not always specifically related to wetlands. For example, Holme Fen mostly supports mature birch wood, with a small area of wet heath (containing a small amount of remnant *Sphagnum*). The birch wood at this site is regarded as a fine example of its type, but conservation activity on part-damaged ombrogenous surfaces in lowland England often consists of removal of birch scrub. At Corsydd Erddreiniog and Nantisaf, the elevated surfaces referable to WETMEC 4 are rather acidic and contain a rather impoverished mixture of species typical of acidic and base-rich fens, with *Erica tetralix* and *Narthecium ossifragum* interspersed with patches of *Cladium mariscus* and *Juncus subnodulosus.* The remnant acidic surface at the south end of Woodwalton Fen has some similarities with this, though is a good deal more rank and impoverished.

The more base-rich samples included in WETMEC 4 are variable in character. Cornard Mere essentially comprises dry, rank, species-poor herbaceous vegetation. By contrast, some of the partly drained grazing levels support various types of fen meadow (*Juncus subnodulosus–Cirsium palustre* fen meadow (M22), *Juncus effusus/acutiflorus–Galium palustre* rush pasture (M23), *Molinia caerulea–Cirsium dissectum* fen meadow (M24)), where they have not been converted for other forms of agriculture. Samples of residual fen from Lakenheath Poor's Fen are perhaps best seen as either M22 or M24, though in the 1970s and 1980s the presence of both *Lathyrus palustris* and *Peucedanum palustre* gave the site affinities to *Phragmites australis–Peucedanum palustre* tall herb fen (S24), and to Wicken Fen. [Neither of these species is thought still to occur.]

The overall breakdown of communities represented in the WETMEC 4 samples is: CM: (15%); M24: (15%); S26: (15%); M16: (7%); M21: (7%); M22: (7%); S05: (7%); S24: (7%); S25: (7%); S27: (7%). One of the units listed here (CM: *Cladio-Molinietum*) is a non-NVC unit which has been described by Wheeler (1980a). It has greatest floristic affinities variably with M24 and M25. The samples allocated to M21 come from Cors Nantisaf and represent a rather dry and impoverished version of this community, which are a poor match – but better than with any other *NVC* type. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 4 is given in Table 6.3.

Altogether, 56 plant species were recorded in samples of WETMEC 4. These include a number of local or regionally uncommon species, such as *Carex pseudocyperus, Lysimachia vulgaris, Rumex hydrolapathum* and *Schoenus nigricans.* Some of these species (*C. pseudocyperus* and *R. hydrolapathum*) are frequently found in swamp or wet fen habitats, and their persistence in examples of WETMEC 4 is notable and possibly precarious. Some base-rich examples of WETMEC 4 support one or more nationally rare plant species, but the total number recorded is small: *Calamagrostis canescens, Carex appropinquata, Cladium mariscus, Dactylorhiza praetermissa, Thalictrum flavum.* By comparison with the more base-rich examples of WETMEC 4, examples of drained, acidic ombrogenous surfaces are often very species poor, and may support little more than *Eriophorum vaginatum* and *Molinia caerulea* as representatives of wetland species, along with some less desirable species such as birch and bracken. [The nationally rare *Andromeda polifolia* has been observed on ombrogenous surfaces referable to WETMEC 4, but was not present in any of the examples sampled.]

6.7.14 Vulnerability

Quite deep drainage, both on site and sometimes in the surroundings, has already occurred at the sites within this WETMEC. In the absence of grazing, tree invasion (especially by birch) can occur readily, and is seen generally as undesirable (though at Holme Fen the mature birch woodland is considered an important feature). Some sites offer potential for rewetting, where topographical and water management circumstances are appropriate. Rewetting of drained ombrogenous surfaces can sometimes be difficult, depending on local circumstances, and may have undesirable knock-on effects. For example, at Cors Nantisaf, significant elevation of the water table in the highest locations might well require inundation of the lower surroundings.

In some circumstances, restoration procedures may benefit from peat removal (to reduce the surface level, to remove an enriched mineralised surface and, sometimes, to configure the surface better to store rainwater). However, in some bog sites the depth of ombrogenous peat is fairly shallow (around 1.5 m at Holme Fen) and deep peat removal may expose the underlying fen peat. The introduction of telluric water to the peat surface, or the exposure of minerotrophic peat, is likely to be prejudicial in the short term to any attempt to restore ombrotrophic conditions, though in the longer term seral ombrotrophication may result from a range of starting conditions. Indeed, in some contexts a minerotrophic starting point may provide a more sustainable, if slower, basis for bog restoration than ombrotrophic conditions (see Money and Wheeler, 1999).

6.8 WETMEC 5: Summer-Dry Floodplains

6.8.1 Outline

This category covers wetlands on floodplains, usually on deep peat or alluvium, fed mainly by surface water (episodic flooding and some bank seepage) and by rainfall, but with significant constraints on lateral water flow through the deposit, which usually has low permeability charactetristics. Examples are typically wet in winter (when they may be flooded by river water) but are often rather dry during the summer. Schematic sections are provided in Figure 6.16.

6.8.2 Occurrence

Example sites: Berry Hall Fens, Biglands Bog, Broad Fen Dilham, Burgh Common, Catfield and Irstead Fens, Cors Gyfelog, Drabblegate Common, Esthwaite North Fen, Strumpshaw and Bradeston Marsh, Wheatfen and Rockland Broad, Wicken Fen, Woodbastwick Fens and Marshes, Woodwalton Fen

Outlier sites: Cranberry Rough (Hockham Mere)

Most of the samples clustered within this WETMEC were from the extensive floodplain wetlands of the Norfolk Broadland and the remnant fens of Fenland, but a few examples were available from elsewhere (Figure 6.15). It probably occurs in all of the Broadland fen sites, but only those in which extensive examples are known (and have been sampled) are listed below. This WETMEC may be rather widespread outwith Broadland, but undersampled, in some cases because eligible sites are not designated as having particular conservation importance. For example, Drabblegate Common (which was included) is not designated as an SSSI.

The East Anglian examples mostly occupy typical floodplain sites, that is, they generally occupy the waterlogged floodplains of mature rivers. Other examples are also typical of floodplain contexts, for example along the Black Beck near its debouchment into Esthwaite Water. However, WETMEC 5 also occurs in other topographical contexts, such as some infilled basins where throughflowing streams have (usually small) associated floodplains (such as Biglands Bog (Cumbria), Cors Gyfelog (Gwynedd)). In some basins (such as Cranberry Rough, Norfolk) the characteristics that cluster the samples within WETMEC 5 appear to have been produced by partial drainage.

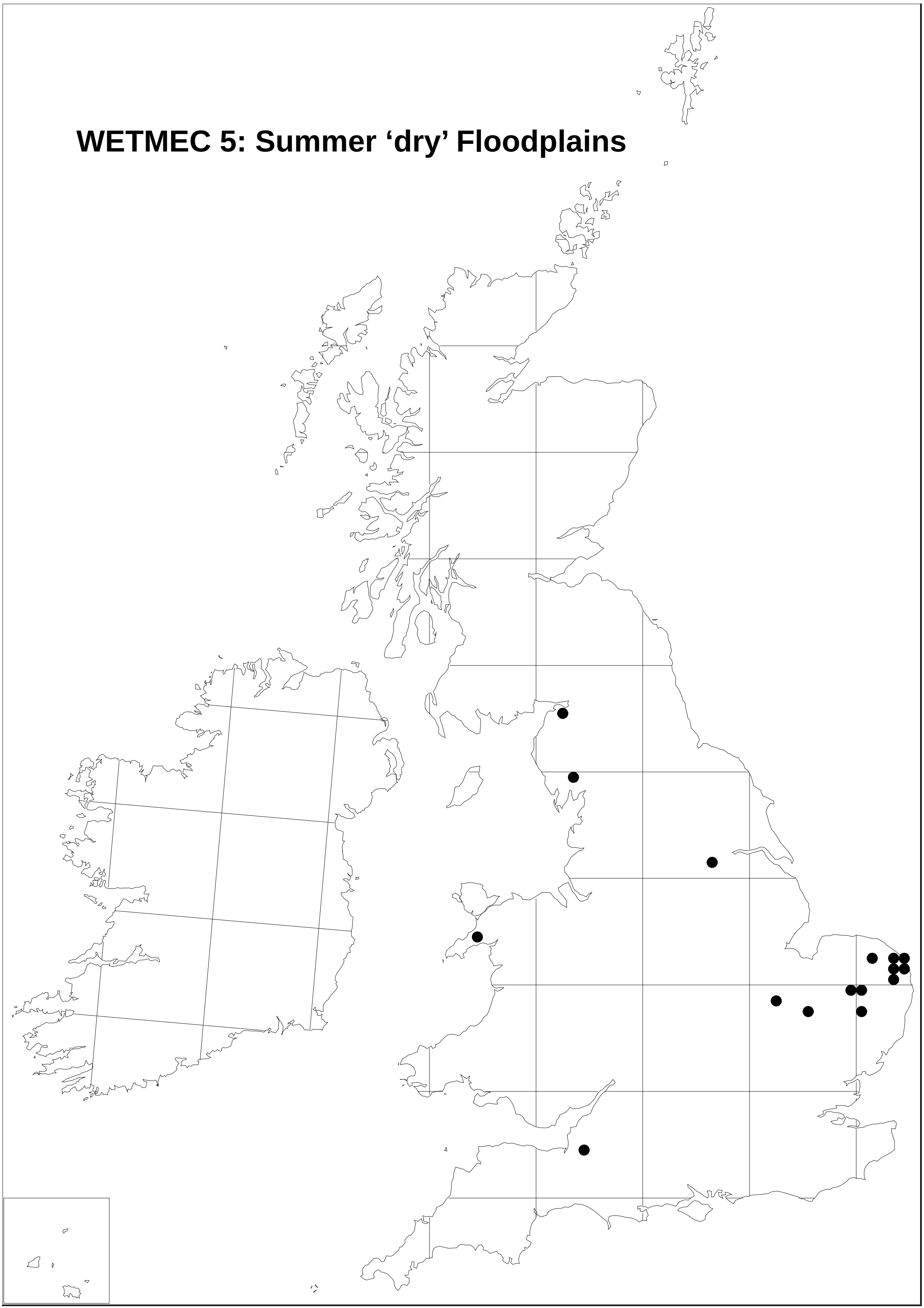


Figure 6.15 Distribution of examples of WETMEC 5 in sites sampled in England and Wales

6.8.3 Summary characteristics

Situation	Floodplains.
Size	Usually large (more than 10 ha).
Location	Mainly sampled from East Anglia, but fairly widespread.
Surface relief	Flat and generally fairly even (except for vegetation tussocks and so on).
Hydrotopography	Topogenous.
Water: ***supply***	Surface water (mainly from rivers) and rainfall.
regime	Mean summer water level typically relatively low (–25 cm), but flooded in winter/spring.
distribution	Episodic flooding from rivers or ponded-back rain water.
superficial	Some examples are adjoined by lakes or rivers. Dykes often dissect the unit. The examples sampled here do nousually include streams, ox-bow lakes and so on (which can occur in this wetland unit elsewhere), or pools.
Substratum	Deep peat, sometimes intercalated with mineral layers (such as estuarine clay), and sometimes with deposits of alluvium.
peat depth	Mostly deep (3–6 m) except near upland margins.
peat humification	Uppermost layer is usually quite solid and well humified. Underlying peat varies in humification, but basal peats are typically thick, strongly humified and solid.
peat composition	Variable. Uppermost layers generally reed, sedge or brushwood peat. Basal layers usually dense brushwood peats. These may be continuous upwards to the surface layer, or may be replaced or interrupted by bands of fresher herbaceous (reed or sedge) peats, or by layers of alluvial material or estuarine deposits.
permeability	Wetland infill and basal substrata have generally low-permeability characteristics.
Ecological types	Ranges are mainly from base-rich–sub-neutral, eutrophic–mesotrophic, depending mainly on water source and substratum characteristics.
Associated WETMECs	Often in association with WETMEC 6, but this is sometimes the only WETMEC in entire sites. Occasionally seepages can occur at the adjoining upland margin, most usually WETMEC 11.
Natural status	Some examples are more or less natural, but others have been much modified by drainage and peat removal.
Use	Mostly former sedge and litter fens. Some examples may have been grazed. Many former examples have been converted to farmland.
Conservation value	Mesotrophic examples may support Eu-Molinion vegetation (EU SAC Habitat).
Vulnerability	Some examples affected by nutrient enrichment, some by drying (drainage or attempts to exclude enriched water), some by base-depletion (lack of river flooding). Highly susceptible to scrub encroachment.

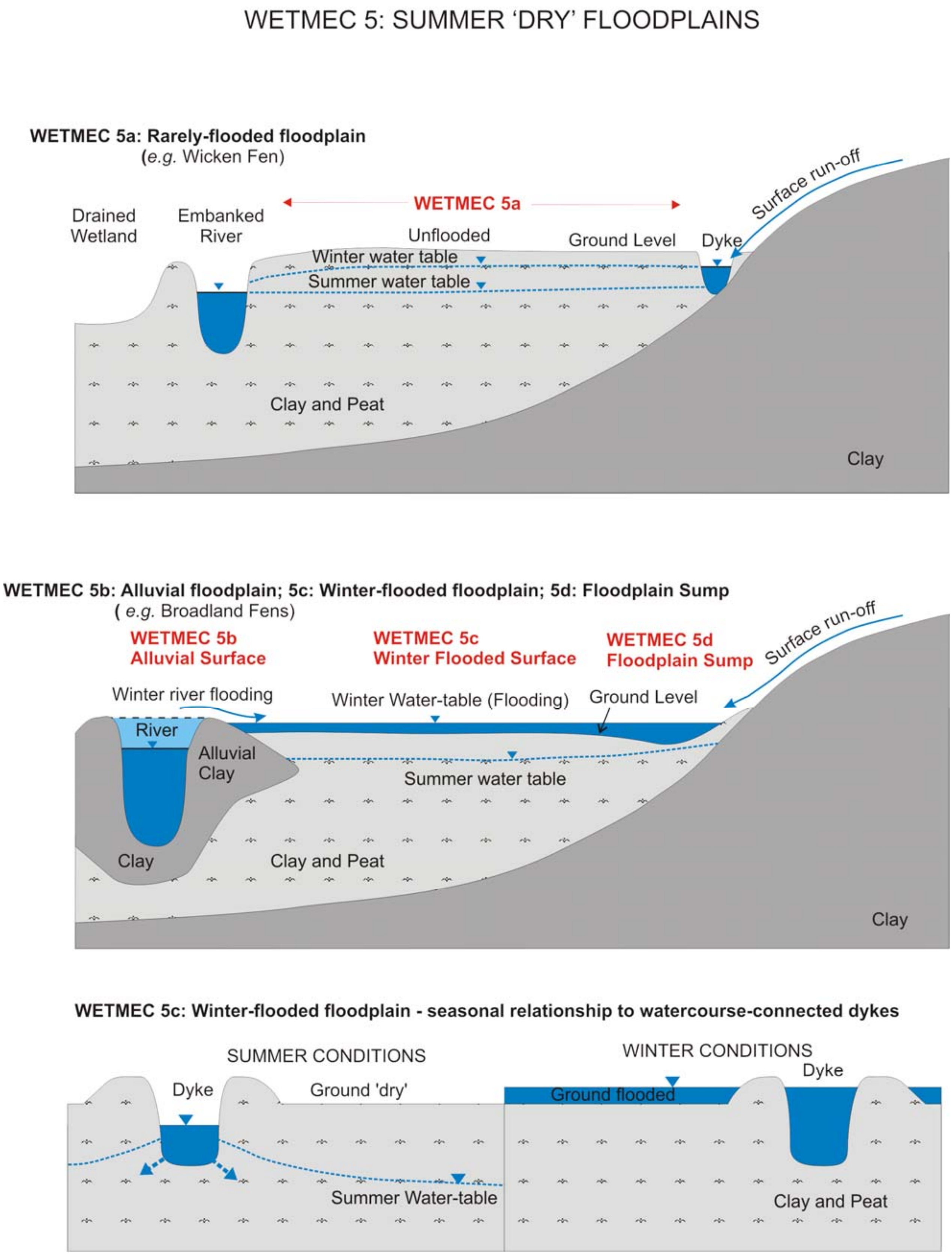


Figure 6.16 Schematic sections of Summer-Dry Floodplains (WETMEC 5)

6.8.4 Concept and description

CLUSTERS: 5 AND 6

This unit includes surface water-fed floodplain sites that usually have high winter water tables – often shallowly flooded – but which may usually dry out considerably during the summer (though occasional summer inundation is not unknown). These sites are superficially similar to WETMEC 6 (Surface Water Percolation Floodplains) surfaces, but differ primarily in having upper peat horizons that are more solid and have lower permeability characteristics (lacking the effective sub-irrigation system provided by overgrown turf ponds)[1]. This appears to constrain lateral flow of water through the peat deposit from proximate surface water sources, so that surfaces distant from these may receive surface water only during flooding episodes. In consequence rainfall is often an important, sometimes dominating, influence upon the hydrodynamics of WETMEC 5, and in a few isolated instances may well be the only significant water source. There is generally little evidence for significant groundwater outflow into this wetland type, mainly because of low-permeability substratum characteristics.

The water supply mechanism for WETMEC 5 is most associated with topographical floodplains, alongside rivers and so on, but some samples from other topographical situations (such as infilled basins) have also been clustered into this WETMEC, where (usually small) floodplain-like surfaces occur alongside streams that flow through the sites. Their water supply mechanisms appear to be similar, but the topographical context (and associated WETMECs) may be very different to those of waterlogged river-valley floodplains.

Summer-Dry Floodplains can occur as the main, or only, WETMEC in some floodplain fens, including some quite large examples such as Wicken and Woodwalton Fens. However, in Broadland most fens are composed of both WETMECs 5 and 6. The proportion and distribution of these two types varies much between sites, but in most sites the WETMEC 5 unit at least occurs immediately alongside the rivers, forming a rond of solid peat or of peat and alluvium.

Affinities and recognition

WETMEC 5 corresponds very closely with the analogous unit identified in Phase 1 (Wheeler and Shaw, 2000a). This is not surprising, as this WETMEC is overwhelmingly dominated by examples from Broadland and only a small number of samples have since been added to it. However, an important difference is that some of the driest stands and drained ombrogenous samples which were formerly clustered with the other Summer-Dry Floodplains in Phase 1, have been allocated to a separate cluster (4) in the current analysis. This is closely related to the two clusters (5 and 6) which comprise WETMEC 5 and could be considered to form a sub-type of WETMEC 5, but – partly because it includes both ombrotrophic and minerotrophic samples – it has been designated as a separate, but closely related WETMEC (WETMEC 4). It is, however, clear that there is a more or less continuous intergradation of WETMECs 4 and 5 as units, and any split between the two is likely to be largely arbitrary. In a few sites, this intergradation can be found in the field, usually along a slight topographical gradient.

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[1] Some examples of WETMEC 5 have been subject to peat extraction (*e.g.* Wicken Fen, Woodwalton Fen). However, these peat workings have not developed as hydroseral turf ponds with a raft of vegetation, which provides the specific properties of Surface Water Percolation Floodplains (WETMEC 6), either because of the configuration of the excavations (not closed basins) or because the basins are not connected to surface water sources and thus tend to become dry during the summer.

Examples of WETMEC 5 are distinguished from other WETMECs on floodplains by their high winter water tables, often including regular winter inundation; occurrence on deep peat or alluvium; dense basal peats, often underlain by clay; and an apparent absence of significant groundwater contribution to the water balance.

6.8.5 Origins and development

WETMEC 5 is particularly a feature of the Broadland fens, and parts of Fenland, and its developmental history in these regions essentially reflects the post-glacial development of wetland within the Broadland valleys and the Fenland basin. The wetland stratigraphy of these regions has been quite widely investigated and the patterns of wetland development, though quite complex, are consistent and fairly well known (Box 6.9). Other sites with WETMEC 5 have generally received rather less attention.

Whereas the mires of Broadland and Fenland largely consist of quite deep deposits of peat, variably inter-layered with estuarine deposits, some other examples of WETMEC 5 are much more obviously alluvial, and are variously enriched with sedimentary mineral material. In some sites there is evidence for sediment inwash throughout much of the developmental history of the deposit, whilst in others alluvial layers are intercalated with peat. This is found for example in Esthwaite North Fen, where active alluvial deposition from the Black Beck, flowing into the head of the lake, has created an example of WETMEC 5b (alluvial floodplain). A core from the alluvial area alongside the Black Beck showed a layered alluvial sequence with bands of silty clays, silts, peat and other organic material. Pearsall (1918) reported that in the zone of rapid silting alongside the beck (with *Phalaris* and *Calamagrostis canescens*) the soil had an organic:inorganic ratio of 0.26 whereas further away to the east, in an area that is now mostly woodland, the ratio was more variable, with values of 2.2–3.0 cited.

The developmental history of some of the basins that support some stretches of WETMEC 5 is very different to that of the river floodplains of East Anglia. For example, at Cors Gyfelog Botterill (1988) concluded, based on the stratigraphy of two orthogonal sections across the site, that this mire had been initiated by the post-glacial terrestrialisation of several small lakes within shallow basins, followed by peat accumulation above and beyond the limits of the original lakes and basins, leading to the eventual coalescence of the spreading deposits into a single mire. Part of this ‘valleyhead trough’ is crossed by the canalised Afon Dwyfach, along a course that is unconformable with the underlying basin topographies, and samples from the silts and dense amorphous peats flanking this were clustered into WETMEC 5.

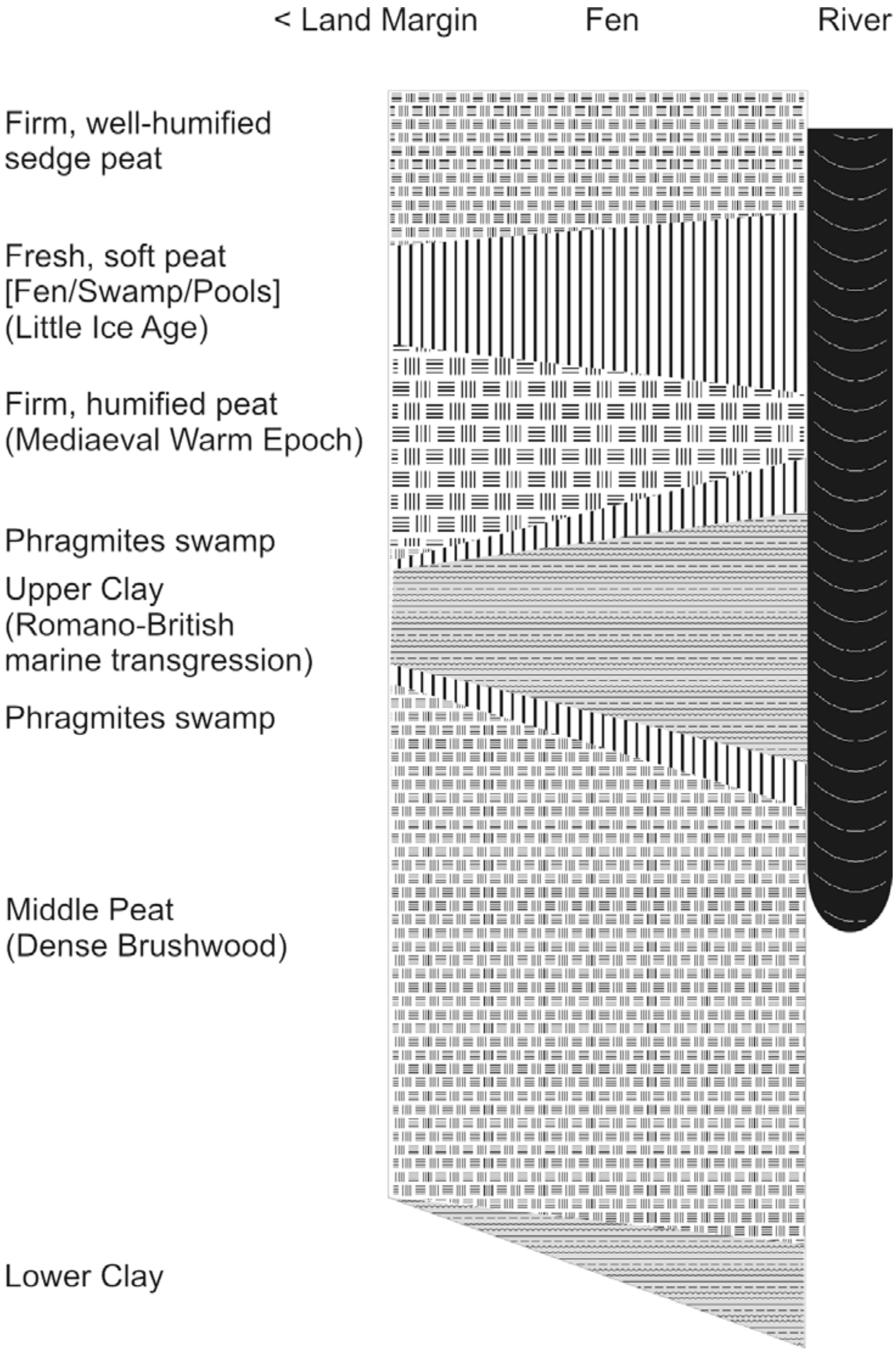
Biglands Bog (Cumbria) (Box 6.5) also supports WETMEC 5 developed within a basin context. Stratigraphical data from the north end of this mire (Wheeler and Wells, 1989) indicate a solid alluvial surface, some one to 1.5 metres of stiff brown silt over a deep deposit of stiff, partly compressed brushwood peat. In this case the silt deposition, probably sourced from the Bampton Beck which flows through the basin, appears to be a comparatively recent event overlain upon a former peat-producing system (though some, or all, of this deposit may be a product of deliberate warping of the north edge of the bog, for agriculture conversion).

Box 6.9: Wetland development in Broadland

Numerous stratigraphical sections are available from the Broadland fens, through the investigations of Lambert (1951; Lambert *et al.,* 1960) and Jennings (1952). Like the once-enormous wetlands of Fenland, they are essentially paludification systems, with development driven primarily by changes in sea and river water levels relative to the fen surfaces. The main events in Broadland can be illustrated by a schematic section (Figure 6.17) from the lower part of the Ant valley (in the vicinity of Reedham Marshes), based on the stratigraphical data of Jennings (1952) and Wells and Wheeler (1999). This illustrates the well-known changes in these valleys, namely an early marine transgression phase (which more or less represents the start of wetland development in many sites), followed by a long phase of freshwater conditions when water tables were sufficiently low in the summer to support fen woodland and the accumulation of a rather dense and humified brushwood peat. This was terminated by surface flooding associated with the Romano-British marine transgressive overlap, which reached its maximum at about 400 AD and led to the deposition of estuarine clays in the lower reaches of the valleys. It was followed by drier and freshwater conditions leading into the Medieval Warm Epoch in which fen woodland and herbaceous (possibly managed) fen developed and when the broads were dug.

The excavation of the broads was terminated by a series of flooding events, which appear to have lasted through to the eighteenth century and which created wet fen, freshwater swamp and pools (over at least the Reedham–Catfield section of the Ant valley), forming loose peats. These were followed by more solid, humified peats which accumulated in less wet conditions. In most WETMEC 5 locations these continue to the surface, but in other locations they were partly removed by another phase of peat excavation in the eighteenth/nineteenth century. Subsequent reflooding of the lowered surface led to the development of the century ‘turf ponds’ which mostly now support WETMEC 6 surfaces. In essence, WETMEC 5 systems mainly consist of a thick lower layer of mostly dense brushwood peat capped by a more variable deposit of herbaceous/ wood peat. Seawards, these two main layers become separated by an increasingly thick and broad layer of estuarine clay.

Although not well documented in the sections available, it appears that over large parts of the valleys the basal brushwood peats are separated from the mineral aquifer by a layer of clay plastered across the valley bottoms. The provenance of this is unclear, but it does not seem to be a product of the early marine transgression phase, and is more probably of Devensian origin. Its character and continuity is not well known. At Catfield Fen, Gilvear *et al.* (1989) suggest that localised windows may occur in the clay, but this requires confirmation. One complication is that, as has been shown at Upton Fen (G. van Wirdum, personal communication), clay beneath the peat may itself be capped by gravel.



Based on the stratigraphical data of Jennings (1952) and Wells and Wheeler (1999).

Figure 6.17 Schematic section from the lower part of the Ant valley (in the vicinity of Reedham Marshes)

WETMEC 5 has also developed at some sites with a long history of alluvial deposition. Some sites have evidence for sediment inwash throughout much of their developmental history, and occur over a more or less continuous profile of alluvial material, whilst in others alluvial layers intercalated with peat indicate that the depositional environment has varied in time and space.

One interesting, if rather anomalous, example of WETMEC 5 occurs at Cranberry Rough, which is essentially a drained lake basin (Box 6.10) in which some of the surfaces alongside the drainage dykes appear to function as examples of WETMEC 5.

Box 6.10: Drainage history of Cranberry Rough (Norfolk)

Cranberry Rough is an outlier member of WETMEC 5 and allocated mostly to sub-type 5d (floodplain sumps). It has a long and quite well-documented history of drainage. In Tudor times (and before), much of this site was a large mere (around 280 acres). By 1737 the lake was considerably overgrown by swamp or fen. Drainage attempts were made in the seventeenth century when the southern part of the site (at least) was converted to agriculture and forestry. There may have been one drainage phase sometime between 1750 and 1790 and a second, more effective scheme, between 1795 and 1798. Mosby (1935) points out that the drains were blocked by 1920 and the water level rose to a peak in 1932, when the railway was raised by about three feet. The Forestry Commission started drainage operations in 1933 and, aided by summer droughts, by 1935 the water table was lowered by about three feet and land was being grazed which had been under water three years before, and it was possible to walk dry-shod over the area. The original depth of the mere may have been some eight feet above the level of 1932. This was gradually followed by drainage dereliction and currently much of the site is extremely wet, year round in some years. The surface of most of Cranberry Rough is quite solid, and has little potential for vertical movement in response to water level change, which may partly account for the strong water level fluctuations that have been reported.

6.8.6 Situation and surface relief

WETMEC 5 is restricted to topogenous situations and is overwhelming associated with floodplains (92 per cent), but it also occupies some small floodplain situations embedded within other (non-floodplain) topographical contexts. Hence, six per cent of the samples were recorded from basins, one per cent from lakesides and one per cent from a valleyhead context. The surface is typically flat and generally fairly even (except for vegetation tussocks and so on) (Table 6.18). Any alluvial deposits do not normally form prominent surface features.

6.8.7 Substratum

Most examples of WETMEC 5 occur on a quite deep wetland infill (mainly peat, but sometimes alluvial silts and clays) (mean depth of 3.7 m), generally with rather low permeability characteristics (Table 6.18). Many examples are primarily peat-based. The surface layer of peat is typically fairly dense, consolidated and humified, and the middle and especially lower layers even more so. In many Broadland examples the middle layers contain an (often thick) layer of estuarine clay, laid down many during the Romano-British marine transgressive overlap, but surface alluvium is generally not prominent. Nonetheless, some locations are variably enriched with sedimentary mineral material, but distinct silt deposits are only normally evident in some riverside situations. Other sites may contain intercalated peat and alluvial material through much of the profile, and a few samples were predominantly alluvial throughout. The basal substratum also typically had low-permeability characteristics, often consisting of a silt or clay – either Till or an estuarine deposit.

Table 6.18 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 5

	Mean	1	2	3	4	5	6	7
Surface layer permeability	3.1	2	24	43	22	8	1	
Lower layer permeability	1.9	19	70	9	2			
Basal substratum permeability	1.8	37	53	2	2	2		
Slope	1.1	95	4	1			X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

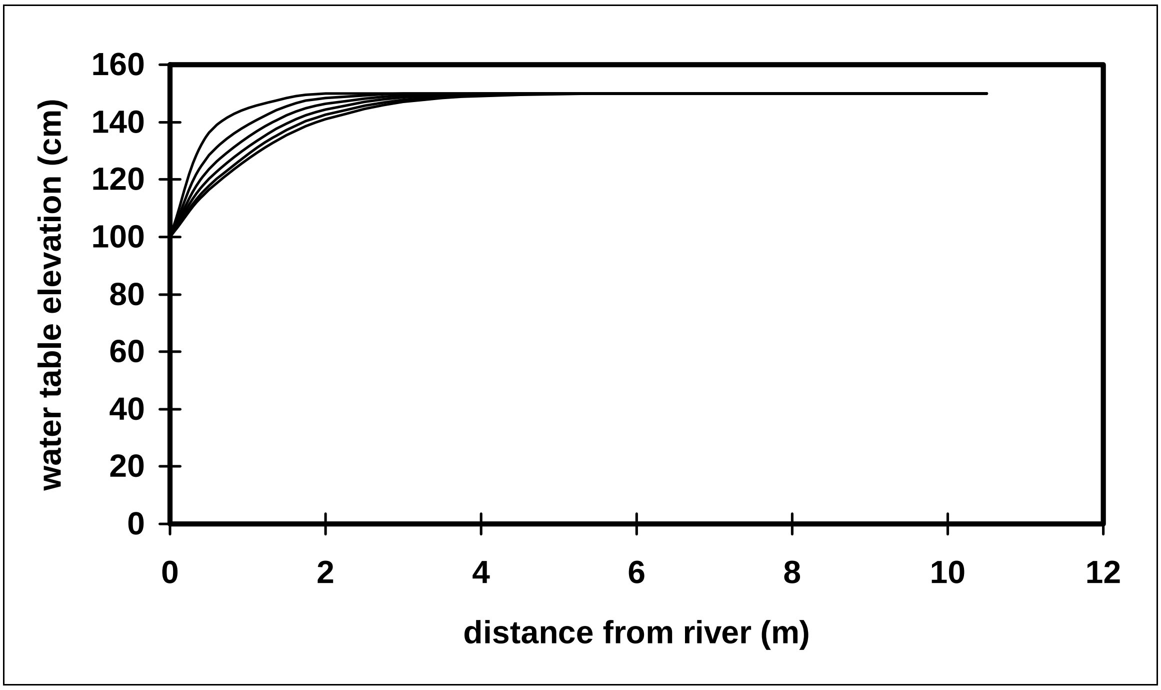
6.8.8 Water supply

Water supply is potentially a mixture of land drainage, river flooding and precipitation. The proportions of these sources vary between sites and probably account for many of the observed differences in base status and fertility. Inundation episodes are most often associated both with river flooding and ponding-back of rainwater. Telluric water supply is either by overbank flow or movement through the peat from adjoining rivers or dykes, though low-permeability peats may constrain lateral flow. The hydraulic gradients are reversible: telluric supply is associated with either particularly high water levels in adjoining watercourses, or with evapotranspiration-induced low water tables within the fen peat, whereas rainfall events may lead to drainage from the peat mass to the dyke system (Surridge, 2005). Surface flooding in winter may not always be associated with significant ingress of telluric water: hydrochemical evidence obtained by Giller and Wheeler (1986b) suggested that in parts of the Catfield fens distant from the river surface, flooding episodes could be sourced mainly by ponded-back precipitation; Gilvear *et al.* (1989, 1997) considered that the hydrodynamics of this site were dominated by meteorological events.

The observed wetness of WETMEC 5 surfaces can vary considerably between seasons and between years. Summer dryness of WETMEC 5 is a consequence of low rainfall, but is also because the level of telluric water in adjoining watercourses is usually below the surface of the fen in summer, whilst the hydraulic gradient into the fen is shallow and the permeability of the substratum may be low. Rather few data on hydraulic conductivity are available, but in the solid peat rond bordering the River Ant at Reedham Marshes, van Wirdum *et al.* (1997) measured K values between 0.48 and 12.48 x 10^{-6} cm s^{-1} and bank seepage appeared to be small. A more empirical demonstration of the capacity of solid peat to reduce water seepage into the interior of the fens is provided by the riverside ronds of uncut peat that seem to have been left *in situ* to facilitate peat extraction in the fens, both during the deep medieval operations and the shallower nineteenth century ones. For this same reason, dykes dug through the solid peat surfaces often have only a localised impact upon fen water levels (see Figure 6.18). In some sites, foot drains were once dug to provide surface irrigation from dykes into the fens, but few of these remain. In a few locations, sluices have been used to elevate dyke levels to cause shallow surface flooding across some of the solid peat surfaces.

The role of groundwater, if any, in these systems is not well understood. In some sites, the groundwater head may lay within the peat, but in at least some (perhaps many) cases, low-permeability clays at the base of the peat seem to provide a rather effective aquitard. The thickness and low permeability of the peats may also limit exchange with groundwater. Van Wirdum *et al.* (1997) were unable to find any piezometric evidence for upflow into the peat in three Broadland fens. At Strumpshaw Fen, where groundwater abstraction has been suspected of lowering fen water tables, Surridge (2005) considered that "*although hydraulic gradients exist between the peat and the underlying mineral aquifer, these are not translated* *into substantial volumes of groundwater flow. It is concluded that a deposit of sufficiently low K exists to minimise the flow of water between the two aquifer units. The location of this deposit is uncertain but is likely to be either towards the base of the peat profile or at the interface between the peat and the underlying Yare valley formation. As a consequence, the peat should be perceived as a perched aquifer, essentially hydrologically disconnected from deeper groundwater formations in terms of the exchange of large volumes of water*". In summer conditions of high evapotranspiration, the hydraulic head in the mineral aquifer could be higher than that of the peat deposit. It is possible that in some sites groundwater within the peat may support the surface water, but the extent to which this is the case is not known. However, in such circumstances it seems likely that the ecological characteristics of the system are still largely determined by the nature of the surface water and precipitation regimes. In some sites, outflows of groundwater at the fen margin may contribute to the water supply to dykes dug into the aquifer rather than to the fen surface, though virtually no quantitative data are available on this.

Whilst these floodplain wetlands have experienced considerable natural changes in their water regimes through the post-glacial period, their basic water supply mechanism (rainfall and episodic river flooding) seems to have prevailed throughout their development, differing from time to time in depth, duration and frequency.



*A one-dimensional model has been used to simulate groundwater flow between a hypothetical river and an adjacent peat deposit with similar hydraulic properties to those measured in the rond at Reedham Marshes (van Wirdum et al., 1997). The model represents an extreme case for Reedham Marshes. The model peat was assumed to have a drainable porosity of 0.3, and a hydraulic conductivity of 12.48 x 10^{-6} cm s^{-1} which is equal to the **highest** value of hydraulic conductivity measured at Reedham Fen. In addition, a very large difference in water levels between the river and the fen was assumed (50 cm). The results from the simulation are shown as water table profiles for a 30-day period. At the beginning of the simulation, the water table was assumed to be at the ground surface everywhere throughout the fen, while the river water level was 50 cm below this fen level. The water table positions at five day intervals from this initial condition are shown in the graph, with the lowest line on the graph showing the modelled water table after 30 days. As can be seen from the graph, the water table response to drainage is minimal except in a very narrow strip adjacent to the river.*

Figure 6.18 Simulated water table elevations in a solid fen peat away from a river channel in Broadland

6.8.9 WETMEC sub-types

The units contained within WETMEC 5 belong to two clusters of the 36-cluster level of the cluster analysis. These have been further subdivided to provide four clusters (and four WETMEC sub-types) at the 72-cluster level. The sub-types relate primarily to summer (and, to some extent, winter) water levels and to the presence of alluvial material in the substratum. Mean summer water levels are: 5a: –50.1 cm; 5b: –24.2 cm; 5c: –17.5 cm; and 5d: –15 cm.

WETMEC 5a: Rarely Flooded Floodplain

CLUSTER: 5.1

Examples at: Wicken Fen, Woodwalton Fen, elevated surfaces in various Broadland sites

In some sites, topographical considerations or river control structures mean that river levels are kept below the peat surface, so that surface flooding with telluric water rarely occurs (Figure 6.16a). In such circumstances, the fen surface away from dykes is effectively fed almost exclusively by precipitation for much of the year. Woodwalton Fen is flooded about once every three to five years, for flood storage. Note that water levels at Wicken Fen may now be higher than when the data used in this analysis were collected because of a water management initiative, and it is not certain to what extent samples from this site would still be classified here. Some examples of WETMEC 5a can be transitional to WETMEC 4.

WETMEC 5b: Alluvial Floodplain

CLUSTER: 5.2

Examples at: Biglands Bog, Cors Gyfelog, Drabblegate Common, Esthwaite North Fen Surlingham Marshes, Wheatfen,

Regularly flooded areas alongside silt-laden rivers can receive frequent deposition of alluvial material, which may have important ecological consequences in creating a high fertility substratum (Figure 6.16 b). Few detailed measurements of mineral content have been reported from the wetlands of Eastern England, but most of the wetlands included in this study show little visual or tactile evidence of alluvial deposits in substratum cores. At Wheatfen, a declining gradient of mineral content for some 200 m away from the river has been recorded (B D Wheeler, unpublished data) and in the more riverward deposits, this can be detected visually in substratum cores. The samples in this sub-cluster represent sites with evident silt or clay near the surface of peat cores. In Broadland, these include some of the riverside stands in the River Yare valley, and Drabblegate Common (Aylsham) (not an SSSI but deliberately included in this study to represent this variety of wetland). This category has been slightly enlarged since Phase 1 by the inclusion of a few alluvial fens elsewhere (such as Cors Gyfelog), but some other alluvial fens which probably belong to WETMEC 5b, such as the narrow strips of fen carr on alluvium alongside some rivers in the New Forest, have not been considered because they are not herbaceous fen. Whilst active alluvial wetlands are probably considerably under-represented in this project, they are not a particularly common feature of wetland sites selected to represent 'good' examples of herbaceous fen vegetation.

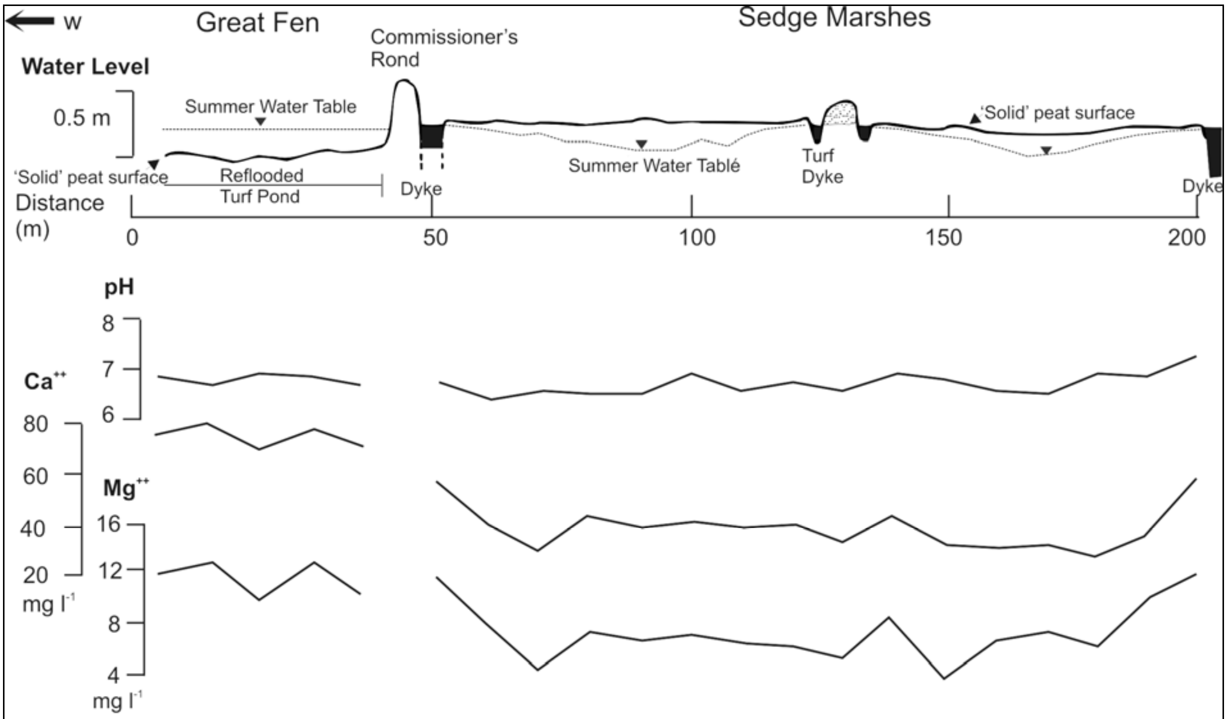
WETMEC 5c: Winter-Flooded Floodplain

CLUSTER: 6.1

Examples at: Berry Hall Fens, Broad Fen, Dilham, Burgh Common, Catfield and Irstead Fens, Cranberry Rough, Hickling Broad Marshes, Reedham Marshes, Strumpshaw and Bradeston Marsh, Sutton Fens Wheatfen and Rockland, Woodbastwick Fens and Marshes

These are wetlands which are shallow-flooded in winter but which experience substantially sub-surface water levels in summer, not only because water levels in dykes (and so on) are relatively low, but because there is only limited seepage of water into the peat through the banks (Figure 6.16). This is the most widespread type of Summer-Dry Floodplains in Eastern England. Most fens in Broadland have examples of it, but there is much variation amongst them. The frequency and duration of flooding varies considerably, depending upon the dynamics of adjoining watercourses. Once flooded, water levels may remain high until early summer, especially in situations where elevated ronds or dredgings around compartments provide some impoundment of standing water. Most of the sites with this WETMEC are floodplains, but Cranberry Rough is a part-drained basin, which over much of its area appears largely to function as a small floodplain.

Some examples of this WETMEC, mostly alongside dykes with high water tables, can often remain fairly wet through much of the summer and in terms of their water tables, are transitional with WETMEC 5d and WETMEC 6a. High water levels in dykes may be created by natural conditions (often associated with deterioration of drainage systems) or artificially (by sluices and so on). Their effect is often limited to a narrow dyke-edge strip; there is little practical value in distinguishing these wetter fringes from other examples of WETMEC 5c, but more extensive examples are better regarded as a form of WETMEC 6a.



This diagram shows variation in summer water level, pH and concentrations of Ca^{++} and Mg^{++} in samples of near-surface interstitial peat waters collected along a transect from Great Fen to Sedge Marshes (Catfield Fen, Broadland)

Sedge Marshes form part of an 'internal' hydrological system, without direct river connection, but there is a connecting sluice through the Commisioner's Rond into Great Fen. Great Fen is part of the 'external' system, which has some direct connection to the R Ant. Water flow across the sluice is most often from Sedge Marshes to Great Fen.

Great Fen was extensively cut for peat in the 19th century and much of its surface is a shallow, reflooded turf pond with a bouyant, loose peat infill. By contrast, Sedge Marshes consists of uncut, solid peat (the 'Turf Dyke' is a broad dyke, dug for transport of peat from the fen; it is now largely overgrown and, where crossed by the transect, is largely covered by a bouyant, quaking raft dominated by *Sphagnum*). Great Fen has a high, fairly uniform summer water table with fairly uniform hydrochemical conditions along the transect, and corresponds to WETMEC Type 6 (Surface Water Percolation Floodplain). Sedge Marshes (which corresponds to WETMEC Type 7 - Summer 'Dry' Floodplains) is shallow flooded during most winters, but the summer water level is usually subsurface, decreasing with distance from the dykes. There is also some evidence for decreased solute concentrations away from the main boundary dykes.

Figure 6.19 Summer water level and hydrochemical features along a transect from Great Fen to Sedge Marshes (Catfield Fen)

WETMEC 5d: Floodplain Sump

CLUSTER: 6.2

Examples at: Berry Hall Fens, Burgh Common, Catfield Fen, Cranberry Rough

This is a rather poorly circumscribed unit containing only a few samples. These are from depressions or particularly poorly drained surfaces within floodplain systems which have quite strongly fluctuating water tables, and tend to become summer-dry. The depressions may be old peat workings which lack direct connection to summer surface water sources, or subsidence hollows (created by past drainage, shrinkage and subsequent reflooding of some areas of wetlands). The lower altitude of the surface and the capacity to store winter water means that these depressions tend to dry out less than the more elevated WETMEC 5 wetlands; anecdotal evidence indicates that some can remain wet year round. Compared with Surface Water Percolation Floodplains (WETMEC 6), these show greater water level fluctuations and lower summer water levels but the differences are sometimes small and WETMEC 5d is conceptually, but rarely spatially, transitional to WETMEC 6a.

6.8.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 5 are summarised in Table 6.19. As might perhaps be expected for Summer-Dry Floodplains, the mean summer water table (–25 cm) for WETMEC 5 was one of the lowest of all WETMECs, second only to the closely related WETMEC 4. The driest samples (water more than 50 cm bgl) were generally from partly drained floodplain remnants such as Wicken and Woodwalton Fens, but some surfaces in Broadland, isolated from surface water sources, also had low summer water tables. The summer-dry character of WETMEC 5 is reflected in the frequent occurrence of species that are sensitive to strongly reducing conditions during the growing season (such as *Molinia caerulea, Myrica gale*) and in the absence of wet fen species. Some mesotrophic examples have a species composition more related to that of *Cirsium dissectum–Molinia* fen meadow (M24) than to true fen and would almost certainly be referable to M24 in the presence of annual summer mowing or grazing. The rather dry conditions also seem to benefit some fen ruderal species, such as *Viola persicifolia.* Nonetheless, a good number of typical fen species still occur in this wetland type, especially some tall forbs and especially in sites that maintain quite high water tables in summer.

The majority of examples of this wetland type were mesotrophic or eutrophic and sub-neutral or base-rich. This may reflect the periodic inundation of many sites by river water, coupled with quite high rates of mineralisation in the dry summer conditions. Nitrogen mineralisation is often considered to be particularly associated with oxidising conditions, and various workers have reported enhanced nitrogen mineralisation in drained wetland soils (for example, Guthrie and Duxbury, 1978; Williams, 1974; Grootjans *et al.*, 1985). On river floodplains, it can be difficult to separate mineralisation effects from import of alluvium and nutrients during flooding episodes (Palczynski, 1984). Perhaps unsurprisingly, phytometric estimates of fertility show that the mean fertility of alluvial floodplains (WETMEC 5b) is significantly greater (26.9 mg) than that of the non-alluvial winter-flooded floodplain (WETMEC 5c) (17.9 mg). Samples from rarely flooded floodplains (WETMEC 5a) had the lowest mean fertility (13.1 mg).

Mesotrophic examples tend to be dominated by *Cladium mariscus* (sometimes *Molinia* or *Phragmites*) whilst eutrophic examples may have *Phragmites*, *Phalaris arundinacea*, *Glyceria maxima* or tall herbs such as *Epilobium hirsutum* or *Filipendula ulmaria*.

Calamagrostis canescens – although nationally scarce – is a pernicious dominant in some (mainly mesotrophic) summer-dry sites. Eutrophic sites with vigorous dominants are usually quite species-poor.

Table 6.19 WETMEC 5: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	3.7	0.1	12.0
Summer water table (cm)	–25	–79	–3
Rainfall (mm a^{-1})	622	539	1826
PE (mm a^{-1})	619	534	627
Water pH	6.3	4.3	7.0
Soil pH	6.4	5.0	7.5
Conductivity (µS cm^{-1})	1,481	114	5,354
K_{corr} (µS cm^{-1})	1,481	112	5,354
HCO_3 (mg l^{-1})	43	16	69
$Fertility_{Phal}$ (mg)	19	5	37
Eh^{10} (mV)	346	333	359

See list of abbreviations in Appendix 1

In sites where this type of wetland is not periodically inundated with river water the surface can become largely rain-fed and a progressive depletion of bases and nutrients can occur. There is evidence for localised acidification at Wicken Fen, which is not normally flooded, but similar processes have also been observed in intact floodplains in Broadland in locations with barriers to river flooding. For example, Sedge Marshes (Catfield Fen) is a block of solid peat largely isolated from flooding by river water because of a bund of peat (the Commissioner's Rond). There are indications of both a drop in summer water levels and concentrations of bases in Sedge Marshes away from the immediate vicinity of the dykes (this contrasts with the adjoining Great Fen, which not only has the loose upper peat infill of a reflooded turf pond, but also appears to receive some river water inputs) (see Figure 6.19). Base depletion of WETMEC 5 surfaces is not usually associated with establishment of *Sphagnum*, probably because of the dry summer conditions, but it may be expected to result in some long-term species loss, including the possible development of species-poor vegetation with much *Molinia caerulea*.

River-connected dykes crossing some WETMEC 5 surfaces are often eutrophic and frequently full of redeposited peat and mud. In some sites, they have been sealed from direct ingress of river water in an attempt to improve their water quality and to prevent ingress of nutrient rich water and alluvial solids into the fens. Such isolation procedures can exacerbate summer drying in the interior of the fens, and sometimes encourage base depletion.

6.8.11 Ecological types

The distribution of samples of WETMEC 5 amongst the pH and fertility categories is shown in Table 6.20. This reflects a preponderance of samples from base-rich sites (mostly in East Anglia). These are mostly mesotrophic in character.

Table 6.20 Percentage distribution of samples of WETMEC 5 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	2	46	18
Sub-neutral	2	16	15
Base-poor	2		
Acidic	0		

Oligotrophic, sub-neutral/base-rich

These represent low-productivity surfaces within some floodplain systems. Most examples occupy bands along the margins of some Broadland fens (such as Burgh Common, Catfield Fen (Middle and South Marshes), where the vegetation is typically M24 (or M24 transitional to S24). However, some examples of upstanding, little-flooded surfaces located more centrally in the Broadland fens also belong to this category, as do some examples of M24/M22 vegetation at Woodwalton Fen.

Oligotrophic, base-poor

This category is represented only by a very small number of samples, all from acidic locations at Woodwalton Fen. They are from situations with thin layers of acidic peat, apparently residual from a former ombrotrophic surface *(*where the ombrogenous peat was not completely removed by peat extraction). These surfaces are closely related to some examples from WETMEC 4 (within which particularly dry and acidic examples from Woodwalton have been clustered).

Mesotrophic, base-rich

This is the largest category of WETMEC 5. In Broadland, it includes surfaces that regularly receive inputs of bases from surface water sources, but nutrient loadings are sufficiently small (perhaps partly because of dilution associated with flooding events) to prevent the development of eutrophic conditions. In some cases (such as Sedge Marshes, Catfield), the swamping water appears to have only a limited telluric component and the system may be undergoing progressive base and nutrient impoverishment. Some parts of Wicken Fen, once fed by calcareous surface water, also belong to this category, as does a sample on alluvial material alongside the Afon Dwyfach at Cors Gyfelog.

Mesotrophic, base-rich on brackish clays

This includes a number of Broadland sites over Romano-British estuarine clays. The clays appear to have only a small influence upon vegetation composition, but they may provide a source of bases and nutrients in systems that are not regularly replenished from river or land-drainage sources. Some examples of this type have very high EC values (> 5,000 µS cm^{-1}) and account for the high mean EC recorded from WETMEC 5 (Table 6.19).

Mesotrophic, sub-neutral

This includes a number of relatively base-poor sites. Examples often occur close to the margins of the wetlands, and some of these *may* have greater connectivity to groundwater systems than is generally the case with WETMEC 5 wetlands – though as other examples are underlain by clays, groundwater inputs are clearly not critical for this type of habitat. Some examples occur in locations largely isolated from river flooding, and include a number of the fens on solid peat in the 'internal system' at Catfield. In these systems base-depletion appears to be associated more with an increase of such species as *Molinia* than with *Sphagnum*, because both the winter inundation with telluric water and the summer low water episodes are generally inimical to the establishment of *Sphagnum*. The vegetation is thus often *Molinia* rich, often S24g, sometimes transitional to M24 (or M25). At Woodwalton Fen, patches of sub-neutral peat – apparently a remnant from past turbary – belong to this category, whilst most of the rest of the surface is eutrophic, base-rich peat (exposed by peat cutting). A sample from alluvial deposits alongside the Black Beck at Esthwaite North Fen also belongs to this category. The vegetation here has greatest affinities with S25a, but nonetheless supports various species (*Calamagrostis canescens, Carex elata* and *Lysimachia vulgaris*) which are typically associated with S24 in Broadland.

Eutrophic, sub-neutral/base-rich

In a few sites (such as Drabblegate Common, Norfolk) the entire site belongs to this category, but in others it includes just the areas closest to sources of nutrient enrichment. There are at least three different contexts in which this habitat develops:

- near points of discharge of nutrient-rich land drainage;
- in areas subject to flooding with river water (with or without silt deposition);
- in sites subject to nutrient release associated with mineralisation of peat.

All of the silt-rich surfaces in Broadland fall into this ecological category. Some are referable to eutrophic forms of S24 (S24b and S24d), but others belong to S25 and S26. The *Calamagrostis canescens*-dominated surfaces on solid alluvium at Biglands Bog (Cumbria) also belong here. These support *Lysimachia vulgaris* in vegetation which has closest affinities with S25b.

Curiously, none of the surfaces recorded for this category are particularly base rich. The majority of pH values were between 6 and 7, straddling the sub-neutral and base-rich categories. There is no consistent difference in vegetation composition of the sub-neutral and base-rich examples.

6.8.12 Natural status

In more or less intact floodplain wetland systems, such as parts of Broadland, many examples of the WETMEC 5 may represent the least modified surface state found. In particular, these surfaces have not been subject to peat extraction, and in some cases have not obviously been much drained and thus have some claim to 'naturalness'. However, in other cases the natural water supply mechanisms have undoubtedly been modified: some former river courses through tracts of fen have been diverted and straightened, and probably deepened; and in a few sites, bunds effectively exclude river ingress into the interior. Such operations may well reduce the natural influence of the river to parts of the fen. On the other hand, dykes have been dug through many fens which, particularly in association with foot drains (not much in evidence now), may have facilitated water exchange with WETMEC 5 (-helping to supply water into the fens during low water periods and providing some drainage after flooding events). It is also possible that some areas of solid peat have experienced partial drainage in the past, in association with water removal from adjacent turbaries; it is not known to what extent their distinctive characteristics (high bulk density, rather low hydraulic conductivity) are partly a product of drainage and compaction.

However, the current characteristics and conditions of these surfaces may be not greatly different from those associated with deposits of the solid, dense brushwood peats that contribute extensively to the peat infill of many parts of Broadland (though there is little reason to suppose that most WETMEC 5 surfaces in Broadland currently accumulate much, if any, peat). The developmental history of the floodplain fens of Broadland (and to some extent Fenland) has consisted of drier phases during which much of these fens may have been analogous to WETMEC 5 separated by wetter phases which perhaps corresponded more to WETMEC 6 (or which were swamp, open freshwater or estuary). In this long-term sense, some examples of WETMEC 5 can probably be seen as natural (and possibly temporary) derivatives of WETMEC 6, induced by changing river levels and so on, though other examples are more likely to have been produced artificially from WETMEC 6, by direct or indirect drainage.

In less intact floodplains (such as Fenland and some parts of Broadland), examples of WETMEC 5 may occur as truncated blocks of undrained peat, isolated from regular river flooding and sometimes perched above adjoining farmland (converted wetland). The water supply and drainage of these systems has been highly modified. Rewetting of these may be seen as desirable, but the low hydraulic conductivities of the peats may mean that effective rewetting is only possible with a dense network of dykes (Hennings and Blankenburg, 1994), foot-drains or mole-drains, or by surface flooding (Scholz, Pöplau and Warncke, 1995). As such options may be expensive and artificial, it would be desirable to establish to what extent summer-wet surfaces were a natural feature of specific examples of this type of wetland, to avoid imposition of an unnatural and unnecessary water regime by excessive rewetting.

In other locations, the status of WETMEC 5 is variable. The small WETMEC 5 floodplain associated with the Black Beck at Esthwaite North Fen appears to be fairly natural. That at Cors Gyfelog is probably more modified – the Afon Dwyfach may follow a largely natural course, but it has been canalised and probably deepened and embanked for much of its course through the mire, though it is not clear to what extent this is artificial or a product of a natural, low levee.

By contrast, at Biglands Bog, much of which is occupied by WETMEC 6, the patches of WETMEC 5 appear to be associated with, and possibly a product of, partial drainage and silt deposition. Likewise the current outlier WETMEC 5 surfaces at Cranberry Rough appear to be a product of the rather complicated drainage history of this former lake site (Box 6.10).

6.8.13 Conservation value

Many examples of WETMEC 5, especially (but by no means exclusively) mesotrophic examples, have statutory conservation status as part of SSSIs. Several sites based mainly around this WETMEC are long-established nature reserves (such as Wicken Fen, Woodwalton Fen) and some examples support designated SAC features (such as Eu-Molinion) (see Tables 3.3 and 6.4). However, the majority of examples do not fit well any of the CORINE-defined habitats, though some contain Eu-Molinion (*Cirsium dissectum–Molinia* (M24)) vegetation and others support stands of *Phragmites australis–Peucedanum palustre* tall herb fen (S24) vegetation which are floristically close to M24. However, M24 is more wet grassland than true fen and as a conservation objective in fen sites, requires the maintenance of relatively low water tables. As a consequence, in some instances elevation of water tables in WETMEC 5, as part of rewetting initiatives, could result in the conversion of a SAC habitat to a non-SAC habitat.

The difficulty of allocating many WETMEC 5 surfaces to an 'EU habitat' category does not mean that this habitat has no value. Indeed, 'dry' fen surfaces support a number of species that are uncommon in Britain (such as *Peucedanum palustre*) and some of these (such as *Lathyrus palustris, Viola persicifolia*) are primarily associated with this WETMEC. Overall, a total of 109 wetland species have been recorded from samples of WETMEC 5. Twenty-two nationally uncommon plant species have been recorded: *Calamagrostis canescens, Calliergon giganteum*, Campylium elodes*, Carex appropinquata, Carex diandra*, Carex elata, Carex lasiocarpa*, Cicuta virosa*, Cladium mariscus, Dactylorhiza praetermissa, Epipactis palustris, Lathyrus palustris, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Plagiomnium elatum, Ranunculus lingua*, Sium latifolium*, Sonchus palustris, Stellaria palustris, Thalictrum flavum, Thelypteris palustris.* It should be noted that a number of these species (marked *) are 'wet fen' species and are much more characteristic of WETMEC 6 than 5. They are generally scarce within WETMEC 5, and are mostly associated with WETMEC 5d.

The percentage occurrence in NVC communities of samples of WETMEC 5 is: S24: (72%); M22: (5%); S26: (5%); S25: (4%); S05: (3%); M24: (2%); M25: (2%); S27: (2%); W05: (2%). The predominance of S24 in the dataset reflects the fact that most of the samples referred to this WETMEC are from the Norfolk Broadland and Fenland. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 5 is given in Table 6.3.

In general, the more mesotrophic examples of WETMEC 5 attract more conservation interest than eutrophic ones, especially examples referable to S26. However, many of these sites appear to be naturally fertile and thus even eutrophic examples may demand a place within a representative series of wetland types. For example, in Broadland the vigorous, floriferous, fertile fens of the Yare valley (S24b) have a character quite different from those of the northern river valleys. This was recognised by Pallis (1911) in her distinction of 'Yare Valley Fen' from 'Bure Valley Fen' and is not some recent development due to eutrophication.

Dykes extending through WETMEC 5 wetlands are generally not of particular note for their complement of aquatic plant species. River-connected examples tend to be filled with eutrophic water and, often, loose anoxic sediments and may contain no aquatic macrophytes. Dykes that are not connected to the rivers tend to be dystrophic and species poor, often with only *Utricularia vulgaris* and perhaps *Hydrocharis morsus-ranae.* In some sites, dykes that are cut into the bedrock near the land margins may be richer in vascular species, such as *Ceratophyllum demersum* and sometimes *Stratiotes aloides* (Wheeler and Giller, 1982b). The reason for this is not known, but it may relate in part to the nature of the substratum, and is not necessarily related to possible groundwater outflows (for further discussion, see the site account for the Catfield and Irstead Fens in Appendix 3).

WETMEC 5 is also important for supporting various invertebrate species, most notably swallowtail butterfly (*Papilio machaon*). It also forms part of the feeding territories of marsh harrier (*Circus aeruginosus*) and some examples may be used as breeding sites, though neither of these activities is specifically dependent on the distinctive hydrological attributes of the WETMEC.

6.8.14 Vulnerability

The summer-dry character of sites of WETMEC 5 sometimes leads to the supposition that their water tables are declining, and in some sites this may be the case; in others, it may just reflect their natural condition. Isolated sites such as Wicken and Woodwalton Fens, perched above the adjoining agricultural land (drained fen), have clear potential for gravitational water loss, which at both sites has been addressed by the construction of low-permeability margins (clay-cored banks at Woodwalton, a membrane at Wicken). Regulation of the Wicken Lode also means that Wicken Fen rarely, if ever, receives surface water flooding.

Some examples of WETMEC 5 floodplains are potentially vulnerable to improved drainage, including canalisation and deepening of the river, in locations where this is topographically feasible. This is probably not much of a problem in many of the Broadland sites, where river water levels are partly tidally controlled, but may be the case elsewhere. The Afon Dwyfach at Cors Gyfelog appears to have been canalised and deepened, and this may well have influenced the flanking surfaces of WETMEC 5. Equally, in some sites there is evidence that partial drainage may have caused the development of WETMEC 5 surfaces from once-wetter conditions (such as Cranberry Rough, Box 6.10).

Many of the Broadland examples of WETMEC 5 are components of more intact floodplains than the 'undrained' fen remnants of Fenland, and are less liable to water loss to adjoining drained levels (though some are embanked). Many are also regularly flooded by river water, although at some sites this has been restricted. At Strumpshaw Fen, an artificial bund has been constructed specifically to exclude river water (which was considered to be of unsuitable quality for the nature reserve). This has been associated with the development of particularly low summer water tables and a rank and productive vegetation (which may be partly a product of drying-induced nutrient release by mineralisation processes, though data are not available on this). The river margin of many other Broadland fens is marked by a line of dredgings, but this is not normally continuous and it is not known what effect, if any, the dredgings have upon the flooding dynamics of the fens.

Concern about ingress of river nutrients into the WETMEC 5 fens in Broadland is legitimate, but there are few measured data which can be used to assess the magnitude of this perceived problem. Zones of elevated productivity occur along the river margins of many fens, but may be more associated with deposited dredgings than with river nutrients; they are in any case rather narrow (usually around 10–30 m). The often low permeability of the peat of WETMEC 5 (which nearly always borders the rivers) may result in limited transfer of both water and associated solutes into WETMEC 5 during low water periods. Few data are available on water quality during flooding episodes, though at Catfield Fen, Giller and Wheeler (1986b) reported substantial dilution of solutes during flooding. However, flooding associated with deposition of some alluvial material (sub-type 5b) normally leads to the development of very fertile conditions, at least near the river margin of the fen. This is a natural process and it is not known if alluvial material deposited nowadays is significantly more fertile than was formerly the case. However, in some sites referred to WETMEC 5 (such as Biglands Bog, Cumbria), stratigraphical observations show that fertile silts form a cap upon peat and hence appear to be relatively recent (though their actual age is not known).

There is some evidence (such as from the Catfield fens) that the absence, or reduced incidence, of river flooding due to river regulation, the presence of barriers (bunds) or diversion of river courses can lead to base-depletion and reduction of species richness. This is not normally accompanied by significant establishment of *Sphagnum* because of the dry surface conditions in summer (and, in some sites, occasional inundation with telluric water).

The dependency of WETMEC 5 upon surface water means that examples are generally unlikely to be much affected by a lowering of groundwater tables. However, it is possible that in some locations, especially near the upland margins of some floodplains, groundwater may support the surface water table so that a reduction of the water table in the mineral aquifer could lead to some lowering of fen water tables. However, there are few data available to permit assessment of the likely magnitude of this.

The solid peats of some former WETMEC 5 surfaces have been excavated in the past and remaining examples of WETMEC 5 are potentially vulnerable to further peat extraction, though now mainly by conservation organisations who wish to introduce open water or wet fen into summer-dry peats (such as Sedge Marshes, Catfield). This primarily poses a threat to the palaeoecological archive and, given the fact that large areas of Broadland have already been cut over (for example, almost 90 per cent of the Catfield Fens is former turbary), seems difficult to justify except in cases when summer water levels are excessively low[1].

[1] With very low water levels, there is likely to be oxidation and wastage of peat which will also damaged the peat archive, though at a slower rate than peat excavation.

6.9 WETMEC 6: Surface Water Percolation Floodplains

6.9.1 Outline

This WETMEC essentially includes parts of ‘flat’ wetland sites with transmissive upper horizons in connection with surface water sources (mostly rivers and dykes). The upper layer can be a loose peat/rhizome infill of high hydraulic conductivity or a semi-floating mat over loose peat and watery muds. Lateral water flow occurs through the upper layer according to the hydraulic gradient. In dry summer conditions, inward water flow can make a significant contribution to the replenishment of evapotranspiration losses from the fen, whilst outward drainage can occur in response to precipitation events. Most examples occur in floodplain fens and are hydroseral in origin, occurring in reflooded, recolonised turf ponds and around the margins of broads and pools. Schematic sections are provided in Figure 6.21.

6.9.2 Occurrence

Example sites: Barton Broad, Berry Hall Fens, Burgh Common, Catfield and Irstead Fens, Cranberry Rough, Hickling Broad Marshes, Hulver Ground, Reedham Marshes, Sutton Broad, Sutton Fens, Ward Marsh and Ranworth Flood, Wheatfen and Rockland Broad, Woodbastwick Fens and Marshes

Outlier sites: Biglands Bog, Cors Graianog

WETMEC 6 is predominantly associated with the Norfolk Broadland, where it is widespread and extensive, occurring around the margins of the broads, in nineteenth century turf ponds and in some areas where the peat surface has been partly drained and reflooded. A few widely scattered examples have been recorded elsewhere. The distribution of examples of WETMEC 6 in sites sampled is shown in (Figure 6.20).

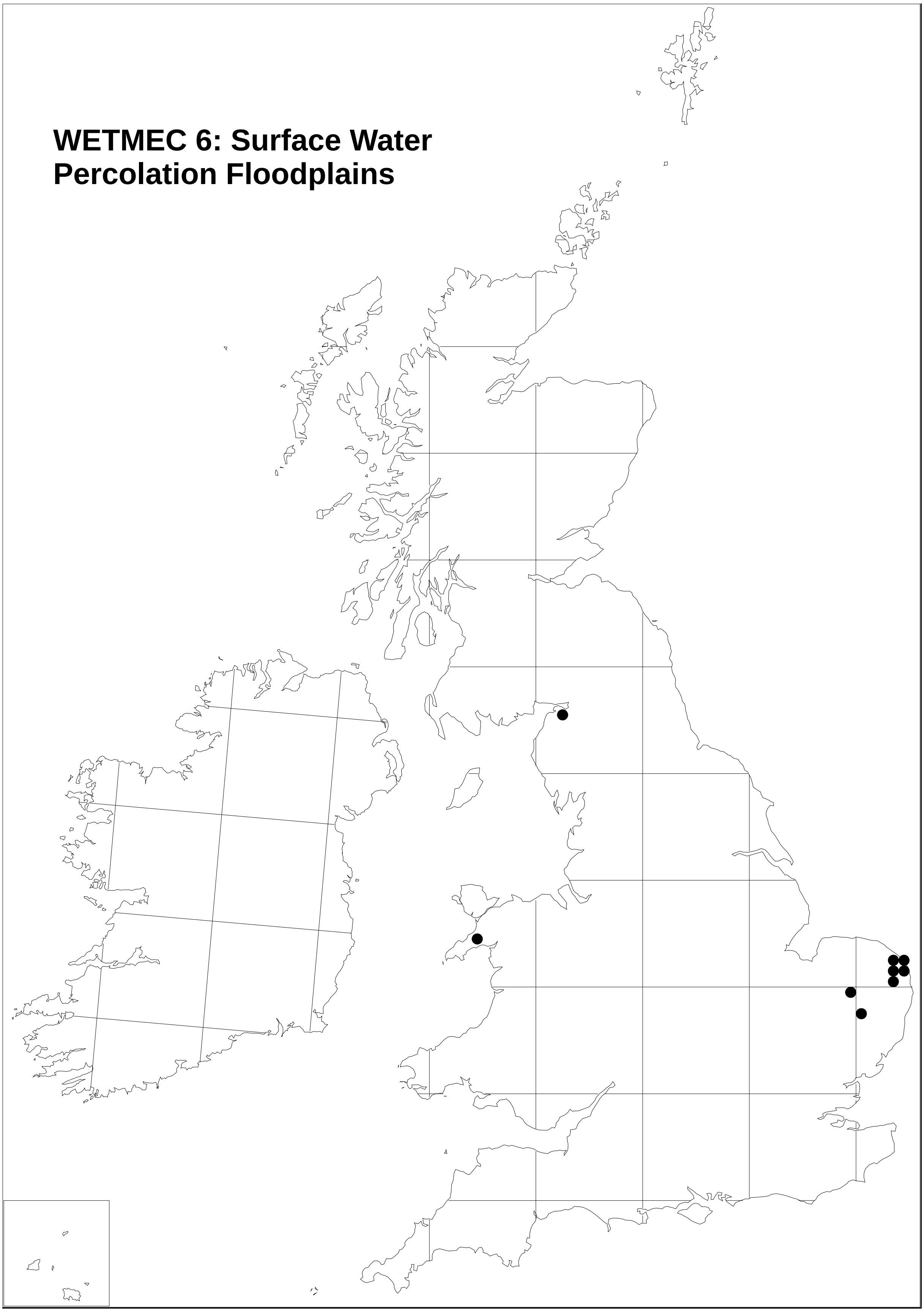


Figure 6.20 Distribution of examples of WETMEC 6 in sites sampled in England and Wales

6.9.3 Summary characteristics

Situation	Mostly river floodplains (also rarely in some basins or valleyheads).
Size	From narrow water fringes to large areas of fen (some units of >10 ha).
Location	Predominantly associated with the Norfolk Broadland, but scattered elsewhere.
Surface relief	Flat and generally even (except for vegetation tussocks and so on).
Hydrotopography	Rheo-topogenous.
Water: ***supply***	Surface water (from adjoining or connected watercourses).
regime	Relatively high and fairly stable water tables (slightly sub-surface), especially where on a buoyant raft. Sometimes flooded.
distribution	Episodic flooding and surface / shallow sub-surface flow.
superficial	Some examples are adjoined by open water or contain pools. River and/or dykes often in close proximity, but not part of unit.
Substratum	Deep peat, sometimes intercalated with mineral layers (such as estuarine clay).
peat depth	Typically deep (3–6 m) except near upland margins.
peat humification	Upper layer is loose and fresh, often hydroseral. May be underlain by deep peat, varying in humification and consolidation. Basal peats are typically strongly humified and solid.
peat composition	Variable. Loose upper layers generally reed, sedge or moss peat (mainly hypnoid mosses, but some *Sphagnum*). Basal layers are usually dense brushwood peats. These may be continuous upwards to the loose surface layer, or may be replaced or interrupted by bands of fresher herbaceous (reed or sedge) peats (or clay).
permeability	The surface layer of peat is typically loose and fairly unconsolidated, formed over a less permeable lower layer. Most deposits are floored by a basal layer of low-permeability clays and silts, but a few examples have more permeable sandy deposits and so on.
Ecological types	Range from base-rich–base-poor, eutrophic–oligotrophic, depending mainly on groundwater source and substratum characteristics. Most examples are base-rich/sub-neutral and eutrophic/mesotrophic.
Associated WETMECs	Occurs almost always in association with Summer-Dry Floodplains (WETMEC 5) (in Broadland is often separated from rivers and land margins by these).
Natural status	Most examples have been created within Type 5 WETMECs by peat extraction, but natural examples can occur (mainly open water fringes).
Use	Mostly former peat workings. Often support top-quality reedbeds (some are mown for sedge), but such usage has ceased in many examples.
Conservation value	Important mainly for mesotrophic sedge beds (EU SAC Habitat), and reedbeds (mainly birds and invertebrates).
Vulnerability	Main threat to most examples is dereliction and hydroseral succession. The latter is associated with consolidation or acidification of the loose surface.

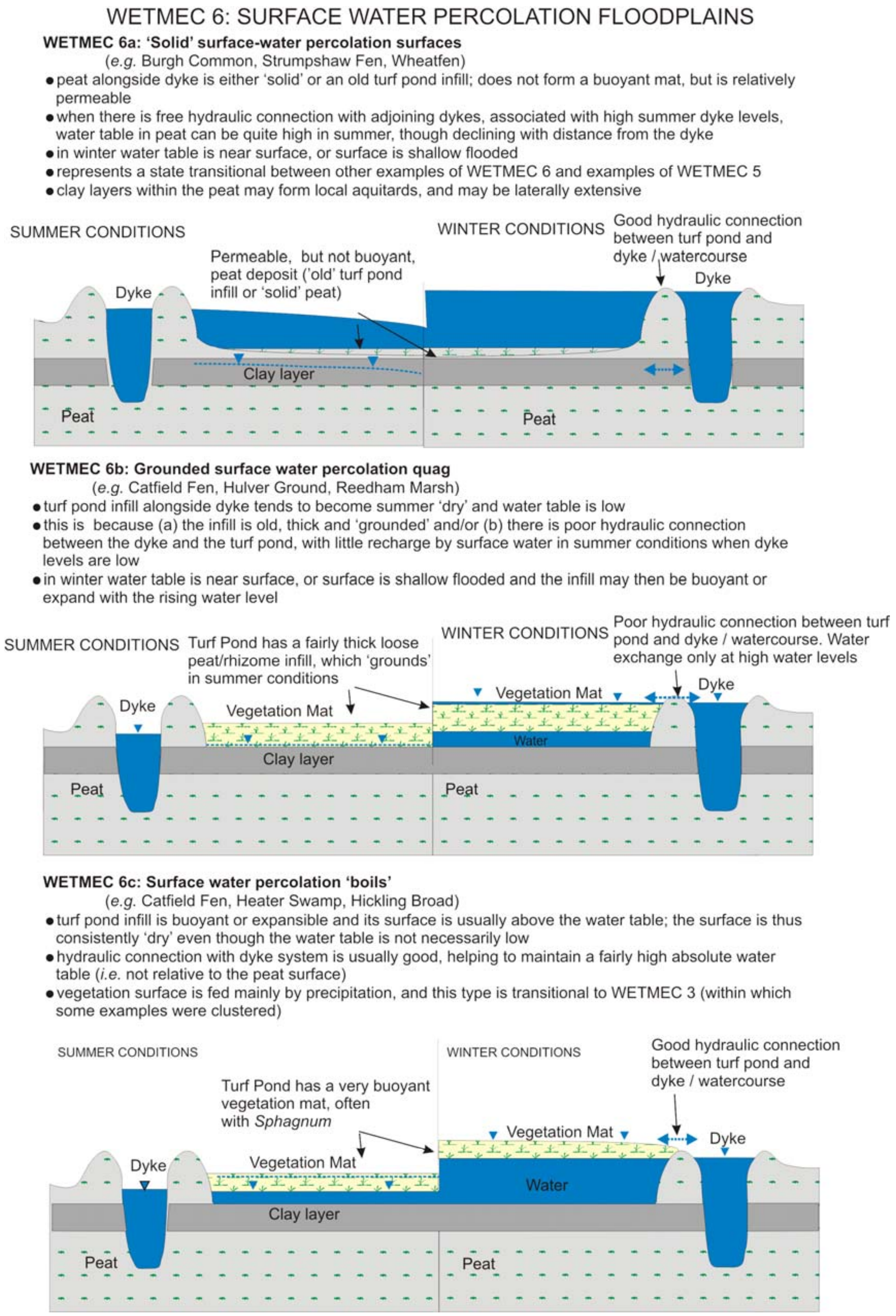


Figure 6.21 Schematic sections of Surface Water Percolation Floodplains (WETMEC 6)

6.9.4 Concept and description

CLUSTERS: 7, 8, 9

WETMEC 6 occurs in a number of topogenous systems, but is especially characteristic of some of the fens of the Broadland floodplains, in situations where a transmissive near-surface layer is connected to watercourses and dykes. It provides a system for penetration of surface water across quite large areas of fen, by surface or sub-surface flow through or beneath the loose vegetation mat [Figure 6.21]. Transmissive upper layers are most often provided by a loose matrix of rhizomes, muds and water beneath a buoyant, expansible and sometimes semi-floating fen mat. It is most typically associated with the hydroseral margins of lakes and the hydroseral infill of reflooded turf ponds that are connected to watercourses, but a few examples are in locations which appear not to have been former turbaries. Many examples of this WETMEC in Broadland occur juxtaposed with the solid peat surfaces of WETMEC 5 (Summer-Dry Floodplains), but in some Broadland sites WETMEC 6 may occupy almost 90 per cent of the fen surface.

In Broadland, WETMEC 5 surfaces often form a band (or 'rond') separating WETMEC 6 turf ponds from the river, though the majority of WETMEC 6 areas retain a (sometimes circuitous) river connection. Some turf ponds are separated from dykes and other channels by a narrow strip of undug peat, but in many cases the dykes alongside WETMEC 6 are within the former peat workings, and essentially represent channels maintained within the terrestrialising pits. There is therefore generally adirect hydraulic connection between the water in such dykes and the adjoining loose turf pond infill, a circumstance which is likely to facilitate water exchange.

Not all examples of WETMEC 6 in Broadland are obviously in old peat workings. Some occupy surfaces that have been partly drained and then reflooded (such as Berry Hall Marshes, Hall Fen, Ward's Marsh), resulting in a loose peaty surface over solid peat that presents a similar stratigraphical sequence to the turf ponds (and which can sometimes be difficult to distinguish from these). At Sutton Fen, much of the surface is occupied by a loose peat mat, locally buoyant, with high permeability (van Wirdum *et al.,* 1997; Surridge, 2005), which is functionally WETMEC 6. However, its origin is obscure – it may represent the infill of very extensive turf ponds, but no clear evidence has been found for this. Also in Broadland, some solid peat surfaces which often maintain high water tables in summer have been clustered within WETMEC 6 (as sub-type 6a which is transitional to WETMEC 5c). It seems likely that these may also have quite high near-surface permeabilities, but relevant data are sparse (Surridge, 2005).

Only a few samples from outside of Broadland have been clustered into WETMEC 6: from Biglands Bog (Cumbria) Cors Graianog (Dwyfor) and Cranberry Rough (Norfolk). These are all sites where (in places) loose peats border a stream and apparently receive water from it. Both Biglands Bog and Cranberry Rough are essentially hydroseral basins, modified by drainage and so on but not obviously turf ponds, whereas the small areas of loose hydroseral peats at Cors Graianog could represent the infill of shallow peat workings.

Affinities and recognition

This WETMEC is formed from 2 clusters recognised at the 36-cluster stage. These show close affinities and are regarded as sub-types of a single WETMEC rather than as separate WETMECs. The equivalent of WETMEC 6 was recognised in Phase 1 (as Surface Water Percolation Floodplains (Type 6); Wheeler and Shaw, 2000a) in more or less the sense adopted here, but some of the sub-types (which are based on the multivariate classification) are rather different, reflecting the wider range of samples included. In particular the ‘water fringe’ sub-type is better represented, and better defined, than in Phase 1.

WETMEC 6 does not fit neatly into any existing published wetland types, but its closest affinities are with ‘water fringe wetlands’. This is obviously the case for those examples that fringe open water, but is also appropriate for former turf ponds which in a sense represent an extensive former open water fringe that extends well into the fens, but from which the open water phase has now largely disappeared because of hydroseral succession. However, some samples allocated to this unit, including some with a vertically mobile fen mat, have neither developed hydroserally nor do they adjoin open water.

The large number of samples available from Broadland, with broadly similar characteristics, strongly dominates the cluster and results in samples from rather different topographical contexts clustering as outliers to the main cluster. This is the case for both Biglands Bog and Cors Graianog, where their outlier status is due mainly to differences in detail from the Broadland samples, not to differences in the conceptual mechanism.

Most examples of WETMEC 6 are distinctive, but there are two main potential problems of identification. One is in distinguishing it from some types of Seepage Percolation Basins (WETMEC 13), as the main difference between the two types is water source (groundwater versus surface water), which may sometimes be difficult to identify or quantify. Nonetheless, many examples of former turf ponds in Broadland can be assigned unambiguously to WETMEC 6, because they are clearly surface-water fed. For example embanked, river-connected sites over a thick layer of estuarine clay are clearly fed by river water (and rainfall). In other sites, dense basal peats and underlying clays may form an effective aquitard in potential groundwater discharge areas and reduce groundwater inputs to insignificance, even though there may be hydraulic connection.

Some examples of WETMEC 6 (primarily sub-type 6a) can be difficult to separate from some examples of WETMEC 5 (especially sub-type 5d: Floodplain Sump) as the two units intergrade conceptually and, in some locations, spatially. Examples of WETMEC 6a usually have higher summer water tables and less dense top-layer peat than the wetter examples of WETMEC 5, but the present dataset is inadequate to identify even nominal separating thresholds.

6.9.5 Origins and development

The majority of examples of WETMEC 6 are artificial in origin, a product of the hydroseral recolonisation of peat workings. In Broadland these include both the broads themselves and the more recent, shallower turf ponds (Box 6.11). Both types of workings form basins situated unconformably within the generic wetland infill of the mires.

Box 6.11: Broads and turf ponds in Broadland

Lambert *et al.* (1960) first demonstrated that the Broads were deep (around three to four metres) turbaries, though this possibility had been postulated by earlier workers. They were apparently dug during the Medieval Warm Epoch when storm surge activity in the North Sea, and possibly relative sea levels, were lower than at present (Wells and Wheeler, 1999), and their excavation was terminated by the subsequent Little Ice Age. After a protracted aquatic phase, the broads began to overgrow centripetally by swamp and fen (Lambert, 1951) to produce surfaces referable to WETMEC 6. The turf ponds are shallower (less than one metre deep), more recent (late eighteenth/nineteenth century) and appear to have been dug when water levels in the fens became lowered after the Little Ice Age (Wells and Wheeler, 1999). Their terrestrialisation has been much more rapid than that of the broads, largely because of their shallower depth.

In Broadland, examples of WETMEC 6 are underlain and bordered by a valley infill that is essentially the same as that described for WETMEC 5 (6.8.5) (Box 6.9). In some cases, particularly in some old turf ponds, the infill has become sufficiently consolidated to resemble that of some uncut top-layer peats. For this and other reasons, the precise extent of turf ponds is not always easy to identify stratigraphically. A further potential confusion is that solid peat surfaces which have been part-drained, and which have usually subsided slightly, can, upon reflooding and development of swamp and wet fen, present top-layer features that can be surprisingly difficult to separate stratigraphically from extensive, shallow turf ponds without recourse to detailed macrofossil analyses and dating. This can be particularly problematic at sites such as Sutton High Fen where there is no known independent evidence for either drainage or peat removal. Nonetheless, however formed, both recolonised turf ponds and some reflooded, drained peat surfaces can have similar top-layer characteristics, and examples of both have been clustered into WETMEC 6.

Recolonising turf ponds have considerable conservational importance, but, as transient features of wetlands, may need to be periodically recreated to maintain their value. Quite a lot is known about the patterns of revegetation within turf ponds, though numerous questions and uncertainties remain (Box 6.12).

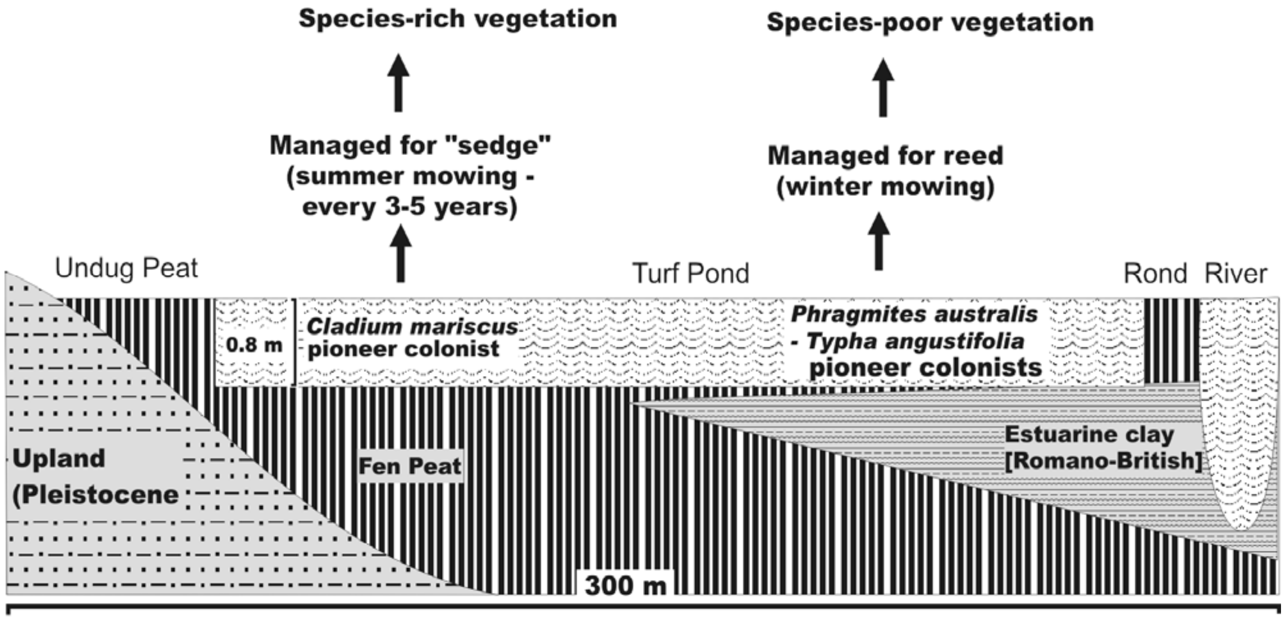
Box 6.12: The recolonisation of turf ponds in Broadland

Recolonised turf ponds support some of the least common fen habitats and species in eastern England. For example, fen orchid *Liparis loeselii* is confined to reflooded peat workings (in UK fens) (Wheeler, Lambley and Geeson, 1998), whilst these have also provided important habitats for uncommon bird species (such as bittern *Botaurus stellaris*). The specific conservational interest of individual turf ponds, or parts of turf ponds, depends upon the revegetation processes that have occurred, which have been examined in some detail by Giller and Wheeler (1986a, 1988) in the context of Broadland.

A broad pattern in revegetation can be identified in Broadland turf ponds, which has essentially resulted in some areas becoming reedbeds and others sedge beds (Figure 6.22). The present-day pattern broadly reflects early recolonisation events. Although exceptions can be found, turf ponds dug over estuarine clays mostly recolonised with *Phragmites australis* and *Typha angustifolia,* whilst those dug into continuous peat recolonised with *Cladium mariscus*. The reason for this pattern is not known, but it has had profound effects upon the subsequent development of the turf ponds. In particular, areas recolonised by reed have tended to be managed by winter-mowing and thus support reedbeds poor in plant species (though sometimes with rare invertebrates or breeding birds), whilst sedge beds have been managed by rotational summer mowing and can be very species-rich. Another difference is that the rhizome mat of *Phragmites* and *T. angustifolia* tends to be rather buoyant, whereas that of *Cladium* tends to be quite dense; thus the former species often form mats semi-floating in the turf pond whilst *Cladium* is frequently rooted in shallow standing water, though this difference diminishes as terrestrialisation proceeds.

A consequence is that within a single turf pond (as is illustrated by Great Fen in the Catfield Fens), the surfaces of the reed areas may appear to be less wet than those of the sedge areas. They are sometimes also more prone to invasion by woody plants and, especially, *Sphagnum*. Colonisation by *Sphagnum* has occurred locally in the fens of the northern Broadland valleys and almost all examples of this are in reflooded turf ponds (a few are in areas of reflooded formerly drained fen). The establishment of *Sphagnum* in floodplain fens such as those of Broadland essentially requires freedom from flooding with base-rich water, and thus occurs in locations where the fen mat is sufficiently buoyant to prevent regular inundation of the surface. This condition is provided primarily by *Phragmites/Typha* mats in the turf ponds and is absent from most of the solid uncut peat surfaces. [See Figure 23.3]

Although the vegetation mats that have developed in reflooded turf ponds can be considered to be hydroseral, they may not always have developed by ‘normal’ hydroseral processes. In particular, there is usually no obvious colonisation gradient as might be expected if there had been centripetal colonisation from the margins of the pits (and as has been the case around the broads). Instead there is a fairly uniform surface, suggesting that recolonisation was initiated across the pits more or less simultaneously. It is possible that after the peat workings were abandoned, but before they became deeply reflooded, there was recolonisation of the wet floor of the cutting which broke away to form a buoyant mat as the water level rose.



Phragmites australis and *Typha angustifolia* are the usually primary recolonists where the turf pond is floored with estuarine clay, but *Cladium mariscus* is often the main recolonist over continuous fen peat. The identity of the initial colonist species appears to determine the subsequent management and species richness of these different parts of turf ponds, although. *Cladium* sometimes invades the reedbeds at a later phase of the successional process.

Figure 6.22 Schematic diagram of recolonisation of reflooded, shallow turf ponds in Broadland

As far as is known, the unusual examples of WETMEC 6 at Biglands Bog have not developed in peat workings, but over the natural basin infill. By contrast, an example of WETMEC 6 alongside the inflow stream at Cors Graianog may well occupy a revegetated turf pond.

6.9.6 Situation and surface relief

WETMEC 6 is restricted to topogenous situations and the samples available are overwhelming associated with floodplains (96 per cent). Two per cent of the samples were recorded from basins and two per cent from a valleyhead context. The surface relief is typically flat and generally even (except for vegetation tussocks and so on) (Table 6.21).

Table 6.21 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 6

	Mean	1	2	3	4	5	6	7
Surface layer permeability	5.6				8	40	40	12
Lower layer permeability	2.2	40	21	31	2	2	3	2
Basal substratum permeability	2.1	14	75	5	2	5		
Slope	1.0	99	1	1			X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.9.7 Substratum

Most examples of WETMEC 6 occur on a quite deep wetland infill (mean depth of 3.5 m). The surface layer of peat is usually loose and unconsolidated, typically over a less permeable lower layer (Table 6.21). The surface layer, which in some cases is semi-floating, represents a fairly recent hydroseral peat which in most cases has formed within reflooded turbaries. In Broadland it occurs extensively in nineteenth century turf ponds, and in this situation the top layer is only some 0.5 to one metre deep. It is underlain by undisturbed deposits, which may be dense peat or estuarine clay (laid down during the Romano-British marine transgressive overlap), similar to those found beneath unworked surfaces (WETMEC 5). However, WETMEC 6 also occurs around the deeper broads and in this circumstance the loose surface layer may be underlain by deep, unconsolidated hydroseral peat and lake muds. Thus, whilst in some examples of this WETMEC the loose top layer is underlain by dense peat or estuarine clay, in others it is underlain by unconsolidated deposits. The outlier example of WETMEC 6 from Biglands Bog represents a location where the basin infill is naturally hydroseral and unconsolidated (at least in the upper 4.5 m of the deposit).

A few samples clustered within this WETMEC (in sub-types 6a and 6b) have a more consolidated top layer than most others. These are either in 'mature' turf ponds or, in a few cases, uncut surfaces where a high water table is maintained by local circumstances and form a unit transitional to WETMEC 5.

Most examples of WETMEC 6 are floored by a basal layer of low-permeability clays and silts, either Till or an alluvial/estuarine deposit, but a few examples have more permeable sandy deposits (Table 6.21). In some of these latter the sandy material may overlay clays and silts, but few coring data are available to be certain.

6.9.8 Water supply

During low water (usually summer) periods, the primary source of telluric water to these wetlands appears to be by sub-irrigation, deriving water from streams, rivers, broads and particularly, river-connected dykes. It is likely that the main driving force on summer water flow into the fen is evapotranspiration losses from the vegetation coupled with water level changes in the surface water system. In winter, inflows may result from high river levels and land drainage and, in combination with precipitation inputs, may result in considerable inundation. The extent to which the vegetation surface becomes flooded by these inputs depends both upon the magnitude of the water level fluctuation and the buoyancy of the vegetation. When the hydraulic gradient is reversed, usually in response to precipitation events, there is drainage out of the fens into adjoining watercourses (Surridge, 2005).

Only a few studies have directly examined the summer surface-water percolation process. Baird *et al.* (1998) showed that water levels in parts of Sutton Fen with a loose upper stratigraphy were very responsive to changes in river water levels, apparently because of water exchange beneath the fen mat with a river-connected dyke. However, the process can be inferred from the stratigraphy and (relatively) high summer water tables of a number of sites. There is clear evidence that some, but not all, fen compartments with loose upper peat horizons show a much smaller reduction of summer water table (relative to the vegetation surface) than is the case with compartments based on solid peat. There are at least three possible reasons for this, with evidence providing some support for each: (i) the vegetation mat has some vertical mobility and can track water level changes; (ii) the loose sub-surface infill has greater water storage characteristics than the more solid peat; and (iii) there is more recharge of water losses by flow of water (from adjoining dykes and so on) through the loose upper peat horizons than through more solid peat. Also, reflooded turf pond sites that are not connected to dykes or other potential water sources appear to dry out more during the summer than connected systems, and are allocated to a distinctive sub-type (WETMEC 6c), pointing to the importance of water recharge from proximate sources. Ongoing seral consolidation of the turf pond infill may well decrease its permeability, as well as its buoyancy and specific yield, and the surfaces may become increasingly like those of WETMEC 5. Some of the Solid SW percolation surfaces (WETMEC 6a) may represent this transitional state, though they could also reflect variation in the salient characteristics of different deposits of solid peat.

The loose peat infill associated with WETMEC 6 permits not only the penetration of surface water but also accompanying solutes. A section across part of Sutton Broad (Figure 6.23), which has a particularly loose and deep infill and is closely associated with a watercourse (which flows through the centre of the former broad), suggests the possibility that river water may penetrate under much of the raft. However, whilst Ca^{2+} concentrations remain high almost to the land margin of the fen, there is a progressive landwards reduction in K^{+} concentration, soil fertility and vegetation productivity. This may indicate a diminishing influence of river water towards the land margin, or that some nutrients are stripped from the percolating water during its passage through the peat and loose rhizome raft. Another possibility is groundwater inputs from the land margin which interact with the penetrations of river water.

The role of groundwater, if any, in these systems is not well understood. In Broadland examples of WETMEC 6 are often located over deep, well humified and solid peat deposits, sometimes with intercalated layers of estuarine clay, and are probably often separate from the mineral aquifer by basal clays. In combination, these are likely to provide an effective aquitard. Preliminary piezometric measurements and data from thermal-conductivity profile probes in a turf pond in the Catfield fens (van Wirdum *et al.,* 1997) provided no indication of groundwater inputs, despite close proximity to the upland margin and the occurrence of some so-called ‘seepage indicator species’. All other known evidence from WETMEC 6 also points to systems dominated by horizontal water flow, with vertical upflow having little importance (Baird *et al.*, 1998; Surridge, 2005). However, it is possible that groundwater outflow from the aquifer contributes to some of the deeper broads and dykes, especially near the fen margins where these have been dug down near to, or into, the underlying Crag, but the occurrence and likely magnitude of this is not known. Similarly, at Biglands Bog and Cors Graianog it is possible that groundwater may make some small contribution to the surface water-dominated supply. In the absence of detailed studies on groundwater inputs into these wetlands, it is proposed that all percolating wetlands which are regularly affected by river flooding and flow should be classed as Surface Water Percolation Floodplains, even though some examples may have small groundwater inputs.

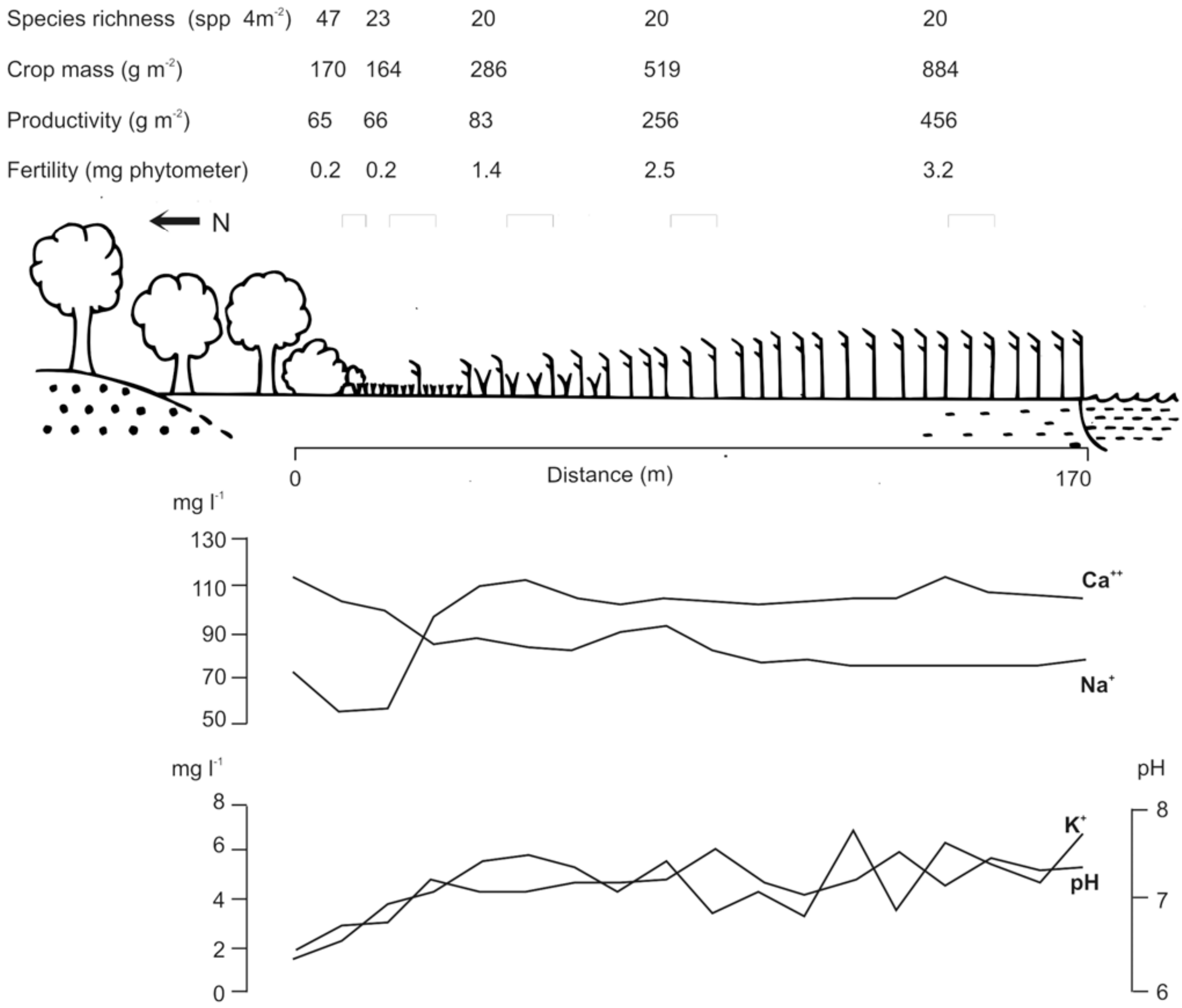


Diagram shows variation in vegetation species richness, crop mass (biomass + litter) and productivity, soil fertility and concentration of selected cations in the interstitial water along a transect across the fen on the north side of the water channel at Sutton Broad. The whole section was located over loose, hydroseral infill within the Sutton Broad basin, upon a semi-floating surface. Soil fertility was estimated phytometrically using *Phalaris arundinacea* as the phytometer species.

Figure 6.23 Vegetation and hydrochemical features along a transect across part of Sutton Broad

6.9.9 WETMEC sub-types

Six WETMEC sub-types have been identified. They correspond to six multivariate clusters at the 72-cluster level and are grouped into three clusters at the 36-cluster level. The sub-types are associated with distinctive mean summer water tables:
6a: –12.3cm; 6b: –18.2 cm; 6c: –16.6 cm; 6d: –4.0 cm; 6e: 12.5 cm; 6f: –1.8 cm.

WETMEC 6a: Solid Surface Water Percolation Surface

CLUSTER: 7.1

Examples at: Burgh Common, Strumpshaw Fen, Wheatfen

This sub-type (a subcluster identified at the 72-cluster level) includes stands which have a relatively solid peat surface coupled with a relatively high summer water level. Some examples (such as parts of Wheatfen and Strumpshaw Fen) appear to be located over old turf ponds, with a rather consolidated infill, but some others (such as Burgh Common) appear to be on uncut peat surfaces where the uppermost peat, although quite solid, is fresher and probably more transmissive than the more humified, solid upper peats typical of WETMEC 5. Such examples of WETMEC 6a typically adjoin a source of potential water recharge (for example, alongside dykes or pools with a high water level, close to that of the peat surface and sometimes overtopping) or are in marginal locations where groundwater inputs may possibly help to maintain a high water table. In general, it is not possible to assess the importance of these factors in determining the high water levels with existing information. For example, fens along parts of the landward margin at Wheatfen have been clustered into this group, and may possibly receive groundwater outflow. However, these are also close to a landspring dyke and may possibly be fed by this; they are also distant from the river and may be particularly poorly drained.

Examples of WETMEC 6a, especially those on solid peat, are transitional conceptually and sometimes spatially to WETMECs 5c and 5d, and cannot always be readily distinguished from these. Examples allocated by the clustering program to 6a generally had a higher water table and fresher top-layer peat than examples of WETMEC 5.

WETMEC 6b: Grounded SW Percolation Quag

CLUSTER: 7.2

Examples at: Catfield and Irstead Fens, Hulver Ground, Reedham Marsh

WETMEC 6b includes a number of turf ponds (and so on) where the summer water table can fall significantly sub-surface but which are normally wet or flooded during winter. Note that the nomination 'dry' is relative to the 'wet' of sub-type 6d – these samples are not normally as summer-dry as examples from Summer-Dry Floodplains (WETMEC 5). Salient features of this WETMEC are that the peat infill is often more consolidated than sub-type 6d examples, and some may be in a more mature hydroseral state than sub-type 6c. However, many examples of sub-type 6b may receive less surface water recharge than 6d. This is because they can be more distant from watercourses, or separated from these by banks of solid peat without apparent breaches. Dyke water levels may also be lower around sub-type 6c stands. At Catfield, examples of sub-type 6b tend to occur in locations remote from the river, where surface water supply is probably limited or even absent. Thus some examples of this sub-type may be drier than type 6d because they are older, more elevated and more consolidated; others because they are separated from surface water sources or because dyke levels are relatively low.

WETMEC 6c: SW Percolation 'Boils'

CLUSTER: 7.3

Examples at: Catfield and Irstead Fens, Hickling Broad, Reedham Marshes

This includes a small number of samples with a sub-surface water table year round, typically associated with a rather unstable, buoyant or quaking, surface. Most examples are dominated by *Sphagnum* and represent small 'boils' of acidic surface that have developed hydroserally in some turf ponds and so on. They have often developed from wet fen or swamp and their apparently surface-dry character is primarily a product of their buoyancy rather than because the telluric water table is low (*cf.* sub-type 6c) – some examples of this WETMEC occur in particularly wet situations. In the more consolidated and mature examples, the dry surface can permit colonisation by tree and shrub species (such as birch and bramble) and ongoing consolidation can take this sub-type in the direction of WETMEC 6b.

WETMEC 6d: Swamped SW Percolation Surface

CLUSTER: 8.1

Examples at: Berry Hall Fens, Cranberry Rough, Hall Fen

This rather poorly characterised unit, to which only a small number of samples have been allocated, essentially consists of solid surfaces of peat or alluvium of rather low transmissivity that are kept wet more or less year round by shallow surface flooding (swamping). The swamp and fen that has developed is rooted on the solid peat, rather than forming a buoyant surface, though in some cases an unconsolidated mat of rhizomes and litter has developed secondarily above the solid surface. WETMEC 6d has been recorded from two main situations: (a) where surface water sources (dykes, streams and so on) are maintained mostly at a higher level than the adjoining fen, usually by a sluice or some other water management structure, so that swamping occurs across the fen surface; and (b) where there are substantial depressions (sumps) within fens, fed either directly by surface water inputs or by seepage from higher level fens (Figure 6.21c). In Broadland, the main origin of such sumps appears to be past drainage, followed by subsidence and rewetting as a result of deterioration of the drainage structures (as at Berry Hall Fens, Hall Fen), though there are also turf ponds in some locations. The main differences between the swamped SW Percolation Surfaces (6d) and the wet SW Percolation Quag (6e) are: (a) that the Swamped SW Percolation Surfaces often have swamp or wet fen rooted on a solid peat surface rather than a buoyant vegetation mat (though in some locations a buoyant mat may eventually develop); (b) they are not necessarily peat-based (in some examples the surface is clay); and (c) some are less connected to surface water inputs than are reflooded turf ponds (for example, rivers and riverward fens have often been embanked to permit the (past) drainage of areas that are now Swamped SW Percolation Surfaces) and they can show a greater tendency than river-connected turf ponds to become dry during the summer period. These latter examples of WETMEC 6d have clear affinities to some of the floodplain sumps of WETMEC 5d.

WETMEC 6e: Wet SW Percolation Quag

CLUSTER: 8.2

Examples at: Biglands Bog, Catfield Fen, Cors Graianog, Hickling Broad, Reedham Marshes, Sutton Broad and Fen, Woodbastwick Fen

This is the most extensive and widespread version of WETMEC 6 in Broadland. All examples are usually summer-wet and most have a buoyant mat of peat. Almost all examples occupy former turf ponds, the possible exception being Sutton Fen, where the cause of the extensive mat of buoyant peat is not certain. In some cases, the vegetation is rooted on the bottom of the turf pond (in which case there is normally standing water amongst the stools of the plants, and loose accumulations of litter and 'protopeat'), but more often the vegetation forms a buoyant mat over a loose mix of rhizomes, redeposited peat and water. The thickness of the mat and its vertical mobility varies considerably. Thin examples are often clearly semi-floating, whereas thicker ones may be more of an expansible rhizome–peat mass than a raft. The turf ponds are fed mainly by surface water from rivers or river-connected dykes which flows into and through this sub-type, apparently beneath the buoyant vegetation mat (and above the solid peat or clay that forms the base to the turf ponds) or through loose accumulations of surface peat (Figure 6.21b). In addition, the buoyant mats can damp water level fluctuations relative to their surface because of their mobility; in conjunction with the turf pond topography, they play an important role in water storage.

The buoyant surface of parts of Biglands Bog (Cumbria), which is over a quite deep natural profile of loosely consolidated deposits, has also been clustered into this sub-type. It differs from the Broadland examples of 6e in the depth of underlying unconsolidated material and by the penetration of a loose, silt-rich ooze, apparently sourced from the Bampton Beck, into at least the upper layers of the profile.

WETMEC 6f: SW Percolation Water Fringe

CLUSTER: 9

Examples at: Barton Broad, Hoveton Great Broad, Sutton Broad, Esthwaite North Fen

This quite widespread but rarely extensive type of wetland includes the (usually hydroseral) vegetation invading the open water of lakes and pools, either as a raft (*hover fringe*) or rooting on a shelving shoreline (*littoral fringe*) (Figure 6.21a). It is particularly important in Broadland and around various other surface water-fed pools and lakes in Eastern England. Note that water fringes which are thought to receive landward groundwater inflows as well as surface water have been clustered into a separate unit (WETMEC 13c: Seepage Percolation Water Fringe).

WETMEC 6f occurs in a distinctive situation and has been recognised in some classifications as an independent wetland type (such as Waterfringe wetland – see Table 3.11). Conceptually, apart from the fact it is bordered on one site by open water or swamp, its main difference from the other sub-types of WETMEC 6 is that this unit occurs *within* a surface water source (lake, river and so on) whereas the others are usually fed *from* a surface water source; however, this is a moot distinction and sometimes difficult to apply (for example, some turf ponds fed from a surface water source can contain residual open water and an associated hydroseral open water fringe).

6.9.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 6 are summarised in Table 6.22. Ecologically, Surface Water Percolation Floodplains have a good deal in common with Seepage Percolation Basins (WETMEC 13), as reflected in similarities in the range of plant communities that occur. The main difference between the two WETMECs is in water source: surface water (mainly river water in WETMEC 6) *versus* groundwater. The water tables of the 'wet' versions of WETMEC 6 (sub-types 6d–f) are fairly similar to those of WETMEC 13, and oxidation–reduction potentials are very similar. WETMEC 6 conditions, however, are generally more variable than in WETMEC 13, largely on account of those examples (WETMECs 6a–c) that experience low summer water tables. Also, WETMEC 6 surfaces typically experience episodic flooding, which does not occur in many examples of WETMEC 13.

Table 6.22 WETMEC 6: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	3.5	0.5	12.0
Summer water table (cm)	–3.6	–29	16
Rainfall (mm a^{-1})	637	603	1,828
PE (mm a^{-1})	622	543	625
Water pH	6.2	4.9	7.3
Soil pH	6.4	4.6	7.0
Conductivity (µS cm^{-1})	1,206	66	5,094
K_{corr} (µS cm^{-1})	1,206	62	5,094
HCO_3 (mg l^{-1})	62	9	142
$Fertility_{Phal}$ (mg)	15	4	33
Eh^{10} (mV)	229	125	358

See list of abbreviations in Appendix 1

The high summer water table is a product of the mechanism of water delivery (6.9.8), which is either through the surface vegetation or, more usually, beneath a buoyant vegetation mat, the surface of which can move to accommodate changes in water level. The low redox potentials refer to measurements at a standard depth of 10 cm bgl. However, there is evidence for a strong increase in redox potentials upwards in some semi-floating mats (Giller and Wheeler, 1986b; Sellars, 1991), related to absence of saturation at the very surface and to photosynthetic oxygenation by moss carpets. Such conditions may favour the occurrence of a number of the more anoxia-sensitive species, both wetland and dryland, and almost certainly help to account for the rich diversity of plant species that occurs in some examples of WETMEC 6.

All of the examined examples of WETMEC 6 are associated with fairly base-rich telluric water sources. However, surface acidification can occur locally, often associated with particularly buoyant or mature patches of fen mat which do not normally become inundated even in winter flooding episodes (Giller and Wheeler, 1988). As the rivers feeding this WETMEC are generally eutrophic, it might be expected that this wetland type is also characteristically eutrophic. However, whilst there are plenty of eutrophic examples, mesotrophic and oligotrophic examples also occur. Moreover, the more fertile examples are not necessarily a product of river-enrichment – most of the eutrophic examples appear to be a product of an intrinsically more fertile substratum and are particularly found in turf pond locations where estuarine clay (from the Romano-British marine transgression) forms the floor of the peat working. This effect can sometimes be seen within a single turf pond. For example, the north part of the turf pond in Great Fen (Catfield) is over peat and has recolonised with mesotrophic vegetation dominated by *Cladium mariscus*, whilst the southern part, over estuarine clay, has recolonised with a more vigorous community dominated by

Phragmites australis and *Typha angustifolia.* The reason for the apparent lack of a strongly enriching effect of eutrophic river water in some Type 6 WETMECs remains to be established. Perhaps the most likely explanation is that nutrients are stripped from the water in passage through or below the vegetation mat[1] (Koerselman *et al.*, 1990). Few data are available on fen water quality during flooding episodes, but at Catfield, Giller and Wheeler (1986b) recorded substantial dilution of solutes during flooding.

River-connected dykes feeding recolonised turf ponds are often eutrophic and frequently full of redeposited peat and mud. These are considered further under WETMEC 5.

6.9.11 Ecological types

The distribution of samples of WETMEC 6 amongst the pH and fertility categories is shown in Table 6.23. This reflects a preponderance of samples from base-rich sites, which are mostly mesotrophic in character. There are notably more samples from base-rich sites (76 per cent) than is the case for WETMEC 5 (65 per cent), even though the two types largely occupy the same fen sites. This is probably a consequence of the more ready penetration of base-rich surface water into WETMEC 6 and the greater proportionate importance of meteoric sources in WETMEC 5, though in some locations it could also be a consequence of slight acidification associated with summer drying in WETMEC 5. Nonetheless, as with WETMEC 5 the samples straddle the sub-neutral to base-rich boundary and many of the ‘base-rich’ samples in WETMEC 6 have water pH values only slightly in excess of 6.5.

Table 6.23 Percentage distribution of samples of WETMEC 6 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	2	47	27
Sub-neutral	4	7	5
Base-poor		8	
Acidic	0		

Oligotrophic/mesotrophic, base-rich/sub-neutral

These examples are often dominated by *Cladium mariscus.* There is a tendency for the most species-rich communities found in this category to occur mainly in sites with a water pH in excess of 6.5 and in low fertility conditions. These straddle the oligotrophic–mesotrophic boundary, but the highest fertilities are all at the low mesotrophic end of the scale. A frequent feature of some of the richest stands is the occurrence of so-called ‘seepage-indicator species’. These do not normally grow in turf ponds over brackish clays and because of this such vegetation often tends to be restricted to a zone close to the land margin. It is possible that some marginal bands may receive inputs of groundwater, as suggested by the seepage-indicator species, but investigations (van Wirdum *et al.,* 1997) have found no evidence for this. If examples of low fertility vegetation receive water from adjoining rivers through connecting dykes, it can only be presumed that nutrients are stripped from the water in passage through the dykes and root mats.

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[1] Because in most sites the clay-based turf ponds are closer to the rivers than are the peat-based examples, this may obscure the rôle of river water supply to eutrophication-gradients within the turf ponds. However, even in up-river sites that are almost entirely peat-based, there is generally little evidence of an obviously river-related nutrient gradient.

Mesotrophic/eutrophic, base-rich on brackish clays

These represent sites where turf ponds were excavated to the upper surface of Romano-British estuarine clays. These appear to determine the character of the terrestrialising vegetation, which is usually dominated by *Typha angustifolia* and *Phragmites australis*, sometimes with *Cladium* as a late-successional colonist.

Mesotrophic, base-poor

Most examples of this ecological type occur in Broadland turf ponds, as small patches of acid fen vegetation, usually with much *Sphagnum* and referable to the *Betulo-Dryopteridetum cristatae*. These areas represent shallow accumulations of peat that have developed slightly above the telluric water table and are irrigated directly, and almost exclusively, by precipitation. They are often associated with particularly buoyant vegetation mats (WETMEC 6c). The distinctive water supply mechanism of these *Sphagnum* mats means that they could be considered a different hydrological type to other examples of WETMEC 6, perhaps more similar to WETMECs 2 or 3, and some oligotrophic examples in locations distant from surface water sources have in fact been clustered within WETMEC 3 (6.6). However, because they are always small in area and are consistently found in intimate association with more base-rich Type 6 communities, it seems best to preserve the multivariate clustering which assigned them to a Type 6 subset.

Of the few samples from outside Broadland that were clustered into WETMEC 6, those from Cors Graianog belong to the mesotrophic, base-poor category, but this is a reflection of the intrinsic chemical properties of the surface water that feeds them, rather than of seral processes within a more base-rich context.

A consistent feature of these acidic examples of WETMEC 6 is that they are mesotrophic rather than oligotrophic. In the Catfield fens, some examples are more fertile (mesotrophic) than nearby oligotrophic, base-rich stands from which the acidic surfaces seem to have developed serally. One possible explanation relates to enhanced nutrient cycling associated with the drier surface conditions that characterise these acidic islands, but this does not account for the weakly mesotrophic conditions measured in wet WETMEC 6e at Cors Graianog.

Eutrophic, base-rich/sub-neutral

These represent turf pond sites in fertile conditions, but not associated with estuarine clays, though they have many similarities with these. They are typically strongly dominated by reed or some other rank vegetation type such as *Glyceria maxima*. Many of the examples of WETMEC 6 in the Yare valley of Broadland belong to this ecological category; the cause of the high fertility is often not obvious, but is presumed to relate to river nutrient concentrations and, occasionally, silt deposition. The WETMEC 6 surfaces at Biglands Bog all belong to this type, and are subject both to silt deposition and ingress of eutrophic water from the Bampton Beck.

6.9.12 Natural status

Most of the examples of WETMEC 6 examined in this study are clearly artificial in origin. Most SW Percolation Water Fringe examples (WETMEC 6f) occurred mainly around the margins of deep medieval peat pits (the Broads) and the majority of the remainder were in shallow peat excavations (turf ponds). These latter, shallower examples may be particularly transient – their distinctive characteristics, hydrological and ecological, are likely to be lost as the turf pond infill consolidates. A possible exception to these generalisations is provided by the surface of much of Sutton Fen (Broadland), which is covered by a very extensive and thick, slightly buoyant fen mat. It is not certain that this represents a turf pond infill.

Water fringe surface water percolation systems can occur naturally, and sometimes extensively, as fringes around lakes and pools. In Eastern England, some small water fringe wetlands are associated with the margins of natural pools. Water fringe wetlands were almost certainly once considerably more extensive than nowadays, as part of the natural character of floodplain complexes such as those of Broadland and Fenland (such as Whittlesey Mere).

It is also likely that extensive buoyant, loose, surface-water fed fen mats also occurred naturally. Kulczynski (1949) has described, from natural mires in Polesie (Belarus), semi-floating *dysaptic* surfaces consisting of an admixture of tall plants (immersive perennials) rooting into a solid underlying layer of peat topped by a buoyant mat of semi-floating vegetation. Structurally, these correspond rather well with the thin semi-floating surfaces found in some turf ponds, despite the artificial origin of these latter. Kulczynski also observed that the upper profiles of many fens did not show the contrasting layering of a dysaptic surface, but had a more uniform profile in which the uppermost layers were generally less humified and which "*undergo the biggest changes in their volume when the ... water level oscillates*". This *cryptodysaptic* surface – which is widespread in many wet, topogenous fens – is more of an expandable peat mass than a true raft and roughly corresponds to the thicker, more mature infill of some turf ponds.

With the possible exception of the Sutton Fens (Broadland), there are no known natural examples of either dysaptic or cryptodysaptic surfaces in Eastern England (though they occur in some less modified wetlands in other regions of Britain), but it seems likely that buoyant fen surfaces corresponding to these once occurred naturally. Layers of fresh, monocot and (especially) hypnoid moss peat within the more solid main peat infill of floodplain fens may represent former phases of surface water percolation, both in Broadland and elsewhere. In Fenland, there is some stratigraphical suggestion that percolating surfaces once occurred in the area of Holme Fen (where they provided the basis for the subsequent seral development of ombrogenous bog) and deposits of hypnoid moss peat in Broadland have also been interpreted as evidence for consistently high water tables (though these could have been a consequence of either consistent surface water inputs (Lambert *et al*., 1960) or groundwater discharge). Thus, infilling turf ponds appear to mimic a wetland habitat that probably once occurred naturally in some wetlands in Eastern England, but which has disappeared from many areas.

6.9.13 Conservation value

Many examples of WETMEC 6 are considered to have high conservation value, and support vegetation types that form much of the basis for the designation of some SAC sites (see Tables 3.3 and 6.4).

The percentage occurrence in NVC communities of samples of WETMEC 6 is: S24: (57%); M9-3: (9%); S04: (8%); M9-2: (7%); BDC: (7%); S27: (3%); M22: (2%); W05: (1%); M05: (0.5%); M25: (0.5%); S02: (0.5%); S28: (0.5%); W02: (0.5%); W04: (0.5%). [One unit listed here is a non-NVC unit, described by Wheeler (1980c): BDC: *Betulo-Dryopteridetum cristatae*; M9-3 is a version of M09, as described in the community accounts.] Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 6 is given in Table 6.3.

A total of 130 wetland species have been recorded from the samples of WETMEC 6. These include 30 nationally uncommon plant species: *Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Carex appropinquata, Carex diandra, Carex elata, Carex* *lasiocarpa, Cicuta virosa, Cinclidium stygium, Cladium mariscus, Dactylorhiza praetermissa, Dryopteris cristata, Eleocharis uniglumis, Epipactis palustris, Lathyrus palustris, Liparis loeselii, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Plagiomnium elatum, Potamogeton coloratus, Pyrola rotundifolia, Ranunculus lingua, Rhizomnium pseudopunctatum, Sium latifolium, Sphagnum teres, Stellaria palustris, Thalictrum flavum, Thelypteris palustris, Utricularia intermedia.*

Mesotrophic examples of WETMEC 6, dominated by *Cladium mariscus* and with a range of so-called 'seepage indicator' (CARICION DAVALLIANAE) species, form a priority EC Habitats Directive interest feature ('Calcareous fen'). They are usually species-rich and sometimes support rare flowering plants (such as fen orchid, *Liparis loeselii*) and bryophytes (such as *Cinclidium stygium*). Pools in such vegetation can sustain uncommon aquatic plants (such as *Utricularia intermedia*) and rare invertebrates, including water beetles, dragonflies and molluscs.

Reedbeds occur widely in WETMEC 6, either as S4 or as *Phragmites*-rich variants of other communities (especially S24). They are generally not botanically rich, though some examples support rather uncommon reedswamp plants such as *Cicuta virosa* and *Sium latifolium.* They do, however, have some special bird species, including reedling (*Panurus biarmicus*) and bittern (*Botaurus stellaris*).

In unmanaged situations, colonisation by woody plants can lead to development of some form of scrub and woodland, especially alder wood in some (mainly mesotrophic) examples. This also constitutes a priority EC Habitats Directive interest feature ('Alluvial forest with *Alnus*'), but in general it is considered to have lower priority for conservation than herbaceous communities within the WETMEC, partly because of its proclivity for spontaneous development – preventing the expansion of woody vegetation across WETMEC 6 surfaces is a focus for much conservation management.

6.9.14 Vulnerability

The biggest threat to the conservation interest of WETMEC 6 surfaces is probably hydroseral succession within the peat workings that support this unit, and the development of substratum conditions more akin to those of the natural state of the floodplains (WETMEC 5). Perceptions that some WETMEC 6 locations are becoming drier may sometimes stem from ongoing stabilisation of the vegetation mats, and peat accumulation, than from a reduction in fen water tables, because these processes reduce the buoyancy of the fen mat and the transmissivity of the top-layer infill, and probably water storage capacity. Vegetation management – a prerequisite for the maintenance of much of the special interest of the WETMEC by inhibiting expansion of woody plants and maintaining a diverse herbaceous sward – does not prevent seral stabilisation of the substratum (though it may slow this process).

Communities such as M9-3 (*Carex diandra–Peucedanum palustre* mire (see Part 3)) occupy a transient phase of the hydroseral colonisation of some turf ponds (Segal, 1966; Giller and Wheeler, 1986a). Even with vegetation management, these can disappear as succession proceeds, because the increasingly solid properties and grounding of the fen mat lead to lower summer water tables, or because of acidification and expansion of *Sphagnum* communities over the surface of a buoyant mat. Similarly, succession and drying in reedbed areas is likely to promote invasion by other plant species and reduce their value for commercial mowing. The loss of extensive areas of swamp and wet fen caused by the hydroseral infilling of turf ponds may be one reason for the collapse of the former bittern population in this WETMEC, though enrichment and infilling of river-connected dykes are also considered to have contributed to this.

Acidification and *Sphagnum* expansion is generally confined to the more buoyant surfaces of WETMEC 6c and can occur both early and late in the successional processes (early *Sphagnum* colonisation is always associated with particularly buoyant rafts). In general, there is little reason to expect ongoing *Sphagnum* expansion and the development of ombrotrophic surfaces, because stabilisation of the buoyant surface may lead to susceptibility to inundation with surface water[1].

Lack of management is often detrimental to the conservation interest of this WETMEC. Although some of the rarer plant species can tolerate a degree of shading and can survive in open-canopy woodland, many are intolerant of dense shade, whether created by trees or rank herbaceous vegetation. The bird species of reedbeds are also detrimentally affected by scrub colonisation, though both reedlings and bitterns benefit from areas of unmanaged reed for nesting.

The dependency of WETMEC 6 upon surface water inflows, and evidence that the fen water table may be perched (for example, Surridge, 2005) means that in general, it may not be much affected by a lowering of groundwater tables in underlying mineral aquifers. However, in some locations, especially near the upland margins of some floodplains, groundwater may help to support the surface water table. The consequences of lowered groundwater tables in this situation are not really known and are likely to depend upon the particular characteristics of individual sites. It is possible that an effect of lowered groundwater tables could be compensated by increased inflow of surface water, though this might also increase nutrient inflow.

The mesotrophic examples of WETMEC 6 are potentially vulnerable to river-borne eutrophicants, but in general there is little evidence for obvious enrichment problems. This may be because such processes are slow and pervasive, and therefore difficult to detect, especially in the virtual absence of appropriate vegetation monitoring. For example, it is suggested that the impoverished moss component of the *Carex diandra–Peucedanum palustre* mire (M9-3) vegetation at Dilham Broad Fen could be a product of enrichment (see Appendix 3), though there is little measured evidence to resolve this possibility. There is no doubt, however, that direct and catastrophic enrichment of WETMEC 6 can occur. Stratigraphical data from Biglands Bog (Cumbria) (Wheeler and Wells, 1989) indicates that at this site, former mesotrophic fen (referable probably to *Carex diandra–Calliergon* mire (M9-2) has been replaced by a rank, eutrophic *Phalaris*-dominated surface (*Phalaris arundinacea* tall-herb fen (S28)), almost certainly as a consequence of the ingress of nutrients and silt, sourced by the Bampton Beck which flows through the basin.

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1 *Sphagnum* colonisation and development of extensive proto-ombrotrophic surfaces has occurred in some fens in the Netherlands which could be classified as WETMEC 6 (*e.g.* De Weeribben). However, an important difference between such sites and Broadland is that river water levels are much more strongly regulated in the Weeribben than in Broadland, reducing the likelihood of surface inundation with telluric water.

6.10 WETMEC 7: Groundwater Floodplains

6.10.1 Outline

This is a rather ill-defined WETMEC of undrained floodplains of groundwater-fed rivers over heterogeneous and often probably slowly permeable alluvial deposits, usually with only shallow peat. Groundwater feeds both the rivers and the fen, and river levels are thought to be in equilibrium with the piezometric head of the aquifer. Groundwater levels in the floodplain may be similar to, or slightly higher than, river levels but there is a tendency for part or much of the floodplain area to be seasonally dry, either naturally or in response to water management. Mire habitats are sometimes restricted to hollows and in some locations, close to watercourses. It has not been possible to provide cross-sections for this WETMEC due to its rather ill-defined nature.

6.10.2 Occurrence

Example sites: Bransbury Common, Chilbolton Common, Chippenham Fen, Greywell Fen

Outlier sites: Tarn Fen (Malham), Stockbridge Fen, Tarn Moor (Sunbiggin)

Not widely encountered in the present survey (Figure 6.24), possibly because groundwater-fed floodplains of this type more usually support (wet) grassland systems rather than fen. Type sites are provided by examples in the River Test valley (Hampshire).

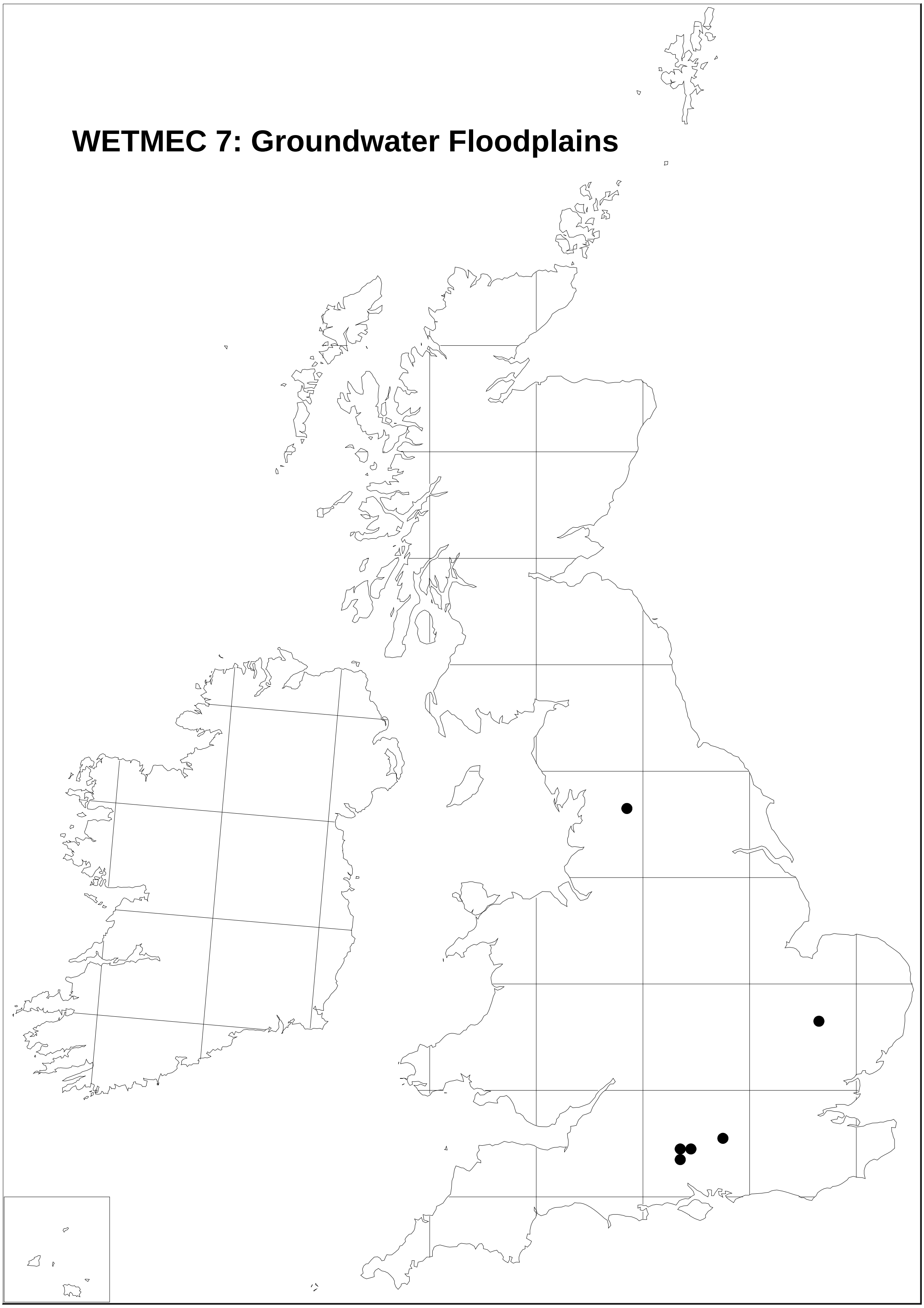


Figure 6.24 Distribution of examples of WETMEC 7 in sites sampled in England and Wales

6.10.3 Summary characteristics

Situation	River floodplains; small floodplains in valleyhead sites.
Size	Small bands alongside watercourses to quite large areas of fen (> 10 ha).
Location	Sampled mainly from Southern England, but also elsewhere.
Surface relief	Even (appears more or less flat, but gently slopes to river or outfall).
Hydrotopography	Rheo-topogenous.
Water: ***supply***	Groundwater; river levels may determine mire water tables, at least locally.
regime	Many examples are fairly summer-dry; wetter if in a hollow or in receipt of groundwater outflow from above. Usually only occasionally flooded.
distribution	Into peat body; dykes.
superficial	Normally absent, except where pools occur in embedded peat pits, and in depressions directly adjoining watercourses. May be dissected by small streams or dykes.
Substratum	Peat over variable deposits (such as clays, silts, marl, gravels). Peat sometimes has bands of marl but not normally much other mineral material, though silt layers occur in some riverside locations.
peat depth	Usually shallow (< 1 m).
peat humification	Upper peat often strongly oxidised. Where present, deeper layers can be much less humified, and sometimes only loosely consolidated, though sometimes with a very solid, black, basal peat.
peat composition	Variable and difficult to determine when well oxidised. Upper layers may be sedge, reed or brushwood peat. When present, unconsolidated lower layers may have swamp species, including *Equisetum fluviatile.*
permeability	Peat mostly of low permeability, but sometimes with more permeable, unconsolidated horizons. Basal substratum variable; mostly of low permeability.
Ecological types	All examples were more or less base-rich, and ranged from oligotrophic to eutrophic.
Associated WETMECs	Often the main/only WETMEC. Sometimes with seepages (WETMECs 10 and 11) on adjoining slopes and feeding into WETMEC 7.
Natural status	Many sites are fairly summer-dry. Often not clear to what extent this is a consequence of groundwater abstraction or manipulation of watercourse levels. Many are probably modified, to some degree.
Use	Unmanaged or grazed. Some formerly used for peat excavation.
Conservation value	Mesotrophic, base-rich sites can support *Molinia caerulea–Cirsium dissectum* fen meadow (M24) or close relative (*Cladio-Molinietum*) (sometimes included within site designation as a SAC features). Patches of M9 occur in a few wet depressions and S24/S25 alongside some watercourses. Occluded drains may support wet fen plants.

Vulnerability	Some sites already damaged by direct and indirect drainage and peat cutting. Vulnerable both to groundwater abstraction and manipulation of water levels in adjoining watercourses. Dereliction and scrub colonisation can occur rapidly in the absence of management.

6.10.4 Concept and description

CLUSTERS: 10, 11, 12

This is a rather ill-defined and variable unit, represented by only a small number of samples. Essentially, it includes a range of sites occupying floodplains where both watercourse and floodplain appear to be primarily fed by groundwater. Most of the samples clustered here were from quite large floodplains of Chalk streams and rivers in Southern England, but some samples from the smaller (and generally wetter) floodplains of small Limestone streams in Northern England were also included. The variability and lack of clear definition of the unit means that it is best described by reference to the individual sites allocated to it.

Parts of the floodplain of the Test valley (Hants) provide what is perhaps the typical expression of WETMEC 7. Here, large parts of the floodplain surface are relatively dry, and many locations with a semblance of mire habitat tend to be moist rather than saturated during summer and support rather dry forms of fen meadow vegetation (*Juncus subnodulosus–Cirsium palustre* fen meadow (M22) or *Molinia caerulea–Cirsium dissectum* fen meadow (M24)) or grassland types. They may be elevated some 50 cm (or more) above river levels during low flows. Wetter wetland development generally occurs immediately alongside the watercourses, or in low-lying locations in close connection with them for at least some of the year. Some of the most extensive areas of mire were recorded from Bransbury Common, where there is a band of fen and fen meadow alongside both sides of the River Dever (a tributary of the River Test). At Bransbury, one of the most important wetland areas is sandwiched between the Dever and a low gravel ridge to the west of this (on the west side of which is the floodplain of the Test proper). The tops of these gravels tend to be very dry in summer, but small seepages have been reported feeding from their base into the riverside fens. Nonetheless, these wetland areas can become quite dry in summer and tend to support fen meadow vegetation.

A rather different example of WETMEC 7 is provided by a series of six small excavated hollows at Stockbridge Fen. These are thought to be either peat workings or former fish ponds which are cut down into a soft, white, clay-like deposit to at least 1.5 m bgl. Although quite close to a stream and ditch, they are not in obvious connection with these.

The grouping of Chippenham Fen with the Test valley floodplains is of interest, as it is often regarded as a ‘valley fen’ (in contrast to the ‘floodplain fen’ at Wicken). However, it shares many common features with the Test valley examples and in the nineteenth century appears to have been more obviously part of the Chippenham River floodplain than is currently the case.

Examples of WETMEC 7 occur on the valley-bottom of Greywell Fen. This is a seepage and spring-fed site near to the headwaters of the River Whitewater. This site has a rather complex valley bottom, partly because of a former mill (two sluices still help maintain a higher water level upstream). North of the mill, the Whitewater flows fairly close to the north-western edge of the fen, whilst on its south-eastern side the valley bottom is crossed by a series of intertwining streams, which appear to drain pools along the eastern margin. It is not clear to what extent this drainage pattern, or the pools, is natural (for example, some channels could be remnants of a former braided river). The samples clustered into WETMEC 7 occupy much of the valley bottom, amongst the various watercourses.

Some other samples clustered here, and representing smaller (and often wetter) examples of WETMEC 7, occur alongside small groundwater-fed streams in some valleyhead situations. The surface of these examples of WETMEC 7 is generally not much above that of the stream, and significant episodic flooding can occur. However, these examples of WETMEC 7 can also receive significant groundwater outflow on their landward side. These form outliers to the main cluster but, although very different in visual character, are little different in concept to, say, those examples at Bransbury Common which receive some (localised) groundwater outflow.

Affinities and recognition

The WETMEC 7 samples constitute a distinct cluster in the analysis, but their characteristics are variable within the WETMEC and show quite strong affinities with WETMEC 9 (Groundwater-Fed Bottoms) and, especially, 8 (Groundwater-Fed Bottoms with Aquitards). The samples appear to have been brought together into clusters of 10–12 by the following combination of characteristics: a fairly low (except in depressions) summer groundwater table; a usually thin, often highly humified surface peat; variable and often low-permeability underlying deposits; more or less flat surfaces; and close proximity to watercourses, with a water level that is usually within around 50 cm of the fen surface in summer. This combination has been encountered infrequently in this survey and gives the cluster a cohesion which may well obscure internal differences and affinities to other clusters.

Conceptually, some of the samples have clear affinities with the drier examples of WETMEC 5a (Rarely Flooded Floodplain), but differ in their apparent connection with the groundwater system; some match flatter examples of WETMEC 11, especially 11b (Slowly Permeable Partial Seepages), but differ in that samples of 11b are generally in valleyheads and are less obviously associated with main watercourses. Peat depths are generally shallower than WETMECs 8 and 9, and some examples with deeper peats are transitional to WETMEC 8 (Groundwater-Fed Bottoms with Aquitard). The wet depressions at Stockbridge have particular similarities with the Fluctuating Seepage Basins of WETMEC 12, and appear to be driven by similar hydrogeological mechanisms. Thus, whilst WETMEC 7 has been identified on the basis of a distinctive combination of characteristics, its relationship with other groundwater-fed fens alongside rivers requires further clarification. This would need better characterisation of hydrological regimes within individual sites and the consideration of additional examples of this type of wetland.

The clustering dendrogram (Figure 6.1) indicates that WETMEC 7a (Cluster 10) is a particularly distinctive member of the Groundwater Floodplains group and a strong case could be made for considering it as an independent WETMEC. This has not been done because of the small number of samples allocated to this cluster and their evident similarity to some samples in Cluster 11. Also, it is likely that comparable wetland habitats may occur in association with watercourses which are not as obviously related to the groundwater system as the cases considered here, but such examples have not figured in the present study. In consequence, the precise status of this WETMEC and its relationship to similar types requires clarification by further investigation.

Box 6.13: Stratigraphical details of some WETMEC 7 sites

Test valley floodplain (Hants)

The alluvial deposits of the Test floodplain are complex, with layers of strongly humified peat, silts and clays above basal river terrace gravels. There are also locally interstratified beds of calcareous marl and nodular tufa (which sometimes also form shallow mounds on the surface of the floodplain, known locally as 'malm mounds'). In some locations (such as Bransbury Common), the shallow peat surface appears to be situated directly upon river terrace gravels, and in places the gravels are exposed within the floodplain, forming low ridges. These features point to a complex alluvial depositional environment, changing considerably with time. The occurrence of humified peat and malm mounds on the surface in locations which now support damp grassland point to wetter surface conditions than is currently the case.

The six small hollows at Stockbridge Fen are thought to be either peat workings or former fish ponds that have been cut down into a soft, white, clay-like deposit to at least 1.5 m bgl. They are separated by a similar deposit capped by a variable depth (typically above one metre) of a very consolidated, humified peat.

Greywell Fen (Hants)

Relatively little is known about the development of Greywell Fen, but it differs from most of the Test valley sites by having a quite deep (greater than 1.5 m in places) covering of peat. This is underlain by a clay-rich alluvium upon a drift infill of low-level terrace deposits (gravel) in the valley bottom. The lowest layer of peat is typically dense, dark and visually amorphous, but it is covered by a less humified deposit, with unconsolidated horizons. Some of these are rich in rhizomes of *Equisetum fluviatile*, and may mark the occurrence of past pools or water tracks in the mire. If natural, this is suggestive of a wetland of fluctuating terrestrialisation states, perhaps with a shifting pattern of small spring-sourced streams and pools, but the possibility that some of this pattern is a product of past human activities cannot be discounted.

Chippenham Fen (Cambs)

Much of Chippenham Fen is covered by a layer of peat, but this is mostly relatively shallow (from a few centimetres to two metres deep). Much material may have been removed by turbary. Aspects of the stratigraphy of this site have been examined by Mason (1990). In essence, it is situated in an area of Lower and Middle Chalk with river terrace gravels on the adjoining upland. An inlier of Chalk Marl, surrounded by a ring of Totternhoe Stone, occurs beneath the fen as part of a north-east to south-west trending anticlinal axis which coincides with the topographic low of the site. Throughout the site, the Chalk is capped by a rather dry chalky material between 0.6 and two metres deep, considered by Mason (1990) to be a solifluction deposit, perhaps derived from the nearby river terrace deposits, and referred to as 'Head'. This is covered by clay and peat. Mason suggests that the clay is a lacustrine deposit (Kassas, 1951a) had previously referred to it as 'boulder clay'). The peat cover varies in depth, and in places there are peats both below and above the clay. The current character of Chippenham Fen is partly due to drainage near the start of the nineteenth century which reputedly lowered water levels of the Chippenham River by about 1.5 m. Before this, the site appears to have been an integral part of the headwater complex of Chippenham River, which apparently once fed the fen with chalk water, and permitted lake clays to be deposited and peat to accumulate.

Tarn Fen, Malham

The fens flanking the Tarn Beck along the northern side of Tarn Moss are situated over a continuous deposit of fen peat, rich in wood fragments and up to three metres deep, upon lake marls up to two metres deep (Pigott and Pigott, 1959). In the vicinity of the Beck the uppermost peat is impregnated with silt and in some places this gives way to a column of organic silt.

6.10.5 Origins and development

Perhaps the main ontogenic feature that WETMEC 7 samples have in common is that their substrata are poorly documented, but with a tendency to be complex. Most samples are underlain by alluvial deposits, which vary in character both vertically and horizontally, and which can be deep, though normally with only rather shallow peat (Box 6.13). The main exception to this generalisation is the North Tarn Fens at Malham, where the Tarn Beck forms a narrow floodplain where it flows across the rather deep hydroseral peats of the former Malham Tarn basin.

6.10.6 Situation and surface relief

Despite the name of WETMEC 7, only 78 per cent of the samples were from sites considered to be ‘floodplain fens’. The remainder of samples were from sites that have generally been categorised as ‘valleyhead fens’. The surface relief is typically even; it may appear more or less flat, but usually gently slopes to river or outfall. Most of the samples were taken from flat locations, with a few from gently sloping areas (Table 6.24).

6.10.7 Substratum

A feature of some examples of WETMEC 7 is the shallowness of the surface peat (mean of 0.5 m). This can be well humified and amorphous and of relatively low permeability (Table 6.24). In some sites, the shallowness of the deposit means that a middle-layer peat cannot meaningfully be identified. At sites with deeper peat the lower layers can also be well consolidated, but unconsolidated horizons may occur in some locations. The ‘basal substratum’ here refers to the mineral material encountered below the peat layers, not to the base of the alluvial infill, and is a variable deposit, with clays, silts, marl and gravels being recorded. At any one sampling point these deposits may well be interlayered, but auger information only relates to the uppermost layer encountered.

Table 6.24 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 7

	Mean	1	2	3	4	5	6	7
Surface layer permeability	3.5		5	42	28	5		
Lower layer permeability	3.1		44	33	5	9	9	
Basal substratum permeability	3.0	43	19	5			33	
Slope	1.4	85	15				X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.10.8 Water supply

The details of telluric water supply to WETMEC 7 surfaces are not well established. The water level in at least some of the watercourses flanking the fens is related to water levels in the mineral aquifer, and may be largely sourced from this. However, its precise relationship to the water table and supply of the adjoining WETMEC 7 is not well established. Many sites have an alluvial infill with extensive aquitard units, in some instances interlayered with more permeable material, and the areas of mire may have only indirect and restricted continuity with the main aquifer (Box 6.14). Some areas of wetland occur immediately alongside the watercourses and in shallow depressions connected to them, and may be assumed to have direct hydraulic connection with the river water. Others are further from the river, on surfaces which may be elevated some 50 cm or more above river levels at times of low flow, or which occupy topographical lows that are either a considerable distance from the floodplain watercourses, or are not connected to them. The mechanism of water supply to these areas is much less certain. Some surfaces are over aquitards and elevated above watercourse levels, and may well be very largely ombrotrophic (Box 6.15) (*cf.* WETMEC 8).

Box 6.14: Water supply to WETMEC 7 in some Test valley fens

The parts of the Test valley sampled are cut into the Upper Chalk, which forms the regional aquifer. The water level in the Test is thought to be the same as the water level in the adjacent Chalk and directly related to the piezometric head of the Chalk aquifer. However, the relationship between river water levels and the water table of the adjoining floodplain is much less clear. Some parts of the floodplain have a long and continuing history of manipulation of river water levels, and of irrigation systems (though no examples of water meadows have been included in this project). Periods of managed, low river water levels may be reflected in low water tables in the adjoining floodplain. The extent and occurrence of uncontrolled flooding episodes within the floodplain is not known, but is thought to be uncommon.

It is possible that there is some groundwater upflow into the floodplain which may feed some of the mires. This is likely to be the case at Bransbury Common, where at least some of the fens that flank the River Dever have deposits of shallow, amorphous peat that are apparently located directly upon river terrace gravels. These are thought to be in hydraulic connection with the Chalk aquifer. Some of these fens may also be fed by seepage from a low ridge of gravels within the floodplain, but their water table is likely to be strongly influenced by water levels in the Dever. In other parts of Bransbury Common, and at Chilbolton Common, the river terrace gravels are capped by an alluvial infill with interlayered, humified peat, silts and clays, and some lens of marl. These deposits seem likely to constrain groundwater upflow and may largely confine the Chalk aquifer. Their resistance to water upflow and its local variation is not known, but low values could explain why large parts of these floodplains support seasonally wet grassland rather than fen. However, the patches of fen usually occupy topographical lows and, with the limited data available, given the general visual flatness of the floodplain surface, it is difficult to assess the relative importance of low-permeability substrata and topography in regulating water regimes away from the rivers.

Considerations of water supply are no more clear-cut for the six hollows at Stockbridge Fen. Whilst no hydrometric data are available for this site, observations on the nature of infill and surrounding substrata all suggest limited hydraulic connection between the water table in the depressions and both groundwater and surface water systems. The hollows are quite close to some streams and ditches across the floodplain, but do not appear to have any direct connection to these (and water levels in the closest stream are seasonally well above those in the nearby fen depressions). Recharge of the hollows with telluric water may occur by slow leakage of water from a largely confined Chalk aquifer or by slow lateral flow from surface water sources through a dense and probably low-permeability peat (or both). It is also possible that stored precipitation is an important component of the water budget of the hollows.

Box 6.15: WETMEC 7, case study: Chippenham Fen (Cambridgeshire)

Chippenham Fen provides a rather different version of WETMEC 7. This calcareous fen site has long been regarded as spring-fed; springs undoubtedly occur, particularly associated with the Totternhoe Stone, but they seem to be mainly in the bottom of dykes that have been dug through the Head into the Chalk. The extent to which there is upward leakage of chalk water into the peat is much less clear. Mason (1990) found no piezometric evidence of upward pressure in the peat and Head, even in a summer-wet compartment over Totternhoe Stone. White *et al.* (1996), analysing EN dipwell data, also reported that dipwells in the area of Totternhoe Stone were not distinguished by distinctive waters tables and hydrographs.

Fen water tables are usually near the surface in winter (typically around 5 cm bgl), but they drop considerably and rapidly during spring and summer (Mason reports up to one metre decrease). White *et al.* (1996) calculated a mean summer dipwell value of 43 cm bgl. The water level in the dyke system is regulated to varying degrees, and in places it appears to determine fen water levels, but Kassas (1951a), Mason (1990) and White *et al.* (1996) all provide evidence that the behaviour of the water table in the fen is partly uncoupled from the dyke water levels, except in close proximity (< 25 m) to the dykes and in situations where surface flooding occurs.

Partly in the absence of evidence of upwelling groundwater directly into the fen, Mason suggested that groundwater inputs to the main area of fen are primarily by spring-flow into the network of dykes, and from the Chippenham River (also sourced by spring-flow), and thence by lateral seepage into the peat. However, as the peat is very shallow over much of the fen, and dyke levels may often be below this, any lateral seepage may be constrained by the nature of the underlying mineral deposits. Available evidence, including the response of fen water tables to manipulation of dyke water levels, suggests that the effect of any bank seepage may be limited to the vicinity of the dykes. This suggests that precipitation is a major water source and that base-rich conditions have persisted because of the highly calcareous character of the peat and associated deposits. However, it may be premature to discount the possibility of some upward leakage of chalk water directly into the fen, though existing piezometric data provide no evidence for this.

In addition to potential water supply from watercourses or groundwater upflow, some WETMEC 7 surfaces undoubtedly receive groundwater inputs from upslope deposits along the upland margins. This is definitely the case at Greywell Fen, probably so at Bransbury Common but not, as far as is known, at Chippenham Fen. The hydrodynamics of the WETMEC 7 surface at Tarn Fen (Malham) are little known: it is undoubtedly episodically flooded by the groundwater-sourced Tarn Beck, and may possibly be recharged by bank seepage when stream levels are high, but it also seems likely that there is groundwater supply from the adjoining Limestone upland, though there is little or no visible evidence for this (in the WETMEC 7 area) except that when stream water levels are low, the fen appears to drain into the Beck. However, no such uncertainties exist at Tarn Moor (Sunbiggin), where strong seepages drain down into the Tarn Sike, so that its narrow floodplain is potentially fed from both sides, with episodic flooding from the Beck interaction with groundwater outflow from nearby slopes. This circumstance (and WETMEC 7) may once have been important in a number of valleyhead sites, but the supply role of the stream has often been much reduced or stopped by deepening and canalisation.

Overall, whilst stratigraphical, topographical and positional features identify WETMEC 7 as a distinct, if variable, unit, mechanisms of water supply are generally not clear and require more detailed on-site investigation.

6.10.9 WETMEC sub-types

Table 6.25 Mean summer water table associated with the three sub-types of WETMEC 7

Sub type	Mean summer water table (cm bgl)
7a (Groundwater-fed river fringe)	10.2
7b (Groundwater floodplain)	12.5
7c (Groundwater floodplain on aquitard)	12.0

WETMEC 7a: Groundwater-Fed River Fringe

CLUSTER: 10

Examples at: Bransbury Common, Chilbolton Common, Greywell Fen

Outliers at: Tarn Moor (Sunbiggin)

This unit represents wetland habitat alongside groundwater-fed watercourses which is probably in fairly free hydraulic connection with the watercourse. Riverine vegetation *sensu stricto* has not been included in this survey and this wetland habitat represents mire vegetation developed as strips alongside watercourses, or sometimes in shallow invaginations extending away from them. The watercourses may include groundwater-fed rivers, streams and artificial channels. Watercourse levels may be directly related to the piezometric head of the relevant aquifer. During periods of high river levels the water surface in the mire may be largely continuous with that in the watercourse, but during low flows the mire surface can be somewhat above watercourse levels. Groundwater discharge from adjoining higher ground towards the watercourse may also sometimes feed into the river partly through WETMEC 7a. This is particularly evident at sites such as Tarn Moor (Sunbiggin) where strong seepages (WETMEC 10 (Permanent Seepage Slopes)) feed down into an alluvial valley bottom alongside the Tarn Sike. It also occurs locally at Greywell Fen, though here much outflow from the Chalk aquifer is focussed into spring streams. It is less obviously the case in some of the flat Test valley examples, especially in those towards the centre of the floodplains, but even here the water table in parts of the floodplain may be slightly higher than in the river, as exemplified by reports of flushes from parts of Bransbury Common (Brewis, Bowman and Rose, 1996).

In the Test valley this WETMEC supports both reed-dominated vegetation and, particularly, a wet ‘mixed fen’ community (transitional between S24 and S25) with much *Carex paniculata* and sometimes species such as *Menyanthes trifoliata.* However, only a small number of samples are available from these wetlands, which are under-characterised in this study.

WETMEC 7b: Groundwater Floodplain

CLUSTER: 11

Examples at: Bransbury Common, Chilbolton Common, Greywell Fen
Outliers at: Tarn Fen (Malham)

This sub-type represents the general valley-bottom wetland habitat of groundwater-fed floodplains. Compared with sub-type 7a it is usually further from adjoining watercourses, or higher above them, so is less frequently fed by surface water from the watercourses. It may be subject to occasional flooding episodes, but the incidence of these is not known. In other respects, it can be seen as a slightly higher and drier version of sub-type 7a (Table 6.25). It is likely that watercourse levels may be an important determinant of the water table in the WETMEC, but it also appears that, at least in some cases at some times, the water table in the WETMEC may be slightly higher than that in the watercourse. This may be due, in part, to water flow from (slightly) higher ground.

The substratum of the Test valley examples usually consists of a rather thin layer of humified peat over gravels with a varying proportion of sand. These latter may be in hydraulic connection horizontally with the watercourse and the Chalk aquifer, but the variable and sometimes deep alluvial infill makes it less clear to what extent there is likely to be significant vertical water exchange. By contrast, at Greywell Fen there is a quite deep accumulation of peat over a clay aquitard and in this case, there may be horizontal water flow from marginal seepages into the peat and towards the river. At this site the peat is very variable, with both highly humified and solid and very sloppy horizons, and it appears to form a rather complex deposit in which certain layers may be in fairly free hydraulic connection both with the main watercourses and the spring streams. However, some surfaces appear to be very slightly elevated above the normal influence of base-rich groundwater, as marked by the occurrence of small patches of *Sphagnum fimbriatum.* Such samples are transitional to WETMEC 8b (with which one was clustered).

The example of WETMEC 7b alongside the Tarn Beck at Malham is as an outlier to the main group. This may be because it was generally wetter and on deeper peat that many other examples. As at Greywell Fen, there is a considerable depth (some two to three metres) of peat over an aquitard (in the Malham case, lake marls).

WETMEC 7c: Groundwater Floodplain on Aquitard

CLUSTER: 12

Examples at: Chippenham Fen, Stockbridge Fen

Sub-type 7c contains two rather different sites, united by the presence of a thin layer of peat over an apparent aquitard. The level of the top of the latter is such that in some circumstances, it is above the level of water in adjoining watercourses and thus may help constrain both horizontal and vertical water flow.

The main groundwater supply to Chippenham Fen appears to be focussed into the dyke system. The capacity of this to irrigate the peat surface is largely dependent on dyke levels which are, in part, determined by water control structures. In dry conditions dyke levels may fall below the level of peat base, whereas in wet conditions there may be some lateral flow into the peat. However, this may only influence the water table in the fen peat for some 10 to 30 m from the dyke, except in special topographical circumstances (depressions and so on). Thus, the main water supply mechanism over much of this site is effectively the same as that of WETMEC 5a. The samples appear to have been clustered into WETMEC 7 because of the shallow depth of humified peat, the presence of a clay-like sediment aquitard close to the surface, and the primary source of telluric water being groundwater outflow from the Chalk into the dykes around the fen compartments.

At Stockbridge Fen, the hollows containing WETMEC 7 have been dug down to a clay-like base, and are surrounded by broadly similar material. They are different from most examples of WETMEC 7 in that the hollows contain a loose hydroseral peat infill, which is believed to have been more buoyant than is currently the case. These hollows are in some respects comparable with turf ponds clustered in WETMEC 13 (Seepage Percolation Basins), but differ in that they have no obvious inflows or outflows nor water exchange with the mineral aquifer. The permeability of the clay-like material in which they are embedded is not known, nor is the main source of water. It seems likely that the hollows are fed by slow seepage from the Chalk aquifer, but their high water table doubtless owes much to their topography and, possibly, rain inputs.

6.10.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 7 are summarised in Table 6.26. The summer water table of examples of WETMEC 7 varies much between locations, reflecting the diverse range of samples clustered within it. However, many examples tend to be fairly summer-dry and the mean value of summer water table is 11.9 cm (similar to that of WETMEC 8). The more summer-wet locations are those in topographical depressions and in some riverside situations, though these can also have rather low water tables in dry summers. In some sites there is a fairly clear zonation of plant communities along a topo-sequence from the river margin. For example, at Bransbury Common a repeated pattern alongside the Dever is the occurrence of stands of S24/S24 alongside the river, grading outwards and slightly upwards into M22 (mostly M22d) and thence into M24 at the drier end of the topo-sequence.

Table 6.26 WETMEC 7: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	0.5	0.1	3.5
Summer water table (cm)	–11.9	–44	0.6
Rainfall (mm a^{-1})	679	546	777
PE (mm a^{-1})	602	582	609
Water pH	6.5	6.2	7.0
Soil pH	6.8	5.6	7.3
Conductivity (µS cm^{-1})	495	359	656
K_{corr} (µS cm^{-1})	495	359	656
HCO_3 (mg l^{-1})	338	214	493
$Fertility_{Phal}$ (mg)	10	5	19
Eh^{10} (mV)	252	123	374

See list of abbreviations in Appendix 1

6.10.11 Ecological types

As all of the samples clustered into WETMEC 7 appear to be fed by groundwater from Chalk or Limestone aquifers, it is not surprising that most samples were base-rich (Table 6.27). However, some samples from Bransbury Common were sub-neutral (pH 5.5 to 6.5), generally in locations away from the River Dever and proximate to the river terrace gravels. Although the river and gravels are thought to be in hydraulic connection with the Chalk aquifer, these data point to some possible mixing of Chalk water with another type (possibly rainwater that has infiltrated into the gravels).

Table 6.27 Percentage distribution of samples of WETMEC 7 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	14	57	24
Sub-neutral		5	
Base-poor			
Acidic			

Oligotrophic, base-rich

Examples referable to this category all came from some of the depressions at Stockbridge Fen, in locations that supported either M9 (*Carex diandra–Calliergon* mire (M9-2)) vegetation or a closely related form of M22.

Mesotrophic, base-rich/sub-neutral

The majority of samples belong to this category, including all of those from Chippenham Fen. Most of them were from relatively dry locations and supported a form of M24 vegetation or, in parts of Chippenham, the related *Cladio-Molinietum.* Most examples of M22 were also mesotrophic. In the riverside fens of the Test valley, examples which were floristically closest to S24 (compared to S25) were referable to this category, though it is not clear what determines whether these mixed fen soils are mesotrophic or eutrophic.

Eutrophic, base-rich

A (mostly) mildly eutrophic condition was encountered mainly in some of the riverside fens of the Test valley and at Greywell Fen. Most samples were referable to S24/S25 or to S25, but in some grazed locations examples of M22 also fell into this category. A stand of eutrophic reed-dominated S25a also occurred in one of the hollows at Stockbridge Fen, presumably in response to some enrichment, but the cause of this is not known.

6.10.12 Natural status

With the possible exception of the narrow floodplain alongside the Tarn Sike at Sunbiggin, all of the sites referable to this WETMEC appear to have been modified to some degree, but in most cases little information has been identified about modification events. Perhaps the most obviously modified site is Stockbridge Fen, where virtually all of the existing wetland interest occupies artificial pits within the floodplain. The pits are separated by baulks, capped with about one metre depth of humified peat, indicating that this part of floodplain was once a peat-producing system, however dry the undug surface may be at present.

In the Test valley river flows have long been managed by weirs, which may have had considerable impact upon the river-flanking wetlands, but little information has been uncovered about this. It is however clear from the deposits of dry surface peat and the malm mounds that the surface of parts of the floodplain are now drier than was once the case, though the reason for this is not known.

In general, Greywell Fen is a good deal wetter than most of the Test valley fens and is less obviously manipulated. The various small streams, some draining spring-fed pools, have a natural appearance and may be indicative of the former character of a number of spring-fed valley bottoms prior to more efficient artificial drainage. However, the proximity of the mill suggests the possibility of some modification of the valley bottom, emphasised by a series of small, sometimes occluded, shallow drains aligned transversely across the eastern side of part of the valley bottom. It is also possible that parts of this site were dug for peat, though there is no known evidence for this.

There is little doubt that much of Chippenham Fen has been very much modified. This site was once part of a headwater complex of the Chippenham River before drainage at the start of the nineteenth century reputedly lowered water levels by about 1.5 m (Young, 1805). It is thus quite possible that at one stage, much of this site was fed by Chalk water from the river. The dykes that currently subdivide the site drain to the river, though their levels are regulated by sluices. Parts of the site (such as Snailwell Poor's Fen) have undoubtedly been dug for peat, but it is not clear how widespread this practice was in other parts of the fen.

At Chippenham Fen, the apparent absence of groundwater upflow beneath much of the fen, and the fact that the fen water table seems to be largely independent of dyke water levels, except in their immediate vicinity, raises the question of former water supply regimes. In 1991, concern about the possible adverse impact of proximate groundwater abstractions resulted in a scheme to provide compensatory piped Chalk water into the dyke system. If, as seems to be the case, the dykes are the main source of telluric water to the fen, this is an appropriate supplementation approach, but it begs the question of the relationship between dyke levels and the fen water table.

6.10.13 Conservation value

Mesotrophic, base-rich sites can support *Molinia caerulea–Cirsium dissectum* fen meadow (M24) or close relative (*Cladio-Molinietum*) (sometimes included within site designation as a SAC feature "*Molinia* meadows", see Tables 3.3 and 6.4). Patches of M9 occur in a few wet depressions and S24/S25 alongside some watercourses. Occluded drains may support wet fen plants.

The wide range of water conditions encountered within contrasting versions of WETMEC 7 helps to account for the occurrence of both 'dry' (such as M24) and 'wet' (such as M9) communities within the unit. The percentage occurrence in NVC communities of samples of WETMEC 7 is: M24: (28%); M22: (19%); S24: (19%); S25: (14%); M9-2: (9%); CM: (8%). [One of the units listed here is a non-NVC unit, which has been described by Wheeler (1980a): CM: *Cladio-Molinietum*]. The examples of S24 are all from locations in the Test valley. None of them are particularly 'good' examples of S24 and are perhaps more accurately seen as being transitional between S24 and S25. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 7 is given in Table 6.3.

A total of 71 wetland plant species have been recorded from samples of WETMEC 7. These include eight nationally uncommon plant species: *Calliergon giganteum, Carex diandra, Cladium mariscus, Dactylorhiza praetermissa, Epipactis palustris, Selinum carvifolia, Thalictrum flavum, and Thelypteris palustris.* They also include a number of species that are more locally uncommon, such as *Gymnadenia conopsea, Lysimachia vulgaris, Menyanthes trifoliata, Pedicularis palustris* and *Rumex hydrolapathum.* Some examples of WETMEC 7 occur in regions (such as Hampshire) where species-rich, base-rich fen is uncommon and, although not as species-rich as some other WETMECs, make an important contribution to local and regional biodiversity. For example, Brewis, Bowman and Rose (1996) describe Stockbridge Fen (which is largely WETMEC 7) as "one of the richest examples of calcareous fen in Hampshire", whilst Bransbury Common (which contains WETMEC 7) is "a very large site with an extraordinary range of plant communities. In total some 230 species are recorded here" (this total includes dryland species as well as wetland ones).

At Chippenham Fen, the prominence of the valued M24 (and the related *Cladio-Molinietum*) vegetation is probably a consequence of past damage (drainage). Although rather little is known about the water table tolerances of the flagship species of this site (*Selinum carvifolia*), on mainland Europe this is regarded as a *Molinion* species rather than a true fen species. It is quite possible – though by no means certain – that its current abundance at Chippenham is a consequence of past drainage. A corollary is that any attempts to significantly increase the water table at this site could be detrimental to a key feature of its existing conservation interest.

6.10.14 Vulnerability

The water table in WETMEC 7 sites is determined both by the groundwater table and the water level in nearby watercourses, and the interactions between the two. Water tables naturally show significant seasonal variation, except in certain favoured topographical locations, and may well show natural longer-term fluctuations. However, both groundwater abstraction and changes in river water management regimes can potentially affect the fen water tables.

Some of the larger WETMEC 7 floodplains appear to have been modified by water management of the river systems. This may also be the case in some valleyhead systems, and it is possible that WETMEC 7 surfaces were once more widespread than is currently recognised. Deepening of axial streams to prevent flooding or supply to adjoining wetland surfaces may remove a former floodplain element from some valleyhead sites. Flordon Common (Norfolk) is a possible site where this has occurred.

Examples of WETMEC 7 in direct contact with river water may be affected by changes in the quality of this. For example, in 1996–98 the River Dever was allocated to River Ecosystem Class 2, and this may explain the rather rank and eutrophic fen vegetation that occurs immediately alongside the river where it flows through Bransbury Common.

6.11 WETMEC 8: Groundwater-Fed Bottoms with Aquitard

6.11.1 Outline

This WETMEC essentially comprises poorly drained ‘flat’ valley bottoms and troughs in contexts where there is some outflow of groundwater from mineral aquifers at the margins of the wetland, but little or no upflow from beneath the system due to a well-developed aquitard. This may be a product of low-permeability Till or of extensive low-permeability deposits within the wetland infill itself (lake muds, marls, estuarine clays). In some instances the groundwater outflow percolates into the peat aquifer (sub-type 8a), but in others it appears to be largely captured by a ditch or dyke system (sub-type 8b). The wetland may receive some surface run-off, but this is not normally fed by adjoining watercourses. Schematic sections are provided in Figure 6.26.

6.11.2 Occurrence

Example sites: Betley Mere, Bugg's Hole, Thelnetham, Cors Erddreiniog, Cors Goch, Cors Geirch, Cors Nantisaf, Great Cressingham Fen, Kenninghall and Banham Fens, Newham Fen, Potter Heigham Meadows, Upton Fen and Doles

Outlier sites: Thornhill Moss and Meadows

This WETMEC is probably quite widespread, occurring on a small scale in a number of sites. Most examples were recorded in East Anglia and North Wales (Figure 6.25). The list of example sites includes some of the largest.

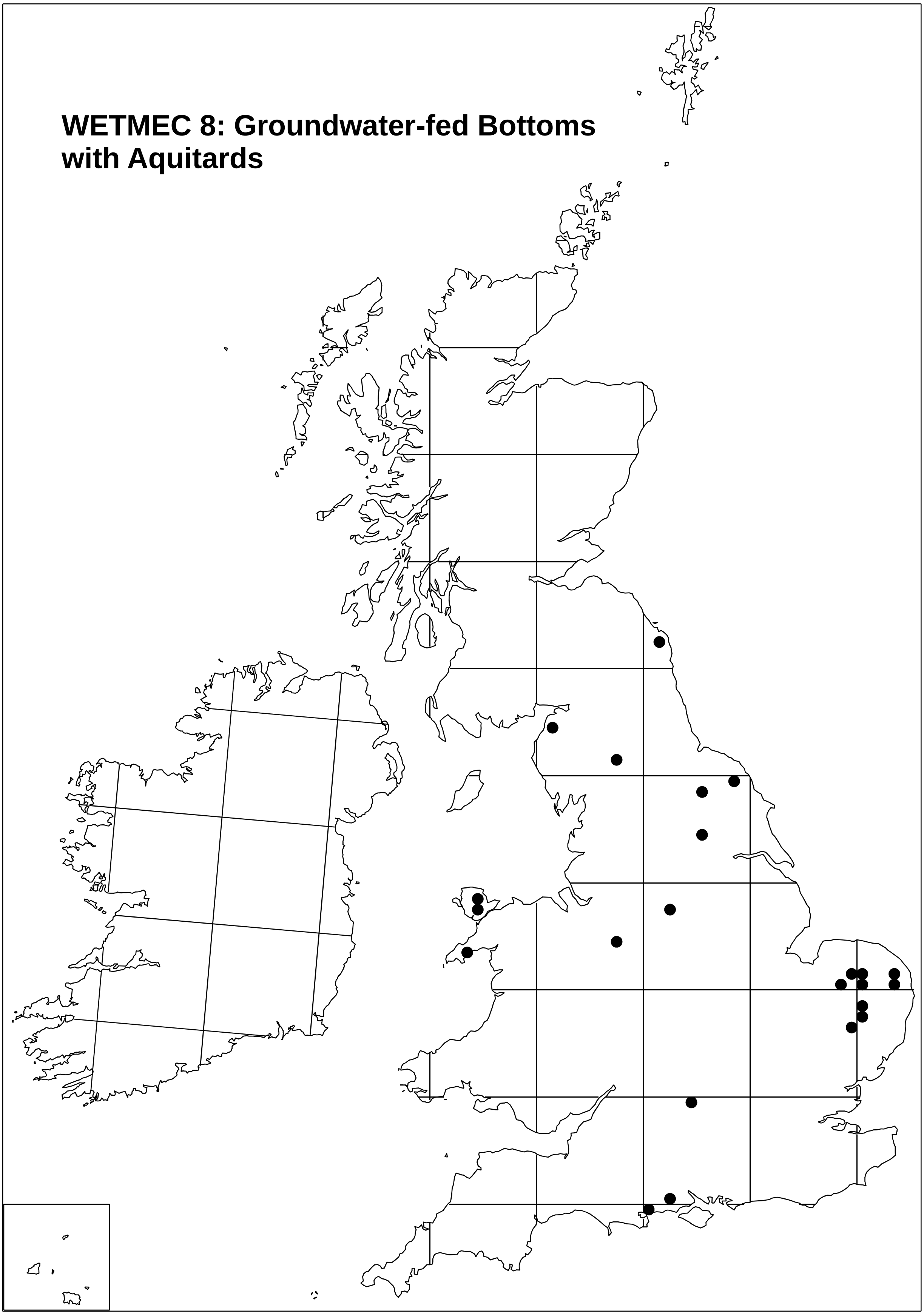


Figure 6.25 Distribution of examples of WETMEC 8 in sites sampled in England and Wales

6.11.3 Summary characteristics

Situation	Mostly floodplains, valleyhead troughs and basins.
Size	Small examples in basins to large areas of fen (> 10 ha).
Location	Most examples were recorded in East Anglia and North Wales.
Surface relief	Even (usually appears more or less flat, but can slope to watercourse, outfall and so on).
Hydrotopography	Rheo-topogenous (part-drained).
Water: ***supply***	Groundwater.
regime	Water table can be well below surface but variable, depending on topography and drainage.
distribution	Into peat body; dykes.
superficial	Normally absent, except where pools occur in embedded peat pits. Dykes and ditches can dissect WETMEC.
Substratum	Fairly consolidated peat; sometimes has bands of marl but not normally much other mineral material, though silt layers can occur alongside rivers.
peat depth	Sometimes shallow but usually deep (2–3 m). Peat may be interlayered with, or overlay, lake muds, marls, silts and (occasionally) estuarine clays.
peat humification	Upper peat often strongly oxidised. Underlying deposit varies in humification, but generally quite dense.
peat composition	Variable. Upper layers can be sedge–moss peat (mainly hypnoid mosses), but may also be sedge, reed or brushwood peat. Herbaceous peat can be quite thick. Basal peats are often dense brushwood peats.
permeability	Peat variable, but mostly probably of moderate to low permeability. Basal substratum generally of low-permeability clays and silts.
Ecological types	Range from base-rich to base-poor, eutrophic to oligotrophic, depending mainly on groundwater source and substratum characteristics. Most examples were base-rich/sub-neutral and mesotrophic.
Associated WETMECs	Can be the main/only WETMEC. Sometimes separated from the upland margin by WETMEC 9 and, occasionally, WETMEC 13. Can grade into WETMEC 4 on more elevated surfaces away from the influence of dykes and so on. Adjoining slopes may support WETMECs 10 and 11.
Natural status	Many sites have become rather dry, usually through direct or indirect drainage. Some may once have been referable to WETMEC 13.
Use	Some are unmanaged, others lightly grazed. Some may have been used for peat excavation. Some, perhaps many, have been converted to farmland, at least in part.
Conservation value	Mesotrophic, base-rich sites can support *Molinia–Cirsium dissectum* fen meadow (M24) (sometimes included within site designation as a SAC feature), or close relative (*Cladio-Molinietum*). A few places have patches of rather dry M9. Occluded dykes may support wet fen or swamp plants.

Vulnerability	Sites already somewhat or considerably damaged. Possible threat is further drying (improved drainage). Dereliction/scrub colonisation can occur rapidly in the absence of management. Some suggestion of nutrient enrichment by tip leachate or agricultural inwash in a few sites.

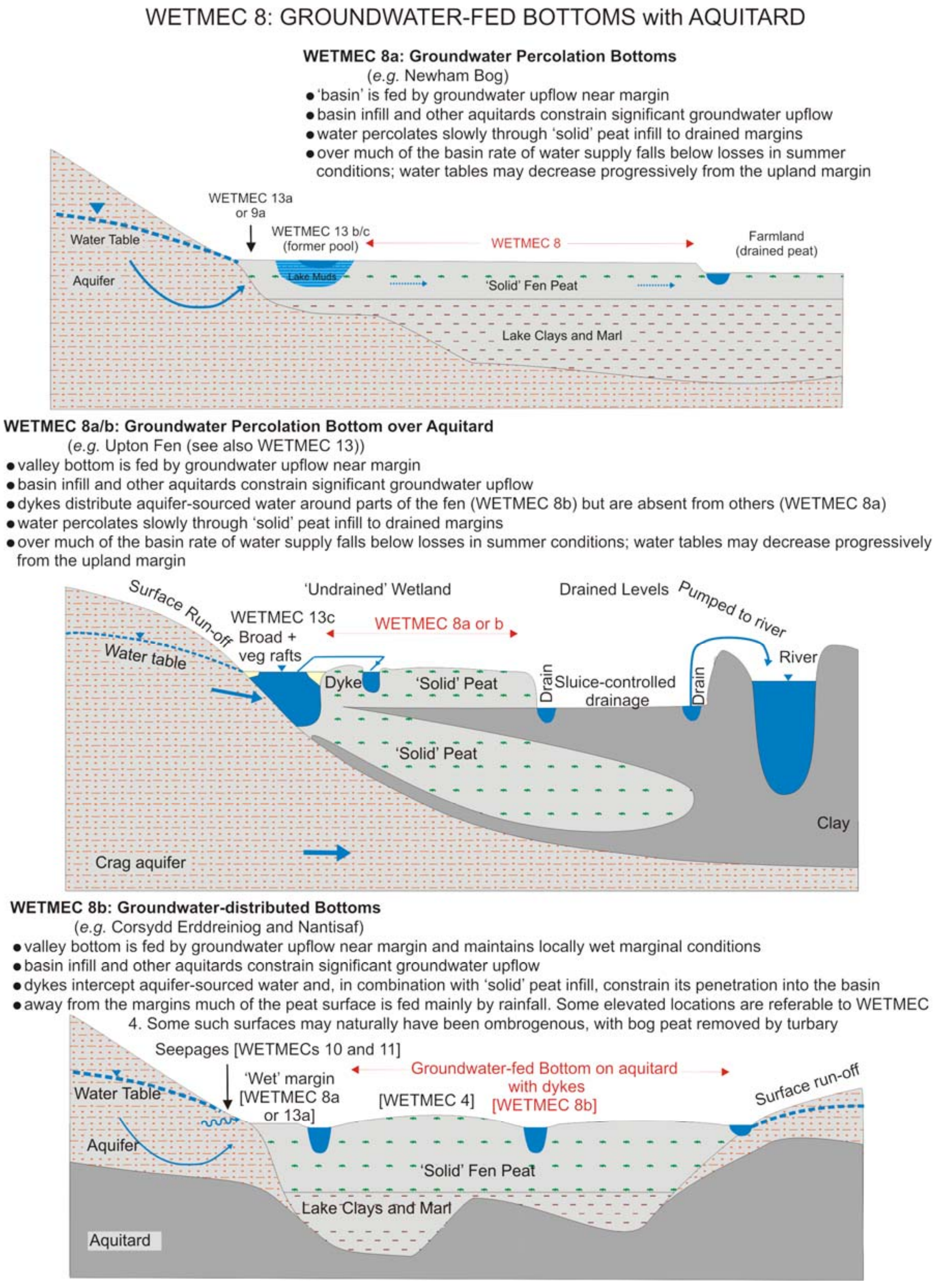


Figure 6.26 Schematic sections of Groundwater-Fed Bottoms with Aquitard (WETMEC 8)

6.11.4 Concept and description

CLUSTERS: 13, 14

The key features of this WETMEC are that it consists of topogenous wetland without evidence of groundwater upflow to the surface; that there is a well-developed aquitard below, or within, the wetland substratum; and that the upper substratum layers may also be of restricted permeability. This WETMEC shares many similarities with WETMEC 9 (Groundwater-Fed Bottoms), but differs in that sites, or parts of sites, clustered within it have a well-developed aquitard which is thought likely to prevent much groundwater upflow, resulting in groundwater supply to the stands being sourced primarily by lateral flow from the margins. In some sites (such as Corsydd Eddreiniog and Nantisaf), there are visible marginal strong springs and seepages with the potential to feed into the WETMEC, but in many instances there is no visible evidence for groundwater outflow at the margins.

Peat depth is variable, but it can be more than four metres deep. It is often well humified, solid and amorphous, at least near the surface. Most examples have developed in some form of basin, and the upper peats may overlie a looser hydroseral deposit. The suspected aquitard is provided by a deep lacustrine deposit (gyttja or marl) (such as Great Cressingham Fen, Kenninghall and Banham Fens, Newham Fen), by layers of estuarine clay intercalated within the peat (Upton Fen), by thick layers of low-permeability (often brushwood) peat, or by a combination of these.

Most, perhaps all, examples of this WETMEC have been influenced by drainage to some degree, directly by ditches dug through the stands themselves or by deepening of adjoining watercourses, or indirectly by the drainage of adjoining wetland areas. However, the degree of drainage varies considerably, with both ‘wet’ and ‘dry’ examples having been recorded. Wetter examples are usually transitional to another WETMEC (such as WETMEC 13 (Seepage Percolation Basins)). In some locations (such as parts of Cors Geirch, Dwyfor), small hollows (usually remnant peat workings) within WETMEC 8 support wet conditions that can be allocated to other WETMECs (such as WETMEC 13, 14, 15), though where these are small and without any different water supply, there may be little practical merit in distinguishing them separately.

In some sites (such as Upton Fen, Norfolk; Newham Fen, Northumberland), WETMEC 8 occupies a drawdown zone between wetter wetland conditions nearer the groundwater source on one site and a tract of drained wetland on the other. The impact of adjoining drainage may be more than just the associated drawdown of the groundwater table – it may also have resulted in a substantial change of water supply mechanisms to the site. For example, Upton Fen is along the margin of the River Bure floodplain and once had hydraulic connection with, and probably water supply from, the river. Drainage of the levels between the residual fen and the river has removed the river connection, and has resulted in the site becoming dependent on groundwater as its primary source of telluric water. As the levels are pump drained and are (now) lower than the fen, it may also have resulted in water drawdown towards the riverward margin of the remnant site.

Many examples of this WETMEC are crossed by dykes, with much variation both in their spacing and probable role (as far as water distribution and supply is concerned). In some sites (such as Corsydd Eddreiniog and Nantisaf), the dykes clearly intercept some marginal groundwater discharges and may reduce, or largely prevent, the penetration of such water into the adjoining topogenous fen. However, dyke networks may also help to transfer groundwater into the peatland, well away from the margins, though the potential importance of this as a water source to WETMEC 8 surfaces is usually limited by dyke water levels being lower than the peat surfaces, and by the apparently low permeabilities of the upper peat layers in many instances.

Poorly drained areas in some drained grazing levels which are on an aquitard are also loosely referable to this unit (such as Potter Heigham Meadows, Priory Meadows (Hickling), Barnby Broad Meadows). In principle, this unit could probably be extended to encompass all drained levels that are primarily groundwater-fed from the margins, but in practice in this project it has been limited to sites which still support recognisable wetland plant communities (such as *Cirsium dissectum–Molinia* (M24) and *Cirsium palustre–Juncus subnodulosus* (M22) fen meadows) with comparatively high water tables. Some samples with particularly low water tables, although having clear affinities to this WETMEC, have been clustered into WETMEC 4.

6.11.5 Affinities and recognition

This WETMEC is formed from two clusters recognised at the 36-cluster stage of the multivariate classification, which correspond to the two sub-types recognised. Most of the Phase 1 sites now allocated to this cluster were previously grouped into the broader category of 'summer-dry percolating wetlands' (Type 5), but WETMEC 8 also includes a small number of samples that were previously classed as 'intermittent and shallow sub-surface seepages' (Type 2) together with some 'degraded' examples of 'Seepage Percolation Basins' (Type 4). As this suggests, WETMEC 8 encompasses a considerable degree of variation, containing samples united by a (often deep) peat aquifer over an aquitard (marl, gyttja, Till or solid peat); fairly low, but not extremely low, summer water tables; and fairly consolidated surface peat.

WETMEC 8 samples have affinities variously with WETMECs 9 (Groundwater-Fed Bottoms), 13 (Seepage Percolation Basins) and 4 (Drained Ombrotrophic Surfaces) and occur juxtaposed with these in some sites. In some instances, wet hollows or occluded dykes within WETMEC 8 support quaking patches which form small examples of WETMEC 13, though there may often be little practical value in separating them. WETMEC 8 surfaces can be distinguished from examples of WETMEC 9 by the occurrence of a laterally extensive aquitard (though some samples of WETMEC 9 can be underlain by a *local* aquitard, such as a lens of marl). They can usually be separated quite easily from samples allocated to WETMEC 13 or 14 (Seepage Percolation Troughs) by the presence of rather consolidated surface peat (rather than a buoyant or quaking mat) and by a lower summer water table. Perhaps the greatest difficulty (both in the clusters and in the field) is in separating some samples in this unit from those in WETMEC 4. This is because the surface of many of the drier examples of WETMEC 8 is probably fed only by rainfall for most of the time, and the split from WETMEC 4 is essentially based on the water table – samples allocated to WETMEC 4 normally having lower summer water tables.

6.11.6 Origins and development

Many examples of this WETMEC have originated by drainage of once-wetter sites which, in their natural state, may have had rather different water supply mechanisms and developmental histories. They are united by their occurrence in topogenous contexts, mainly basins, floodplains and valley troughs.

The majority of WETMEC 8 sites examined have developed, at least in part, by the terrestrialisation of shallow lakes, many or all of which appear to be of late-Devensian origin. In many cases the lake deposits include both silts and marl, which were subsequently colonised hydroserally by peat-producing systems. This is the case in some basin locations: in East Anglia the deeper parts of Great Cressingham Fen contain some three metres of lake marls overlain by almost two metres of peat (much as moss peat) (B.D. Wheeler and R.P. Money, unpublished data). Kenninghall and Banham Fens also contain considerable deposits of lake marl.

Box 6.16: WETMEC 8: examples of development.

Newham Fen (Northumberland) occupies part of the margin of a former large lake basin, much of which has been drained and converted into farmland. The residual mire occupies some of the eastern margin of the basin, along the foot of an esker ridge (Lough Bank), which may be the primary source of groundwater supply. The main basin reaches around 12 m depth in places, with a considerable depth of gyttja overlain by marl and peat (Thompson, 1964). There is a shallower shelf along the east side of the main basin, some three to five metres depth bgl. This was apparently not part of the original main lake basin and corresponds to the present area of Newham Fen. The shelf supports layers of marl variously overlain by peat and, in places, continuous deposits of peat and organic muds. Wheeler and Shaw (1998) reported that some parts of the shelf, corresponding to much of the area of the former Newham Lough, were underlain by sand and gravel material as had been found by Thompson (1964), but elsewhere the peat and marl was underlain by a deposit described mostly as a (sometimes gritty) grey clay. Huntley (1986) likewise refers to a 'blue-grey sandy clay' underlying the marl–peat sequence and this material, along with the more recent marls, occurs beneath the WETMEC 8 surfaces. By contrast, the Newham Lough area (once a shallow pool) is partly over sands and gravels and referable mainly to WETMEC 13. The water table across Newham Fen has been monitored in a dipwell network since 1983 (Newson, 1986, 1989, 1995; Newson *et al.*, 2002). In essence, the data show that the fen water level in the vicinity of the former Newham Lough clearing (and close to the esker) is generally consistently higher than in dipwells further from the margin, and nearer the western and north-western edges of the fen, adjoining farmland (converted mire).

Cors Erddreiniog (Anglesey), much of which is referable to WETMEC 8, consists of a series of basin-like Till-lined troughs which may originally have supported separate lake systems. The basins contain lake clays, mostly overlain by lake marls, to some three metres depth. Subsequent peat development (again to three metres depth) has not only covered most of the lake deposits, but has also buried some of the shallower ridges that once subdivided the site (Gilman and Newson, 1982; see) (see also Box 6.17).

Not all locations for WETMEC 8 have developed from obvious former lakes. At ***Thornhill Moss*** (Cumbria), WETMEC 8 occupies a patch of peat along the upland edge of the mostly alluvium-filled Crummock Beck valley. A section recorded by Tratt (1991) across a residual M9 area consists of up to four metres depth of peat overlying red clay, in places with a thin band of organic mud separating the basal clay from the peat. The peat contains a thick basal layer of humified wood peat rich in monocot remains, which appears to represent a quite long period of fen carr. In the cores near the upland margin, this was replaced (at around 180–200 cm bgl) by a phase of herbaceous mixed fen but westwards (riverwards) *Phragmites* was more important at this level, forming a more humified peat locally with plentiful wood remains. Then, at about 120–130 cm bgl, the fen woodland and herbaceous fen were replaced quite abruptly and consistently by a fresh swamp peat with much *Phragmites*, within a greasy matrix of silty material, indicating the establishment of higher water levels, and possible flooding, over a formerly drier mire surface. Other macrofossils present in this layer include *Scirpus lacustris, S. maritima* and *Apium graveolens*, suggestive of the occurrence of particularly wet brackish conditions over this part of the site or nearby. This layer occurs below about 50–60 cm bgl. The surface layer above this is composed of a variable mix of peat, including herbaceous elements, *Phragmites* and some wood remains, typically rather well humified. This layer, which may owe its characteristics to the partial drainage of wetter fen and swamp, supports current WETMEC 8.

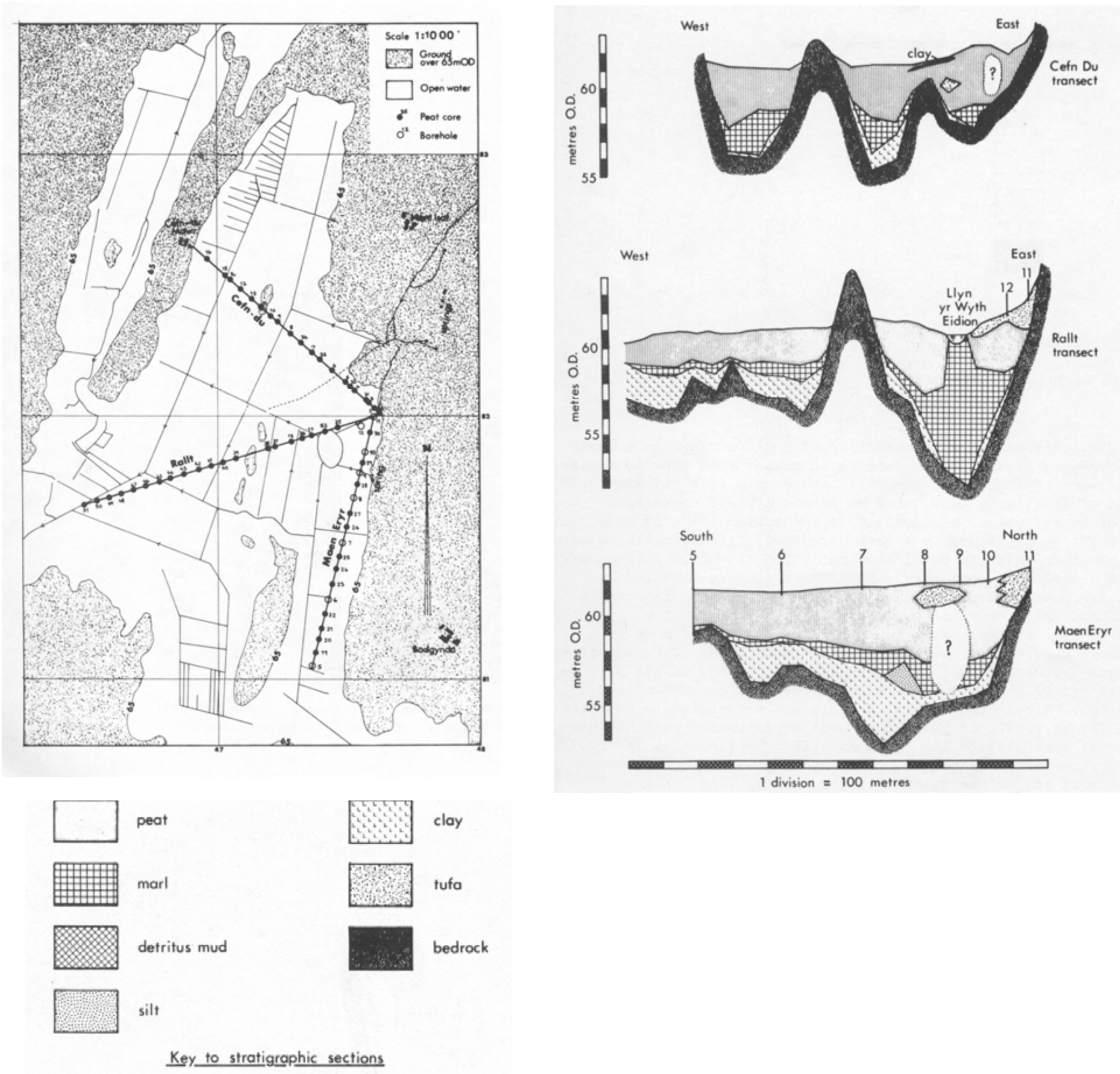


Figure 6.27 Stratigraphical section across Cors Erddreiniog

Taken from Gilman and Newson (1982)

6.11.7 Situation and surface relief

WETMEC 8 is restricted to topogenous, though sometimes slightly sloping, situations, but occurs in a variety of landscape contexts: 35 per cent of the samples were recorded from floodplains, 30 per cent from valleyheads, 26 per cent from valley troughs and nine per cent from basins. The surface relief is typically even; it may appear more or less flat, but usually gently slopes to river or outfall, or towards any ditches and dykes that border the WETMEC (Table 6.28).

6.11.8 Substratum

Most examples of WETMEC 8 occur on quite deep wetland infill (mean depth of 3.7 m). This can consist mainly of peat but may also contain a substantial thickness of lake muds, marls, silts and, in a few instances, estuarine clays. The surface layer of peat is quite variable. In some samples it is fairly dense, and probably of limited permeability, but in others it is fairly loose. Some of these latter represent loose, former hydroseral peats which have become partly drained. The lower layers of the deposit are also variable, but there is a preponderance of low-permeability material (Table 6.28) including dense peats but also, at many sites, former lake muds and marls, and in some cases silts and clays. Most examples of this WETMEC are floored by a basal layer of low-permeability clays and silts, either Till or an alluvial/estuarine deposit.

Table 6.28 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 8

	Mean	1	2	3	4	5	6	7
Surface layer permeability	3.4		13	44	35	4	4	
Lower layer permeability	2.7	13	48	17	9	9	4	
Basal substratum permeability	1.8	26	65	9				
Slope	1.1	96		4			X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.11.9 Water supply

Samples clustered within WETMEC 8 do not appear to receive significant water supply from rivers or streams, though some (such as Upton Fen) may formerly have been fed from watercourses. Several sites are not associated with watercourses and those which are appear to drain into them. Small surface water inflows (field drainage and so on) occur locally in some sites, but they do not appear to much influence the WETMEC as a whole, and may be more of a nuisance by creating locally eutrophic conditions than acting as a significant water source.

The main source of telluric water to WETMEC 8 appears to be groundwater outflow along the margins of the unit, sometimes supplemented by rain-generated run-off. However, the extent to which either source penetrates into WETMEC 8, so as to influence surface conditions, is strongly dependent on local conditions, *inter alia* presence of interceptor ditches, hydraulic gradients and peat permeability. Marginal springs and seepages are visible alongside several examples of this WETMEC (such as Corsydd Erddreiniog and Nantisaf, and Great

Cressingham Fen), but groundwater outflow from these is often intercepted by a dyke system. In other cases (such as Newham Fen) there is no visible evidence for marginal seepages (though they are suspected).

In some sites, water exchange with mineral aquifers may be constrained to some degree by the peat deposit. At Cors Geirch rising head tests conducted on peat piezometers in the northern section indicated that the peat generally acts as an aquitard, with permeabilities of $4.4 \times 10^{-4} – 0.019\ m\ d^{-1}$. However, in general the character of the basal material is likely to be the main constraint upon groundwater upflow.

Details of water supply are quite strongly site-dependent, and can be illustrated by reference to two examples for which some hydrometric data are available (Newham Fen (Northumberland)) (Box 6.16) and Corsydd Erddreiniog and Nantisaf (Môn) (Box 6.17).

Box 6.17:	**Water supply to Corsydd Erddreiniog and Nantisaf (Anglesey)**

In the Corsydd Erddreiniog–Nantisaf complex, spring flow along the eastern edge is intercepted along part, but not all, of the margin by drains. In the absence of interception, seepages (with *Schoenus nigricans–Juncus subnodulosus* mire (M13) vegetation) may extend further from the margins into the topogenous bottom than when ditches are present. It seems very likely that groundwater outflow from the margins once had a more pervasive effect upon the valley bottom than is currently the case. For example, in the vicinity of Llyn yr wyth Eidion, layers of marl and the macrofossil record point to a once wider distribution of seepage water. Currently, although spring flow may contribute about one-third of the total outflow from Cors Erddreiniog (Gilman and Newson, 1982), much of this may have little direct role in water supply to the valley-bottom mire. Except for former examples that have become inundated by recent water management initiatives, WETMEC 8 surfaces at Erddreiniog–Nantisaf are elevated above normal dyke levels and flooding is rare. Gilman and Newson (1982) concluded that the main function of the ditches was to remove surface and near-surface water, though they may also provide local recharge if the normal hydraulic gradients become reversed. They estimated *K* in some peat boreholes (using a rising head method in plastic piezometers) and reported values in the range of 0.4–1.0 m d^{-1}, generally decreasing with depth below the surface. These *K* values are not especially small, but the low permeability of the peat was demonstrated by the narrow measured drawdown zone alongside the main drainage ditch which was typically only about 15–20 m wide. Problems of water deficit in summer are exacerbated by high interception losses from the tall vegetation that covers much of this site: Gilman and Newson (1982) provided evidence that in a wet summer, well over half of the rainfall is intercepted by vegetation (and litter) at Cors Erddreiniog.

Elevated surfaces away from the dykes at Erddreiniog–Nantisaf may have low pH and soil Ca concentrations (Meade, 1981). They also tend to be dry in summer and samples from these locations have generally clustered into WETMEC 4 rather than WETMEC 8, and may be considered to be ‘ombrotrophic, legacy telluric’. However, it is far from certain that even in an undrained, natural state the surfaces distant from the margins were necessarily much influenced by groundwater, because of resistance to lateral water flow through the peat deposits.

6.11.10 WETMEC sub-types

WETMEC 8a: Groundwater Percolation Bottom

CLUSTER: 13

Examples at: Cors Goch, Cors Geirch, Greywell Fen, Newham Fen

Samples allocated to this sub-type are not associated with ditch or dyke systems. They are thought to be fed by groundwater outflow at the margins, with lateral percolation into the peat aquifer, but the summer water table is often significantly sub-surface because of a drainage gradient. In some systems, this sub-type forms a zone between a wetter habitat alongside the margin and better-drained wetland or farmland (such as Newham Fen). In others (such as Cors Goch), it essentially represents areas of solid topogenous peat in parts of the valley bottom, sometimes peripheral to wetter, quaking examples of WETMEC 13.

WETMEC 8b: Groundwater-Distributed Bottom

CLUSTER: 14

Examples at: Corsydd Eddreiniog and Nantisaf, Kenninghall and Banham Fens, Great Cressingham Fen, Upton Fen

Samples allocated to this sub-type are associated with ditch systems, which can both intercept and redistribute water from groundwater outflows at the margins. In some sites there is gravitational water flow through the ditches, which typically have summer water levels (well) below the peat surface (such as Kenninghall and Banham Fens); in others, sluices may be used to help maintain high ditch levels (such as Cors Erddreiniog). In some locations, the peat surface away from the ditches is well above their water level (such as Corsydd Erddreiniog and Nantisaf) and is never normally flooded, or even kept especially wet, by the ditch system. For these stands the ditches, if they have any significant hydraulic impact at all, act more as drains than as water sources, and the mire surfaces then have affinities with, and in some instances are transitional to, the ombrotrophic surfaces of WETMEC 4; some particularly isolated and dry stands were clustered there in this analysis.

On some occasions, mostly in summer, water levels in ditches crossing the wetland can be higher than those in the adjoining fen. The ditches then sometimes have a water supply function (Figure 6.26), at least to the immediately adjoining mire. The actual influence of the ditches depends strongly on the hydraulic conductivities of the adjoining peat as well as the water level within the ditches[1], both of which can show much variation.

The water in the ditches appears to originate primarily from groundwater inputs, though this is not always well established and in some sites is confused by semantic considerations. For example, in Kenninghall and Banham Fens the ditch system is partly spring-fed but there are also apparent inputs, at least periodically, from the River Whittle. However, this site is near the headwaters of the river, and sources for both the river and ditches are apparently groundwater from the same aquifer, in close proximity, so in this context distinctions between surface water and groundwater sources are of limited consequence.

6.11.11 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 8 are summarised in Table 6.29. WETMEC 8 has a fairly low mean summer water table (–11.1 cm), which is rather similar to that of WETMEC 7 (Groundwater Floodplains) (–11.9 cm) but significantly higher than that of WETMEC 9 (–19.2 cm). However, there is a good deal of variation in measured water tables in WETMEC 8, associated with varying degrees of drainage and the occurrence of small hollows embedded within the WETMEC. In general, the fairly low water tables are associated with fairly high oxidation–reduction potentials, and account for the preponderance of *Molinia*-dominated vegetation (especially M24) within this WETMEC. However, wet depressions may support M9-like vegetation.

Table 6.29 WETMEC 8: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum

[1] The magnitude of any lateral water flow is partly dependent on water level in the ditches. High ditch levels not only provide a greater hydraulic gradient but may also be able to feed water into the top-most peat layers, which are often more transmissive than lower layers; the extreme situation is where ditch levels are kept sufficiently high to produce overbank flow.

PAL depth (m)	3.7	0.8	6.0
Summer water table (cm)	–11.1	–43	11
Rainfall (mm a^{-1})	807	589	1,090
PE (mm a^{-1})	602	552	625
Water pH	6.4	5.6	7.0
Soil pH	6.5	5.2	7.4
Conductivity (µS cm^{-1})	443	197	813
K_{corr} (µS cm^{-1})	443	196	813
HCO_3 (mg l^{-1})	199	79	390
$Fertility_{Phal}$ (mg)	13	4	27
Eh^{10} (mV)	309	188	412

See list of abbreviations in Appendix 1

6.11.12 Ecological types

Most examples of WETMEC 8 were generally of fairly low fertility and high pH, probably because the majority were fed by groundwater from a Chalk or Limestone aquifer. Precipitation makes a proportionately large contribution to the better-drained examples and in some cases is associated with the development of base-impoverished surfaces, especially in wetter regions (see below). Relatively few examples were eutrophic, and these can be explained mostly in terms of local circumstances. For example, parts of WETMEC 8 at the northern end of Cors Geirch may receive enriched leachate from the Maesoglan tip, whilst an enriched example (dominated by *Phragmites*) at Great Cressingham Fen is downstream of small land-drainage inflow from arable fields. Examples on former floodplains may have some residual fertility from former river water supply or, in the case of Upton Broad, have deposits of estuarine clay quite close to the surface. At Newham Fen, an example of WETMEC 8 located upon a silty substratum was quite strongly eutrophic, whereas examples over peat and marl were mesotrophic or oligotrophic.

Table 6.30 Percentage distribution of samples of WETMEC 8 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	9	50	9
Sub-neutral	13	9	9
Base-poor		2	
Acidic	0		

Oligo–mesotrophic, base-rich/sub-neutral

This is the characteristic condition of examples primarily associated with groundwater from Chalk or Limestone aquifers. At some sites the substratum is intrinsically highly calcareous, which helps to maintain base-rich conditions even in locations with low water tables and where the surface is fed primarily by precipitation. The most characteristic vegetation type of this habitat is *Cirsium dissectum–Molinia* fen meadow (M24), which is found both in grazed and mown locations. In Northern England this may be replaced by M26 (*Molinia caerulea–Crepis paludosa* mire). Unmanaged stands may support an impoverished dereliction-derivative of these fen meadows, sometimes a ‘dry’ form of *Phragmites australis–Peucedanum palustre* tall herb fen (S24) or *Phragmites australis–Eupatorium cannabinum* tall-herb fen (S25). Wetter elements within these sites may support small, but quite rich, examples of M9. These are often associated with old peat workings, but in some sites (such as Thornhill Moss, Cumbria), patches of M9-like vegetation persist in a fairly dry situation, probably sustained by relatively high precipitation (881 mm) and fairly low PE (552 mm).

Mesotrophic, sub-neutral/base-poor

Low pH surfaces have been found in association with some grazing levels on partly drained floodplain sites in Broadland. M24 occurs in some places, but in an (often impoverished) acidic variant (sometimes with *Sphagnum*). In particularly acidic conditions, the yet more species-poor M25 community can occur. An acidic, apparent seepage area at Potter Heigham Meadows (water pH range: 4.9–5.5; soil pH range, 3.1–3.5) supports a number of locally uncommon species (including *Drosera rotundifolia* and *Eleocharis multicaulis*) and, although of debatable syntaxonomic affinities, is perhaps best classified as a form of *Carex echinata–Sphagnum recurvum/auriculatum* mire (M6), grading into M25. The generally low pH of these surfaces is in some cases probably because they are fed only by precipitation, though in others it could be a consequence of oxidation of sulphur-rich soils. The importance of base-poor groundwater outflows to the characteristics of this ecological type is not clear.

Examples of this category also occur in such sites as Corsydd Erddreiniog and Nantisaf, though in general the most base-poor surfaces there have been clustered within WETMEC 4.

Eutrophic, base-rich/sub-neutral

Most examples of this category were ungrazed and supported rather rank, impoverished, tall herb (*Phragmites australis–Eupatorium cannabinum* tall-herb fen (S25), *Phragmites australis–Urtica dioica* fen (S26)) and graminoid (*Glyceria maxima* swamp (S5)) vegetation. Grazed examples mainly had *Juncus subnodulosus–Cirsium palustre* fen meadow (M22).

6.11.13 Natural status

Many examples of WETMEC 8 have been drained to some degree, and in some cases it is difficult to deduce their natural water supply mechanism. Some would almost certainly once have been part of a Seepage Percolation Basin (WETMEC 13) (such as Great Cressingham Fen, parts of Newham Fen (to the west of the Lough clearing)). However, in large sites such as Corsydd Erddreiniog and Nantisaf (where the influence of groundwater may once have been naturally more pervasive than is currently the case in the valley bottoms), it is less certain that the hydrodynamics of the mires were naturally strongly dominated by groundwater in locations distant from the margins, and it cannot be assumed that all of the surfaces now referable to WETMEC 8 were formerly WETMEC 13.

The water supply mechanisms of WETMEC 8 sites are likely to have changed both through natural successional processes and as a result of water management operations. For example, in the early stages of their developmental history, large areas of Corsydd Erddreiniog and Nantisaf were swamp and wet fen and probably referable to WETMEC 13; hydroseral processes and the progressive accumulation of a more solid peat in the basins are likely to have progressively restricted the ingress of base-rich groundwater outflow from the mineral aquifer to the margins of the site, well before any impact of drainage and excavation of ditches. On the other hand, some marginal peat cuttings probably *increased* the penetration of base-rich water into the margins of the valley bottoms, by providing preferential sub-surface water flow paths.

Natural water supply mechanisms to the more central locations of some of these sites, distant from the margins, are not really known. There are at least two possibilities. Significant ingress of base-rich water from the margin to the centre may once have been maintained by near-surface flow through a loose, transmissive, acrotelm-like peat; there is currently no evidence for such a surface layer, but the drainage, grazing and, in places, peat cutting to which the surface has been subject might be expected to remove all traces of such a horizon. Alternatively, ombrotrophic conditions may have established in the centre of the mire, leading to the development of small raised mires; there is also no evidence for extensive former *Sphagnum* surfaces (though there are patches of *Sphagnum* peat), but again it is possible that any such material could have been removed by extensive peat stripping. It is certainly the case that some central locations of WETMEC 8 bottoms are currently ombrotrophic and acidic (and referable to WETMEC 4), and it is difficult to see why this would not have been the case in the past, unless the water regime permitted episodic flooding, or at least penetration of base-rich water across the surface. The climate characteristics of these sites (annual ppt: 994 mm; evap: 611 mm) is well within the range occupied by raised bogs elsewhere in Britain.

In some sites, surfaces referred to this WETMEC may once have been irrigated by a quite different mechanism. For example, the hydrodynamics of the northern section of Upton Fen were probably once considerably influenced by the R. Bure, before the river connection was severed.

The impact that the various drainage operations have had upon WETMEC 8 sites depends upon the nature of the starting condition and the magnitude of change. In locations that were apparently once seepage percolation (WETMEC 13) systems, the impact of partial drainage may have been to ground a buoyant fen mat, or consolidate a quaking surface, thereby decreasing permeability and reducing the potential for lateral water flow into the system. It is not known whether such a process is reversible, but at Newham Fen preliminary estimates of the hydraulic conductivity of the surface layer pointed to quite high permeability characteristics, suggesting that there was considerable scope for rewetting (Wheeler and Shaw, 1998). At Cors Erddreiniog, empirical attempts to spread groundwater from the marginal springs further onto the fen bottom have met with some success (L. Colley, personal communication.). However, this solution is only appropriate for those parts of wetlands that seem naturally once to have been seepage percolation systems.

Elsewhere, it may be possible to recreate a seepage percolation surface from WETMEC 8 by a reversal of successional processes engendered by the removal of peat. An excellent demonstration of the potential of this approach can be seen at Cors Geirch. The central part of this system had been drained and converted into farmland and has recently been the subject of an innovative restoration initiative, involving the removal of top soil and peat (necessary to remove a superficial layer of nutrient-enriched grassland soil and to create shallow topogenous basins (Shaw and Wheeler, 1992). A 5.5 ha plot was prepared by stripping off around 30 cm depth of top soil, followed by irrigation of the surface by spring water diverted from the valley side. This initiative has been spectacularly successful, and has led to the development of a percolating fen surface, with soakways and, at least near the margin, quaking vegetation mats which have quickly recolonised with typical wetland species, including some uncommon taxa (Colley and Jones, 2004). The success of this project probably owes much to the availability of a copious supply of groundwater of suitable quality.

6.11.14 Conservation value

The surfaces of this WETMEC are often summer-dry and sometimes of fairly limited conservational interest. Greatest importance attaches to the occurrence of *Cirsium dissectum–Molinia* fen meadow (M24) (and related vegetation types) in base-rich/sub-neutral, oligotrophic/mesotrophic sites. This community is well developed in some examples of WETMEC 8, and can form one of the EC Habitats Directive interest features ("*Molinia* meadows") providing the basis for SAC designation (see Tables 3.3 and 6.4). However, locations remote from base-rich influences may support a rank and species-poor mix of *Molinia* and *Myrica,* which is more akin to *Molinia caerulea–Potentilla erecta* mire (M25). Such surfaces have limited diversity: they tend to be acidic, but may have only limited colonisation by *Sphagnum* (possibly because they are too summer-dry). However, some of the less base-rich examples of WETMEC 8 contain much *Sphagnum* (such as Priory

Meadows, Hickling) and can sometimes have considerable affinities to wet heath and acid mire communities (such as Potter Heigham Meadows, which contain a range of locally uncommon calcifuge wetland species).

Ditches and dykes extending through this WETMEC can have considerable value because of their aquatic vascular plants, ranging from rather base-poor dykes with such species as *Hypericum elodes* to calcareous examples with *Potamogeton coloratus.* These dykes may also be of importance in supporting rare invertebrates, including molluscs, water beetles and dragonflies, as well as birds.

The percentage occurrence in NVC communities of samples of WETMEC 8 is: M24: (21%); M22: (17%); S25: (13%); CM: 8%; M9-2: (8%); M25 (8%); S4 (8%), S24 (8%), S26: (4%). [One of the units listed here is a non-NVC unit, which has been described by Wheeler (1980a): CM: *Cladio-Molinietum*]. The range of communities is broadly similar to that of WETMEC 9. The preponderance of M24 probably reflects a bias in sampling towards more base-rich sites. If more base-poor samples had been included, it is likely that M25 would have been represented. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 8 is given in Table 6.3.

A total of 74 wetland plant species have been recorded from samples of WETMEC 8. These include 14 nationally uncommon plant species: *Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Carex diandra, Carex elata, Carex lasiocarpa, Cladium mariscus, Epipactis palustris, Lathyrus palustris, Oenanthe lachenalii, Peucedanum palustre, Rhizomnium pseudopunctatum, Sphagnum contortum, and Thelypteris palustris.* Most of these were recorded from only a very small number of samples, mostly from ‘dry’ versions of M9 and S24.

6.11.15 Vulnerability

WETMEC 8 includes sites that have already been partly drained. Some may be susceptible to a further reduction in water levels, especially examples which retain vestiges of wetter vegetation types. A distinction can be made between sites where the established vegetation (such as M24) is compatible with fairly low water tables and those which support some species often associated with higher water tables and which may be particularly vulnerable to further water table reduction. Where communities associated with relatively low summer water tables (such as M24) are well established, it should be appreciated that existing conservation interest may be a product of partial drainage and that initiatives aimed at increasing summer water tables may be detrimental to this.

As a groundwater-fed WETMEC, this unit is potentially influenced by groundwater abstraction, but the impact of this may be much influenced by the topographical and stratigraphical characteristics of the sites, and needs to be assessed on a site-by-site basis. The topogenous character of the sites means that in some situations, a reduction of groundwater supply can be remedied by reducing outflow from the site. In some examples of sub-type 8b, it may be more appropriate and effective to remedy interception of groundwater outflow from the mineral aquifer by the ditch system before reducing groundwater abstraction in the vicinity. The presence of an aquitard means that vertical transfer of water between the peat and mineral aquifers may be limited, and in some circumstances recharge of the peat aquifer can become critically dependent on meteoric inputs.

Examples of WETMEC 8 can become rank and colonised by trees when unmanaged. In the case of oligotrophic and mesotrophic examples (with M24, M25 or *Carex echinata–Sphagnum recurvum/auriculatum* mire (M6)) this may be expected to result in loss of many of the characteristic species, though in such cases the dereliction process may be relatively slow. Surface acidification, and associated species loss, is a potential problem in some sites, but this process has been little documented.

6.12 WETMEC 9: Groundwater-Fed Bottoms

6.12.1 Outline

A rather heterogeneous unit which encompasses a range of topogenous sites (basins, valley bottoms, floodplains), with groundwater discharge as the main water supply of telluric water, but where the water table is regularly or permanently sub-surface. The peat aquifer is not underlain by a laterally persistent aquitard and groundwater outflow from the mineral aquifer is not necessarily restricted to the margins. Schematic sections are provided in Figure 6.29.

6.12.2 Occurrence

Example sites: Bransbury Common, Blo' Norton and Thelnetham Fens, Bugg's Hole (Thelnetham), Cavenham Poor's Fen, Cors Geirch, Decoy Carr (Acle), East Ruston Common, Hopton Fen, Limpenhoe Meadows, Pakenham Meadows, Poplar Farm Meadows, Redgrave and Lopham Fens, Roydon Fen (Diss)

Most examples of this WETMEC were recorded from East Anglia (Figure 6.28), but it is probably quite widespread.

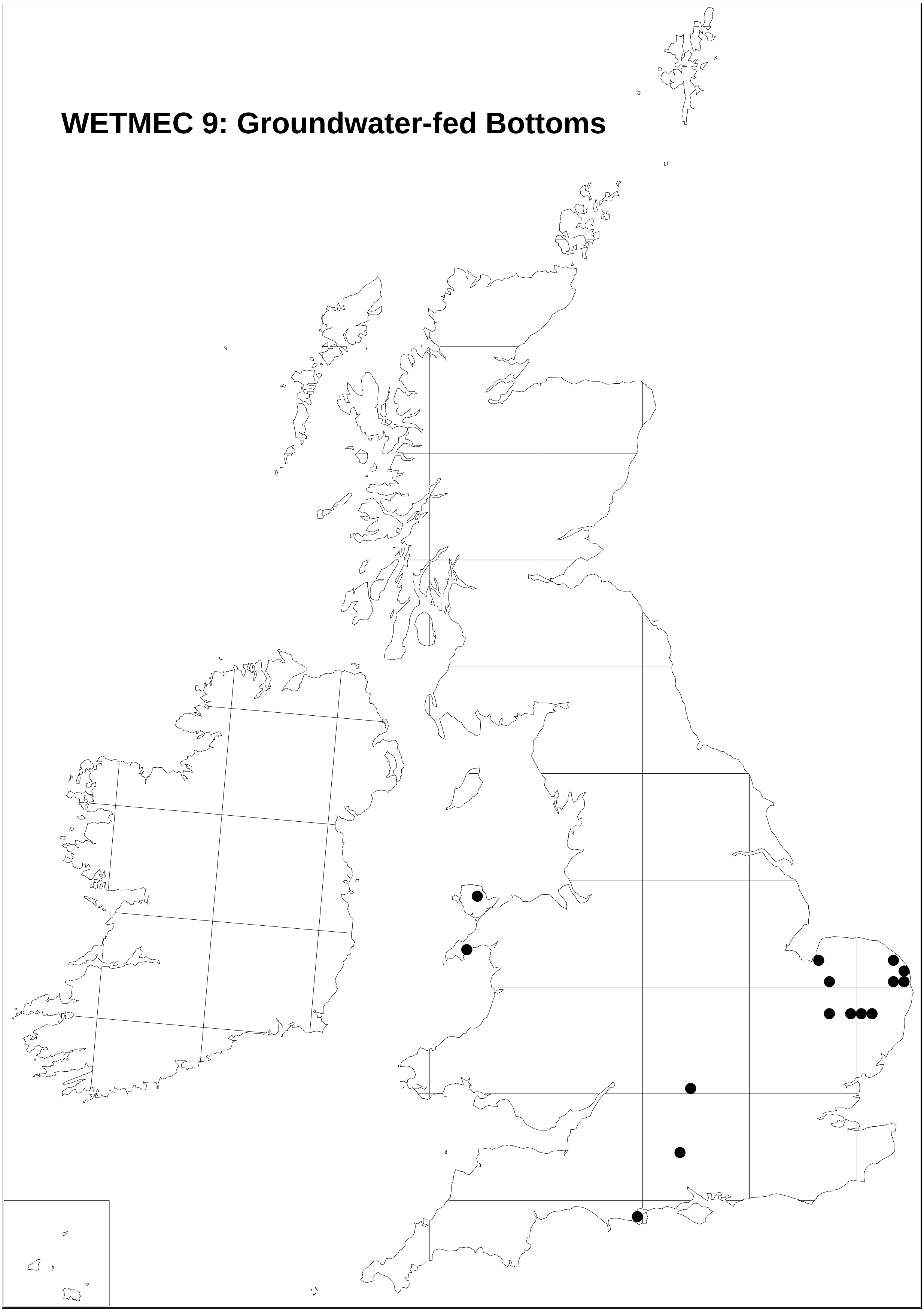


Figure 6.28 Distribution of examples of WETMEC 9 in sites sampled in England and Wales

6.12.3 Summary Characteristics

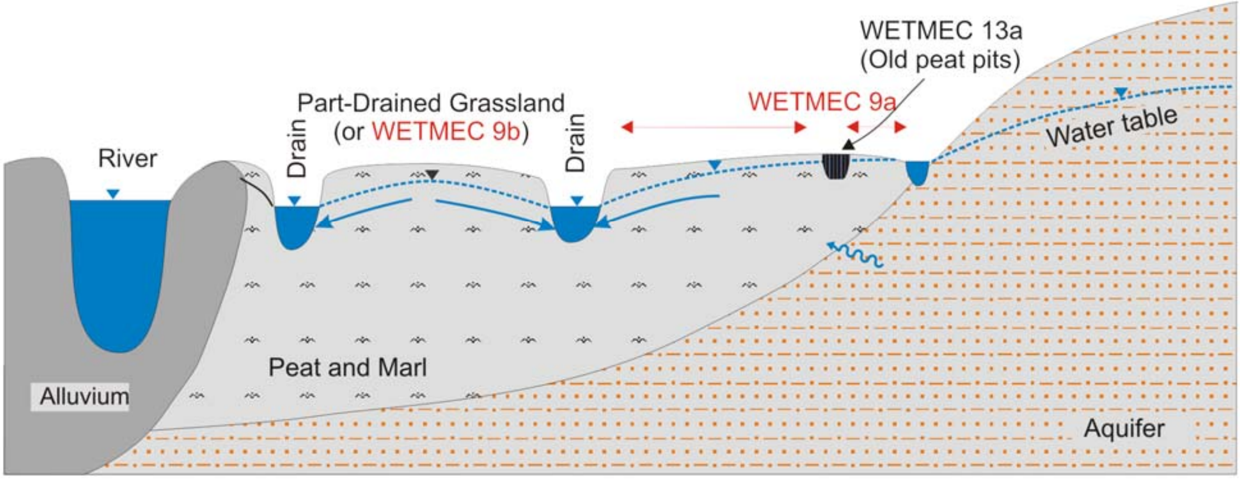
Situation	Valleyhead basins, river floodplains (margins).
Size	Tiny examples in basins to quite large areas of fen (> 10 ha).
Location	Most examples recorded from East Anglia, but probably quite widespread.
Surface relief	Even (appears more or less flat, but gently slopes to river or outfall).
Hydrotopography	Rheo-topogenous (part-drained).
Water: ***supply***	Groundwater.
regime	Summer water table often low, but higher where in a depression.
distribution	Into peat body; dykes.
superficial	Normally absent, except where pools occur in embedded peat pits. Dykes can dissect WETMEC.
Substratum	Fairly consolidated peat. Peat sometimes has bands of marl but not normally much other mineral material, though silt layers may occur in some riverside locations.
peat depth	Sometimes shallow but often deep (2–3 m).
peat humification	Upper peat often strongly oxidised. Underlying deposit varies in humification; often more strongly humified and solid than the surface layers, but not as much as in many examples of WETMEC 8.
peat composition	Variable, and sometimes difficult to determine. Upper layers can be sedge–moss peat (mainly hypnoid mosses), but may also be sedge, reed or brushwood peat. Herbaceous peat is sometimes quite thick. In floodplains, basal peats are often dense brushwood peats.
permeability	Variable, but apparently mostly of moderate permeability. Basal substratum usually quite permeable (rich in sands and gravels, with a variable silt component).
Ecological types	Range from base-rich to base-poor, eutrophic to oligotrophic, depending mainly on groundwater source and substratum characteristics. Most examples are base-rich/sub-neutral and mesotrophic.
Associated WETMECs	Often the main/only WETMEC. May form a narrow band along the upland margin, separating this from WETMEC 8.
Natural status	Many sites rather dry, usually due to direct or indirect drainage.
Use	Some are unmanaged, others grazed. Some may have been used for peat excavation. Some may have been converted to farmland, at least in part.
Conservation value	Mesotrophic, base-rich sites can support *Molinia caerulea–Cirsium dissectum* fen meadow (M24) (sometimes forming a SAC feature), or close relative. Patches of (rather dry) M9 or M13 occur in a few places. Occluded dykes may support wet fen plants or sometimes, a good development of aquatic species.

Vulnerability	Sites already partly or considerably damaged. Possible threat of further drying (some sites would be amenable to agricultural improvement). Dereliction and scrub colonisation can occur rapidly in the absence of management.

WETMEC 9: GROUNDWATER-FED BOTTOMS

WETMEC 9a: 'Wet' Groundwater Bottoms
(*e.g.* Thelnetham Fen)

- valley bottom is fed by groundwater
- highest water tables occur along upland margin, where hollows (old peat workings) can support locally very wet conditions
- partial drained of valley bottom and low river levels result in lower water tables away from the upland margin, and in some cases these areas support farmland
- marl layers within the peat may form local aquitards, but are not laterally extensive



WETMEC 9a: 'Wet' Groundwater Bottoms
(*e.g.* Poplar Farm Meadows)

- valley bottom is pump-drained and no longer normally receives episodic river flooding
- margin is fed by groundwater, where there appears to be localised upflow
- alluvial clays close to the river help to confine the aquifer locally and, when drained, provide a firm surface suitable for livestock

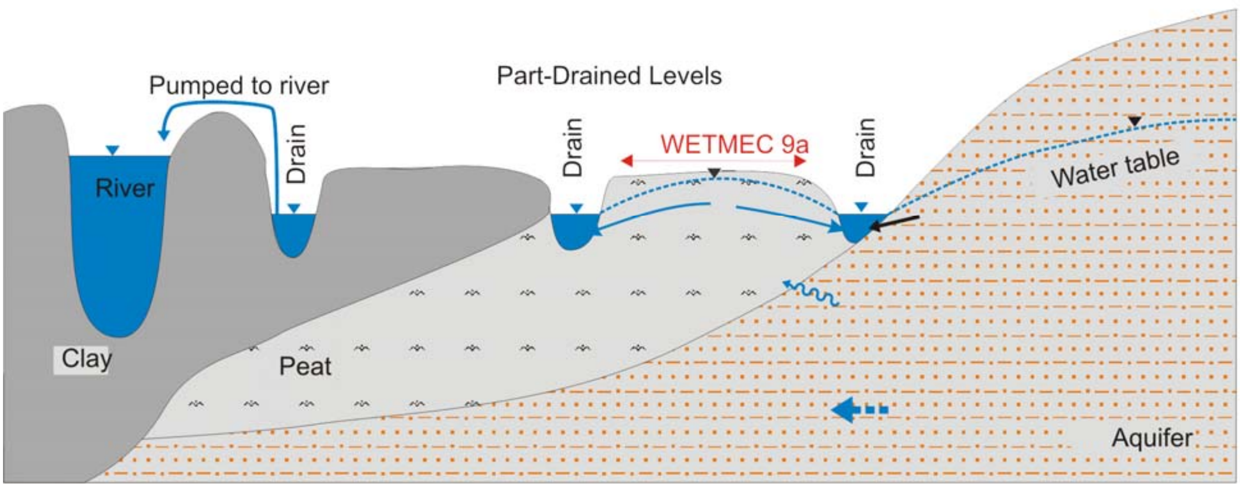


Figure 6.29 Schematic sections of Groundwater-Fed Bottoms (WETMEC 9)

6.12.4 Concept and description

CLUSTERS: 15, 16

This type of wetland occurs in more or less flat, topogenous situations, in ground hollows, valley bottoms and in some floodplains (especially near the margins) where groundwater inputs occur. The degree to which the surface of the wetland is fed by groundwater varies considerably, both spatially and seasonally. The wettest locations (those in which a high water table persists longest in dry periods) are usually those closest to the upland margins or in topographical lows, the latter frequently provided by old peat workings. However, in many examples of this WETMEC the water table is usually sub-surface (at least in the summer and sometimes year round), and the dominant water supply to the fen *surface* appears often to be precipitation, at least in summer.

In a number of places, especially the Waveney–Ouse valley fens in East Anglia, this WETMEC forms much or all of the topogenous wetland in the valley bottom. However, some of the samples clustered here form a narrow band along the upland margin of a larger wetland complex, in a location where the peat is relatively thin and where the basal substratum is formed from a permeable material. This can occur along the landward edge of other WETMECs, especially WETMEC 8 (Groundwater-Fed Bottoms with Aquitards) (such as part-drained margins of Cors Nantisaf). It also occurs, very locally, along the landward edge of some Broadland floodplains, where most of the land between the margin and the (often embanked) river channel has been drained and converted into farmland (such as Limpenhoe Meadows, Poplar Farm Meadows). In these sites, it is likely that groundwater upflow occurs at transmissive marginal locations within a valley infill that generally acts as an aquitard.

Many of the sites which support examples of this WETMEC appear to have become drier than was once naturally the case. In some instances this may be attributable to groundwater abstraction, but it is also associated with better drainage of the valley bottoms. In some locations, both processes seem to have occurred. For example, in the headwaters of the Waveney–Ouse valley in East Anglia, deepening of adjoining river channels appears to be a particularly important cause of drying, but groundwater abstraction may also have had an impact on water tables. In other cases, such as the Broadland sites or Bugg's Hole (Thelnetham) and Thelnetham Middle Fen, drying appears to be partly due to drainage of the peaty levels (former wetland) which separate WETMEC 9 surfaces from the river. In some locations, the surfaces now referred to WETMEC 9 would have been allocated to WETMEC 13 (Seepage Percolation Basins) prior to drainage, and in some instances (such as the Thelnetham Fens) particularly small, wet areas near to the margins still have clear affinities with WETMEC 13, though most have been clustered into the current WETMEC (as sub-type 9b) rather than into WETMEC 13.

Peat depth is variable in WETMEC 9, from shallow (around 0.5 m) to quite deep (two to three metre) accumulations. Peat character varies from rather solid amorphous deposits to looser accumulations of monocot and moss peat. The basal substratum beneath most samples was sand, gravel or rock. In those sites that also supported WETMEC 8, the latter was typically on a deeper, more solid peat, with an extensive basal substratum of clay or lake muds. Quite detailed stratigraphical data are available from some sites, especially in the Waveney–Ouse valley, which generally point to a rather variable stratigraphy. Whilst it appears that the WETMEC 9 deposits are likely to be more conducive to groundwater upflow than those of WETMEC 8, in some cases WETMEC 9 deposits may also place significant constraints upon this. Indeed, locally within WETMEC 9 some areas function effectively as WETMEC 8 (for example, where patchy layers of marl locally constrain upflow), but as these are generally not laterally persistent it would be both difficult and of little practical value to try to separate them as functional units.

Affinities and recognition

WETMEC 9 is based on two clusters which form the basis of the two sub-types recognised. They differ primarily in their situation and summer water table: WETMEC 9a mostly occurs near the upland margin, often on fairly shallow peat, and has a higher summer water table. WETMEC 9b often occurs away from the edge, often on deeper peat, and has a lower summer water table. However, some examples of 9b occur closer to the upland margin than 9a, especially in topographically higher locations.

WETMEC 9 is closely related to WETMEC 8 (Groundwater-Fed Bottoms with Aquitard), but can be distinguished from the latter by the occurrence in WETMEC 8 of a laterally extensive aquitard (though some individual samples in WETMEC 9 may be underlain by a local aquitard, such as a lens of marl). Examples of sub-type 9a can be similar to samples allocated to WETMEC 13 (Seepage Percolation Basins). Typical examples of 9a have a more consolidated surface peat (rather than a buoyant or quaking mat) and a generally lower summer water table than WETMEC 13, but transitional examples undoubtedly occur. It can also be difficult, both conceptually and practically, to separate some samples in this unit from those in WETMEC 4 (Drained Ombrotrophic Surfaces in Bogs and Fens). This is because the surface of many of the drier examples of the present WETMEC, especially sub-type 9b, is probably fed only by rainfall for most of the time, and the split from WETMEC 4 is essentially based on the typical position of the water table – samples allocated to WETMEC 4 normally having lower summer water tables than those allocated to WETMEC 9.

6.12.5 Origins and development

In some WETMEC 9 sites (such as East Ruston Common), so much peat has been removed by turbary (Bird, 1909) and other activities that little is known about their developmental history. In others the upper layers of the stratigraphy have been much disturbed, but the deeper deposits remain largely intact. Some detailed stratigraphical data are available for some of the Waveney–Ouse Fens (see Box 6.18).

Box 6.18: Waveney–Ouse Fens (Norfolk/Suffolk)

The Waveney–Ouse fens are developed upon, or alongside, a deep buried channel about one km wide in this vicinity and which appears to represent a major pre-Anglian river, draining west to east from the English Midlands (Rose, 1991). Cores and some sections of this deposit have been described by RHP (1990) and Aspinwall (1992). The channel contains fluvial deposits (around 2–12 m thick) underlain by glacial sands some 5–20 m thick, that in turn rest locally on a band (< 15 m) of boulder clay overlying the Upper Chalk. Along the valley to the east-north-east the thickness of sands and boulder clay increases. The glacial sands show considerable heterogeneity and some cores show (fairly thin) layers of silt or clay. Tongues and ridges of sand extend variably into the fens, resulting in complex variation of peat depth. The sandy ridges are thought to have been derived from rain-wash, wind-blow, ice flotation and solifluction (Tallantire, 1953, 1969). The varied deposits of the buried channel infill complicate assessment of likely groundwater inputs into the fen, and different locations may have different hydraulic relationships with the Chalk aquifer. Low-permeability deposits within the buried channel, especially layers of boulder clay, may help limit or effectively prevent direct hydraulic connection between the Drift and Chalk, and the Chalk aquifer may be either largely confined or leaky. Any hydraulic connectivity between the Chalk and peat aquifers may be indirect (for example, by lateral connections through sand and gravel layers within the river channel). Thus, whilst these systems are not obviously developed over a laterally persistent aquitard, as is the case for WETMEC 8 sites, neither are they necessarily in direct hydraulic connection with the mineral aquifer.

Redgrave and Lopham Fens

The stratigraphy of Redgrave and Lopham Fens has been described by Tallantire (1953, 1969), Heathcote (1975), Price (1978a, b) and ECUS (1995). Interpretation of the more recent phases of development is hampered by oxidation and decomposition of the upper peats, caused by low water tables, and by past peat removal (Wheeler and Shaw, 2000b). There is evidence for several late-glacial–early post-glacial marl lakes in the deeper parts of the mires. They were apparently separated mostly by swamp or wet, herbaceous paludification fen. However, similar herbaceous vegetation, sometimes rich in sedge and moss remains, developed over the lakes and the accumulating hydroseral peat merged with paludification peat forming on the seepage terraces and wet valley bottom. The upper peats are rather amorphous and humified, and plant remains can be difficult to distinguish, but there is evidence of seeds of sedges (*Carex elata, Cladium*) and *Menyanthes trifoliata*, sometimes with moss remains and nekron mud, suggesting that, despite their humified condition, these layers also formed in relatively wet conditions and that their humification is secondary (probably caused by drainage). Wood fragments also occur and locally there are isolated horizons of very woody peat, but these do not appear to be continuous across the fen. Small lenses of marl are found in the upper profile. Overall, available information broadly supports the view of Heathcote (1975), based on a section from Lopham Middle Fen, that there is no obvious successional stratification in the upper peat. After the initial differences in mire development, which mainly probably reflect the different starting points of terrestrialisation and paludification processes, it appears that for most of their development fens consisted of a patchwork of pools, swamp, sedge-rich (and sometimes moss-rich) fen and scrub.

Thelnetham Fens

Tallantire (1969) summarised the stratigraphy of Thelnetham Fen as "*one to two metres of Cladium peat, a half-metre of calcareous lake mud resting on a layer of grey coarse sand, of variable depth, beneath which were up to four metres of silty lake muds underlain in places by a thin peat layer*". He considers that the lower lake muds and sand bed represent late-glacial lake deposits, with post-glacial lake and peat deposits above the sand. A more recent investigation focussing on the upper peats (Wheeler and Shaw, 2003) very broadly supported the observations of Tallantire, but noted some significant differences: (a) *Cladium* was by no means the dominant component of upper peats in all locations; (b) marl bands were not necessarily restricted to the base of the upper peats; and (c) no evidence was found for a continuous marl lake across the centre of the site. Wheeler and Shaw (2003) reported that much of the upper peat was dominated by monocotyledons, with bryophytes abundant in places. In some locations, especially the deeper ones, this was underlain by a fairly dense brushwood peat, but in others, especially near the margins, fairly loose herbaceous peat extended to the base of the deposit. There was a tendency for more solid and dense accumulations of peat towards the river, and in places the wetland alongside the river was drained and converted to farmland. Some of these deposits contain a near-continuous deposit of rather amorphous peat, or peat rich in wood fragments. There is some enrichment of the peat with silty material immediately alongside the river course, but this is not extensive. Layers of marl, often rich in shells, occur widely, especially towards the margins, at all depths in the deposit, and in places form a quite thick basal layer of marly muds, but these were not laterally persistent. In a few cores the peat and marl infill was underlain by a silty-clay, but most terminated in a sandy deposit.

6.12.6 Situation and surface relief

WETMEC 9 is restricted to topogenous, though sometimes slightly sloping, situations, but occurs in a variety of landscape contexts: 68 per cent of the samples were recorded from (mostly inactive) floodplains, 26 per cent from valleyheads, three per cent from valley troughs and three per cent from plateau–plains. The surface relief is typically even; it may appear more or less flat, but usually gently slopes to river or outfall, or towards dykes and ditches. Most of the samples were taken from flat locations, with some from gently sloping areas (Table 6.31).

Table 6.31 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 9

	Mean	1	2	3	4	5	6	7
Surface layer permeability	3.8			47	32	18	3	
Lower layer permeability	3.3		12	59	18	9	3	
Basal substratum permeability	4.8			24	6	38	32	
Slope	1.3	74	24	2			X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.12.7 Substratum

Most examples of WETMEC 9 occur on a fairly deep wetland infill (mean depth of one m), which consists mainly of peat. The surface layer of peat is quite variable, and is generally not very different to that of WETMEC 8. The lower peats are generally more humified and solid than the surface peats (Table 6.31), but often fresher and less solid than equivalent horizons below WETMEC 8 surfaces. They sometimes contain (mostly thin) layers of marl and muds, but these are not usually laterally persistent. Most examples of this WETMEC are floored by a basal layer rich in sands and gravels, with a variable silt component.

6.12.8 Water supply

The main source of telluric water to WETMEC 9 appears to be groundwater outflow from a mineral aquifer. Rain-generated run-off is probably of little importance in maintaining summer water tables, partly because much rainfall is likely to infiltrate into the permeable deposits that adjoin many examples of this WETMEC. WETMEC 9 is generally more closely associated with watercourses than many examples of WETMEC 8, but there is little reason to suppose that these make a material contribution to water supply. In some cases (for example, at the edge of floodplains in Broadland), the surfaces are remote from the embanked rivers and feed into a pump-drained network of ditches. In others (such as the Waveney–Ouse fens, Cors Geirch), the sites adjoin small rivers and streams which appear mainly to drain the fens rather than feed them (and are partly responsible for their current part-drained status). It is possible that before they were deepened, rivers contributed episodically to the water balance of some of the fens, but in the case of fens near their headwaters (such as Redgrave and Lopham Fen) any such distinction is more semantic than functional: the watercourses there are endotelmic and, before drainage, the fens and associated watercourses would have formed a single groundwater-outflow complex. In the case of fens further down the valleys (such as Cavenham Poor's Fen, East Ruston Common), there is also little reason to suspect significant water input from the rivers in current circumstances (for example, East Ruston Common visibly drains into the Hundred Stream and is not in normal circumstances, if ever, flooded by it). However, it is not clear whether this was also the case before the river channels were deepened and, in parts of East Ruston Common, diverted around the periphery of the fen.

Some WETMEC 9 sites are crossed by dykes/drains but, unless artificially manipulated, water levels in these tend to be below the fen surface, at least in summer. Together with drainage by adjoining watercourses, these circumstances help account for the summer dryness of the surface that is typical of much WETMEC 9, especially in locations distant from the groundwater sources. Some surfaces, particularly in some pump-drained levels, may also not receive telluric inputs in winter conditions. The upper substratum layers are often dense and rather amorphous, sometimes probably as a consequence of drainage and compaction, and may constrain lateral water flow from seepages or dykes through the peat (see 6.12.12).

The pathway of groundwater supply into many of these wetlands is not really known. One difference from WETMEC 8 is that samples from WETMEC 9 are not located over a known laterally persistent aquitard, and in some sites allocated to this unit (such as Pakenham Fen) there is no known evidence for any obvious aquitard unit. However, in locations with a more complex alluvial basis (such as the Waveney–Ouse fens) local aquitards probably exist, and some samples allocated to WETMEC 9 may have many affinities with those of WETMEC 8, especially sub-type 8a. In this respect, the separation of some examples of WETMEC 9 from WETMEC 8 is partly a function of scale. In some large sites (such as Cors Geirch) most samples of topogenous mire were underlain by clay (alluvium or Till) and clustered into WETMEC 8, but some mire-margin examples near Maesoglan clustered into WETMEC 9.

6.12.9 WETMEC sub-types

Two sub-types have been identified, which correspond to clusters 16 and 17 of the multivariate analysis at the 36-cluster level. Sub-type 9a is restricted to near the margins of the sites and contains some of the wetter examples of WETMEC 9; the wettest locations are mainly associated with shallow hollows (old peat pits). However, some examples of sub-type 9a also have low water tables and overall there is only a small, though statistically significant ($p < 0.05$), difference in mean summer water tables between the two: WETMEC 9a: –17.4 cm;
9b: –20.8 cm.

WETMEC 9a: Wet Groundwater Bottom

CLUSTER: 15

Examples at: Cors Geirch, Limpenhoe Meadows, Pakenham Meadows, Poplar Farm Meadows, Potter Heigham Meadows.

This includes a number of relatively summer-wet examples of WETMEC 9 located close to the edge of partly drained floodplains and valley bottoms. All were in topogenous locations and many were on fairly deep peat. In some locations (such as parts of the Thelnetham Fens), this sub-type forms an interrupted zone along parts of the upland margin, grading into the drier sub-type 9b further from the edge. Some samples cluster close to WETMEC 13 and are transitional to this. In other sites (such as Limpenhoe Meadows), this WETMEC grades upslope at the margin into a seepage system (WETMECs 10 and 11). Little information is available about this type of wetland. In some cases, the relatively high water table may reflect quite wide scale controls on the groundwater table, but in others it seems more likely that patches of WETMEC 9 reflect the occurrence of localised water upwelling (Box 6.19). The cause of such localisation is generally neither known nor obvious. In some sites they may be a consequence of windows of higher permeability in the basal substratum, but very few relevant augering data are available.

Box 6.19: Poplar Farm Meadows (Broadland)

At Poplar Farm Meadows, WETMEC 9a occurs in association with an apparent upwelling of groundwater in a part-drained floodplain compartment surrounded by dykes. This is marked by a 'dry' version of M13, associated with low (> 35 cm bgl) summer water tables, which may be a product of head loss induced by the drainage system. Nonetheless, it seems likely that before this part of the Yare valley was drained, this groundwater input may have been a rather small component of the water budget of this location on the floodplain, both quantitatively and in terms of its ecological significance, and it is possible that partial drainage has emphasised the importance of groundwater supply rather than reduced it.

WETMEC 9b: Part-Drained Groundwater Bottoms

CLUSTER: *16*

Examples at: Cors Geirch, East Ruston Common, Hopton Fen, Pakenham Meadows, Tuddenham Turf Fen, Pashford Poor's Fen,

This sub-unit includes a range of drained areas of topogenous fen in which the water table is usually sub-surface, other than in exceptional circumstances, so that the fen surface is typically rather dry. The depth and fluctuations of the water table depend strongly on local circumstances. This category includes stands that have been partly drained by deep ditches (such as Tuddenham Fen) or by groundwater abstraction (such as East Ruston Common[1]). The groundwater table within the fen is not located over a continuous aquitard, though the basal substratum may sometimes be only slowly permeable. Low-permeability wetland deposits also sometimes occur, but if present they are usually neither thick nor laterally persistent.

This sub-type is prominent in a number of sites. At Hopton Fen it appears to have developed from, and at the expense of, sub-type 9a (and ultimately, perhaps from WETMEC 13), presumably in response to a lowering of groundwater tables within the site. In some sites, it forms a zone between a wetter marginal band of sub-type 9a and a watercourse or converted wetland (such as Thelnetham Middle Fen).

6.12.10 Ecological characteristics

Overall, little is known about the ecology of WETMEC 9 sites, perhaps partly because they are part-drained and often more wet meadow than fen. Sites can be subdivided into those which have long been drained, where the present vegetation may be compatible with the water regime, and those which have recently become dry (such as East Ruston Common) where former vegetation, characteristic of wetter conditions, has recently been subject to drying and modification.

Values of selected ecohydrological variables for WETMEC 9 are summarised in Table 6.32. The mean summer water table in this WETMEC is third lowest in the dataset, and significantly below that of WETMEC 8. This is reflected in the second highest mean value for oxidation–reduction potential. However, there is considerable variation in both water levels and Eh, and some of the sites support quite a rich range of wetland plant species. High water

[1] The East Ruston Common data used in the analysis refer to the period *before* recent rewetting initiatives

tables are particularly associated with small, shallow depressions (old peat pits). Most examples were located on quite deep peat, but in some there was only a shallow peat layer. Most examples appear to have been subject to some degree of drainage, direct or indirect, including groundwater abstraction (such as East Ruston Common). Most were base-rich or sub-neutral and mesotrophic, but some eutrophic surfaces also occurred. A small number of base-poor surfaces were encountered (all from King's Fen, East Ruston Common).

Table 6.32 WETMEC 9: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	1.0	0.1	4.0
Summer water table (cm)	–19.3	–48	5
Rainfall (mm a^{-1})	646	568	1,090
PE (mm a^{-1})	612	598	625
Water pH	6.9	6.3	7.6
Soil pH	6.7	5.4	7.5
Conductivity (µS cm^{-1})	679	358	856
K_{corr} (µS cm^{-1})	679	358	856
HCO_3 (mg l^{-1})	206	180	244
$Fertility_{Phal}$ (mg)	9	6	19
Eh^{10} (mV)	330	288	372

See list of abbreviations in Appendix 1

6.12.11 Ecological types

Most samples that clustered into WETMEC 9 were base-rich, with mesotrophic examples particularly well represented (Table 6.33). This reflects the preponderance of samples from chalkwater-fed sites in East Anglia.

Table 6.33 Percentage distribution of samples of WETMEC 9 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	12	50	27
Sub-neutral	4	3	3
Base-poor	2		
Acidic			

Oligo–mesotrophic, base-rich/sub-neutral

This is the characteristic condition of examples of WETMEC 9 that are primarily associated with groundwater from Chalk aquifers. A typical vegetation type of this habitat is *Cirsium dissectum–Molinia* fen meadow (M24), which is found both in grazed and mown locations. Unmanaged examples may support impoverished dereliction-derivatives of this (often *Cladio-Molinietum*) or sometimes a dry form of *Phragmites australis–Eupatorium cannabinum* tall herb fen (S25). At some sites the top-layer substratum is very calcareous, which may help to maintain base-rich conditions even in locations that are fed primarily by precipitation, though other sites, such as Cavenham Poor's Fen adjoined by heathland and apparently now little influenced by Chalk water, are sub-neutral.

Examples of M13 – mostly in a rather impoverished and dry form – also occur in a few sites with groundwater upflow (such as Poplar Farm Meadows, Thelnetham Old Fen). Small patches of M9-like vegetation occur in shallow depressions (old peat pits) at a couple of sites (Cors Geirch, Thelnetham West Fen) and an example of *Carex diandra–Peucedanum* fen (M9-3) once occurred in a site of this WETMEC at Mown Fen, East Ruston Common, in a location which has since been converted into a lagoon.

Mesotrophic, base-poor

All of the samples in this category were recorded at King's Fen, East Ruston Common, developed under the influence of groundwater discharge from sands of the Norwich Brickearth.

Eutrophic, base-rich

Examples of this category were found mainly in floodplain locations where some degree of enrichment has probably occurred, or where the substratum contains a (small) proportion of alluvial material (such as locations bordering the Little Ouse at Thelnetham Old Fen). In other cases (such as a marginal location at Decoy Carr, Acle (Norfolk)) local enrichment from adjoining farmland may be causal. Ungrazed examples support rather rank, impoverished, tall herb (*Phragmites australis–Eupatorium cannabinum* tall-herb fen (S25) and *Phragmites australis–Urtica dioica* fen (S26)). Grazed examples mainly have *Juncus subnodulosus–Cirsium palustre* fen meadow (M22).

6.12.12 Natural status

All examples of this WETMEC have been drained to some degree and in some cases it is difficult to deduce their natural water supply mechanism. Some may once have been a form of Seepage Percolation Basin (WETMEC 13) or Seepage Percolation Trough (WETMEC 14). Samples from some marginal locations (such as Thelnetham West Fen) are transitional to WETMEC 13 and in some sites (such as Blo' Norton Fen, Cors Geirch), some samples from small turf ponds within WETMEC 9 clustered into the 'embedded' form of WETMEC 13, sub-type 13a. The stratigraphical data available from such sites as Blo' Norton and Thelnetham Fens and from Redgrave and Lopham Fens suggests that these systems may have supported seepage percolation surfaces for much of their developmental history. Indeed, the name 'Waveney' is thought to be a derivative from Old English that means 'quaking fen river' (Ekwall, 1960). The disappearance of such former surfaces may have been relatively recent, in response (in the first instance) to improved river drainage. Although direct documentary evidence has not been found, recorded comments on the state of Redgrave and Lopham fens in the mid-nineteenth century suggest that the site had already been partly drained by then, with locally wet conditions maintained by extensive turbary. The peat removal, accompanied by oxidation and decomposition of the upper peats caused by low water tables, makes it difficult to assess the final natural state of this wetland. It seems likely that peat has been taken from much, if not all, of the surface. Bellamy and Rose (1961) point out "*that even the sandy islands show signs of peat cutting, proving that the peat deposits of the past and thus the fen water table must at one time have stood much higher than at present*".

Restoration of examples of WETMEC 9 back to WETMEC 13 (or 14) is likely to be difficult. Changes in soil structure due to drainage (compaction, loss of macropores and storage capacity, increase in bulk density and decrease in hydraulic conductivity) may constrain any attempts to restore them to their former state (see Schrautzer, Asshoff and Müller, 1996). Additional hydrochemical constraints upon restoration of this type of wetland have been reported to be the development of acidic conditions and potassium deficiency in the peats during the drainage phase (see van Duren, Boeye and Grootjans, 1997), often associated with substantial nutrient release upon rewetting. Drained percolating fens are widespread and extensive in parts of Germany and have been the subject of several recent ambitious restoration projects. There is a general perception that the groundwater percolation components of these systems cannot be readily restored, because of irreversible hydrophysical changes in soil structure (Wichtmann and Koppisch, 1998), and rewetting has focussed on surface water supply. However, experience at Cors Geirch, where successful restoration was achieved by flooding the surface with groundwater outflow (Colley and Jones, 2004), casts doubt on this view, though this project benefited from a copious groundwater supply, which largely feeds into the restoration area as surface water.

In other circumstances, restoration appears to be much more difficult. Various workers have shown that normal dyke spacings are inadequate for effective rewetting of peats by subirrigation. Hennings and Blankenburg (1994) concluded that dyke spacings of less than 10 m were needed for rewetting, whilst Scholz, Pöplau and Warncke (1995) found that mole drains connected to the dykes could provide an effective – if expensive – rewetting solution. However, these workers concluded that flooding, or surface flow from ditches on gently sloping sites, provided the most cost-effective rewetting. Shallow flooding is often seen as the best solution for recreating wet fen on these surfaces (Dietrich, Dannowski and Quast, 1998), not least because it provides both effective distribution of water across the peatland and a restoration environment that is substantially independent of the hydrophysical characteristics of the underlying drained soils.

As nutrient-rich river water is usually the main viable source of summer water supply in restoration initiatives, the main emphasis on fen restoration has been the generation of floodplain reedswamp and fertile wet grassland (Gensior *et al.*, 1998; Koppitz *et al.*, 1998) rather than mesotrophic fen. However, given evidence that surface water percolation systems (WETMEC 6) sourced by eutrophic river water can, in appropriate circumstances, support mesotrophic fen vegetation, probably because nutrients are stripped by passage through the intervening vegetation and peat (Koerselman *et al.*, 1990), the possibility of recreating this habitat upon a river-fed floodplain cannot be discounted, though to be successful may demand reduction of the nutrient status of the wetland surface (by repeated cropping or soil stripping) prior to rewetting.

6.12.13 Conservation value

The surfaces of this WETMEC are often summer-dry and sometimes of fairly limited conservational interest. Some scarcely support wetland and others have rather dry and sometimes rank vegetation (*Juncus subnodulosus–Cirsium palustre* fen meadow (M22), *Phragmites australis–Eupatorium cannabinum* tall-herb fen (S25), *Phragmites australis–Urtica dioica* fen (S26)). Drier surfaces in base-rich/sub-neutral, oligotrophic/mesotrophic sites may support *Molinia caerulea–Cirsium dissectum* fen meadow (M24) (and related vegetation types) (sometimes forming a SAC feature, see Tables 3.3 and 6.4).

Wettest conditions are generally associated with WETMEC sub-type 9a. In some wetter, base-rich locations (such as Poplar Farm Meadows) this unit can support a range of *Caricion davallianae* species and such examples can come close to impoverished versions of *Schoeno-Juncetum* (M13). In situations where small peat pits are embedded within the WETMEC, these can support vegetation with affinities to *Carex rostrata–Calliergon cuspidatum/giganteum* mire (M9), and can sometimes contain aquatic plants (*Chara* spp., *Utricularia* spp.).

The percentage occurrence in NVC communities of samples of WETMEC 9 is: M24: (21%); M22: (17%); S25: (13%); CM: (8%); M25: (8%); S04: (8%); S24: (8%); M9-2: (6%); S26: (4%); M9-3: (2%). [CM: *Cladio-Molinietum*, Wheeler, 1980a]. The preponderance of M24 probably reflects a bias in sampling towards more base-rich sites. If more base-poor samples had been included, it is likely that M25 would have been proportionately more represented.

Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 9 is given in Table 6.3.

A total of 109 wetland species have been recorded from samples of WETMEC 9. These include 21 nationally uncommon plant species: *Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Cladium mariscus, Dactylorhiza praetermissa, Epipactis palustris, Moerckia hibernica, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Philonotis calcarea, Plagiomnium elatum, Ranunculus lingua, Rhizomnium pseudopunctatum, Stellaria palustris, Thalictrum flavum, and Thelypteris palustris.* Most of these were recorded from only a very small number of sites, mostly from dry versions of *Carex diandra–Calliergon* mire (M9-2) and *Phragmites australis–Peucedanum palustre* tall herb fen (S24). *Liparis loeselii* formerly occurred in an example of this WETMEC at Thelnetham West Fen and, possibly, at Mown Fen, East Ruston Common.

6.12.14 Vulnerability

WETMEC 9 includes sites that have already been partly drained. The water table within them can potentially be strongly influenced by deepening of adjoining watercourses and by groundwater abstraction; some may be susceptible to a further reduction in water levels. The sparsity or absence of basal aquitard layers may make examples of this WETMEC more sensitive to drainage and abstraction than some examples of WETMEC 8. The reduction in or loss of M13/M9 habitat in the fens at the headwaters of the rivers Waveney and Little Ouse in East Anglia since the end of the 1950s, when they were examined by Bellamy and Rose (1961), has been dramatic, and may constitute the most catastrophic damage to the calcareous fen resource of England and Wales in recent times. Nonetheless, it is difficult to be certain about the primary causes of this. Harding (1993) showed that a water supply borehole had a significant impact upon the water table in the Redgrave and Lopham Fens, but deepening of the rivers Waveney and Little Ouse may have made the main contribution to reduction in the water table of fens further down the valleys (such as Thelnetham Fens, Roydon Fen).

A distinction can be made between sites where the established vegetation (such as M24) is compatible with fairly low water tables and those (such as Poplar Farm Meadows) which support some species associated with higher water tables and which may be particularly vulnerable to further water table reduction. Surface acidification and associated species loss could also be a potential problem in some sites, but this has been encountered less often in WETMEC 9 than WETMEC 8.

Examples of WETMEC 9 can become rank and colonised by trees when unmanaged. In the case of oligotrophic and mesotrophic examples (with M24 or M25), this can result in loss of many of the characteristic species, though in such cases the dereliction process can be relatively slow.

6.13 WETMEC 10: Permanent Seepage Slopes

6.13.1 Outline

Permanently wet, often small, areas of mire fed by springs and seepages, mostly on sloping ground. Schematic sections are provided in Figure 6.31.

6.13.2 Occurrence

Example sites: Badley Moor, Barnham Broom Fen, Beeston Bog, Bicton Common, Booton Common, Boundway Hill, Buxton Heath, Clack Fen, Cors Bodeilio, Cors Nantisaf, Cothill Fen, Crosby Gill, Drayton Parslow Fen, Fort Bog, Great Close Mire, Greendale Flushes, Gritnam Bog, Hense Moor, Holmhill Bog, Holt Lowes, Landford Bog, Lords Oak, Matley Bog, Nantisaf, Nash Fen, Pont y Spig, Roydon Common, Scarning and Potters Fen, Shortheath Common, Southrepps Common, Stoney Cross, Stoney Moors, Sunbiggin Tarn and Moors, Sutton Heath and Bog, Syresham Marshy Meadows, Warwick Slade Bog, Weston Fen, Whitwell Common, Wilverley Bog

Permanent Seepage Slopes are widespread in lowland England and Wales. The distribution of examples in sites sampled is shown in Figure 6.30.

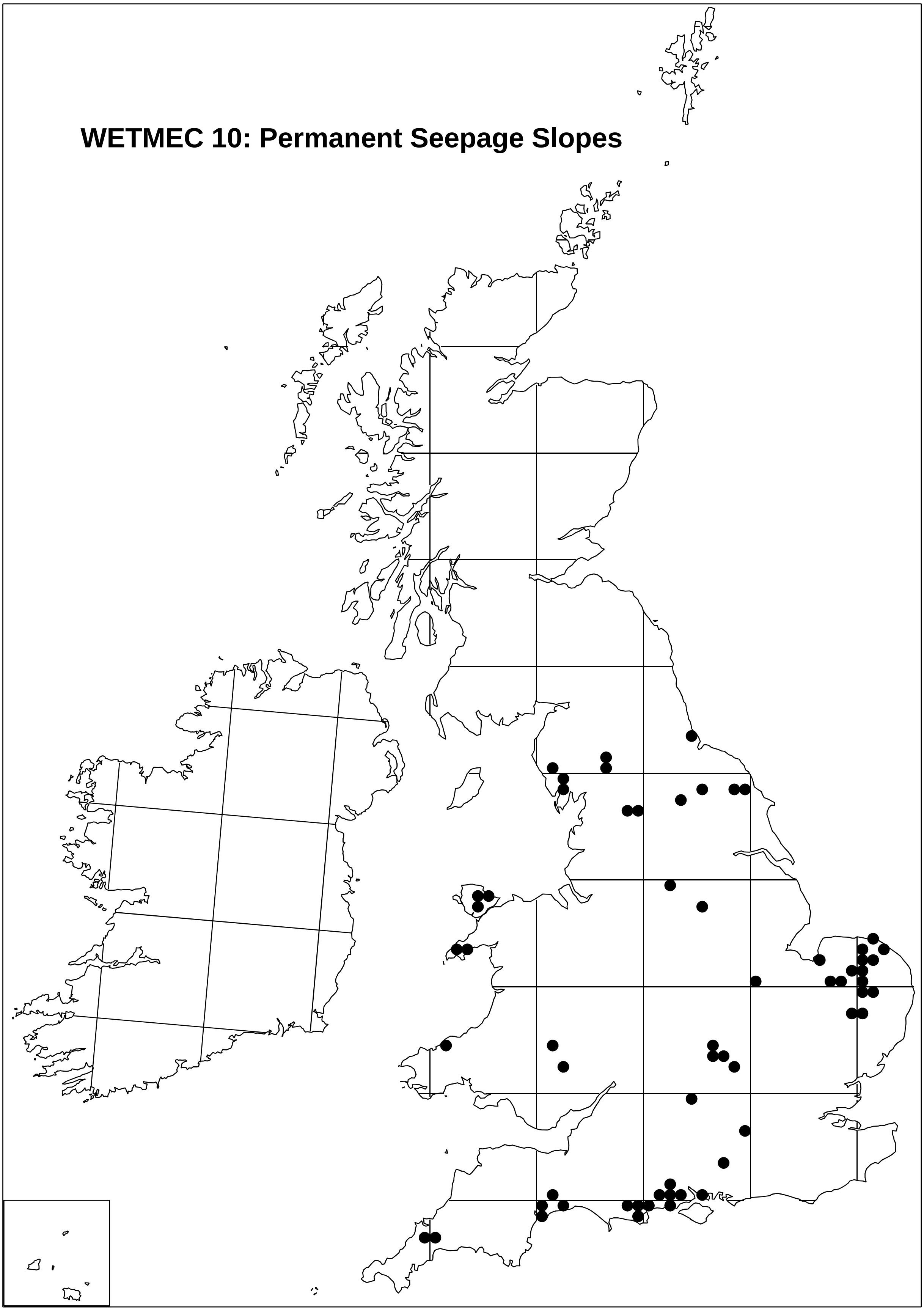


Figure 6.30 Distribution of examples of WETMEC 10 in sites sampled in England and Wales

6.13.3 Summary characteristics

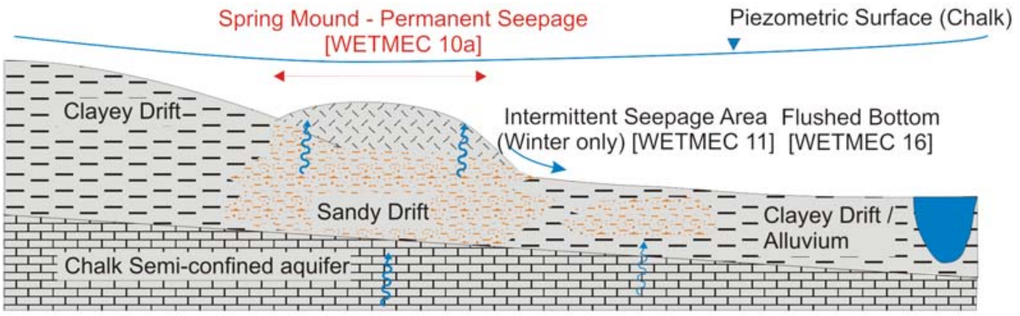
Situation	Mainly valleyheads (a few hillslopes, and sloping margins of floodplains and basins).
Size	Typically very small (< 1 ha, sometimes < 0.01 ha).
Location	Widespread in lowland England and Wales.
Surface relief	Usually sloping. Sometimes form small spring mounds. May have channels and hollows formed by spring flow.
Hydrotopography	Soligenous.
Water: ***supply***	Groundwater (from semi-confined or unconfined bedrock or drift aquifers), issuing in springs and seepages.
regime	Consistently high water tables (just sub-surface), with water usually visible or oozing under foot, often coupled with considerable flow.
distribution	Upward or lateral flow through substratum, surface flow in runnels.
superficial	Sometimes have small, shallow pools; runnels are frequent.
Substratum	Mineral-enriched peat or thin, strongly organic mineral soils, often with sand, silt, marl or tufa. Basal substratum usually sand and gravel.
peat depth	If present, usually < 50 cm.
peat humification	Often strongly decomposed and humified except in some *Sphagnum*-dominated, base-poor examples.
peat composition	Sometimes too decomposed to identify many macrofossils, but examples can contain much hypnoid moss peat, sedge peat and brushwood peat, with *Sphagnum* peat in some base-poor examples.
permeability	Soils of variable permeability. Basal substratum normally apparently permeable.
Ecological types	Range from base-rich to base-poor, eutrophic to oligotrophic, depending mainly on groundwater source, but in some instances influenced by underlying substratum.
Associated WETMECs	Most often found with Intermittent and Part-Drained Seepages (WETMEC 11), occasionally adjoining Seepage Percolation Basins (WETMEC 13). WETMECs frequently found downslope include WETMECs 8, 9, 14, 15 and 16. Less often on slopes above or adjoining WETMECs 5, 6 and 7.
Natural status	Many examples have been partly disturbed (peat removal, part drainage) but water supply mechanism is essentially natural.
Use	Examples usually have no usage or are grazed; a few are mown (for conservation). Some examples (including oligotrophic types) are closely associated with intensive agriculture on adjoining land. Can be difficult to drain effectively, but some examples have been converted into farmland.
Conservation value	Oligotrophic examples, base-rich to base poor, generally support vegetation types of high value and are included in a number of SAC sites.

Vulnerability	Main threats include: dereliction; reduction of groundwater level through drainage or groundwater abstraction; agricultural enrichment.

WETMEC 10: PERMANENT SEEPAGE SLOPES
[see also WETMEC 11]

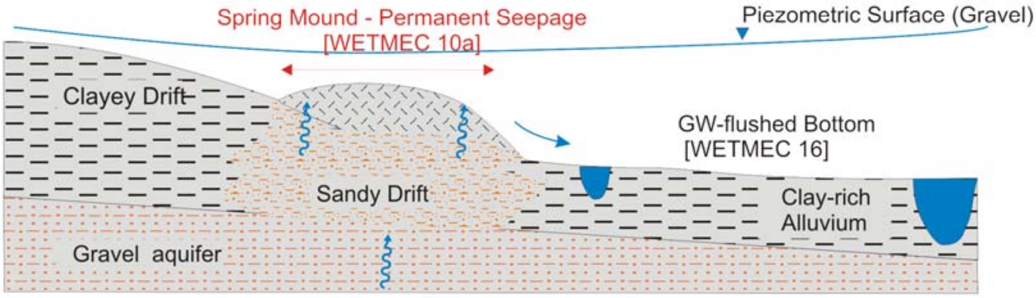
WETMEC 10a: Localised strong seepages
Semi-confined, artesian, e.g. Badley Moor

- strong upflow associated with formation of a (tufa-based) spring mound
- outflow trickles downslope across a low permeability deposit (sometimes percolating through a shallow peat 'aquifer')
- valley floor may contain lenses of more permeable material, which support intermittent groundwater upflow



WETMEC 10a: Localised strong seepages
Semi-confined, artesian Drift minor aquifer, e.g. Clack Fen, Drayton Parslow Fen

- strong upflow associated with formation of a spring mound (inwashed silt and sand)
- outflow trickles downslope across a low permeability deposit (sometimes percolating through a shallow peat 'aquifer')
- interceptor drain often dug along base of seepage to help create a 'dry' valley bottom



WETMEC 10a: Localised strong seepages
Strong gravitational outflow, *e.g.* Sutton Fen

- strong outflow associated with flow paths in aquifer
- outflow trickles downslope across a low permeability deposit (sometimes percolating through a shallow peat 'aquifer')
- interceptor drain may be dug along base of seepage to help create a 'dry' valley bottom

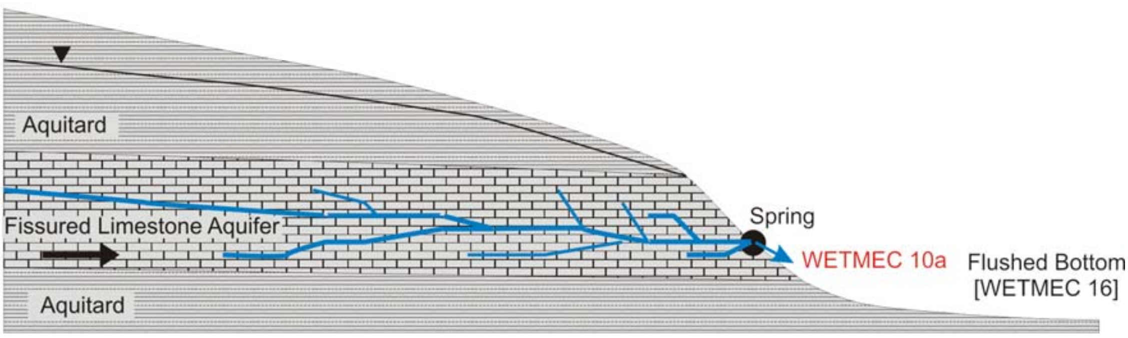
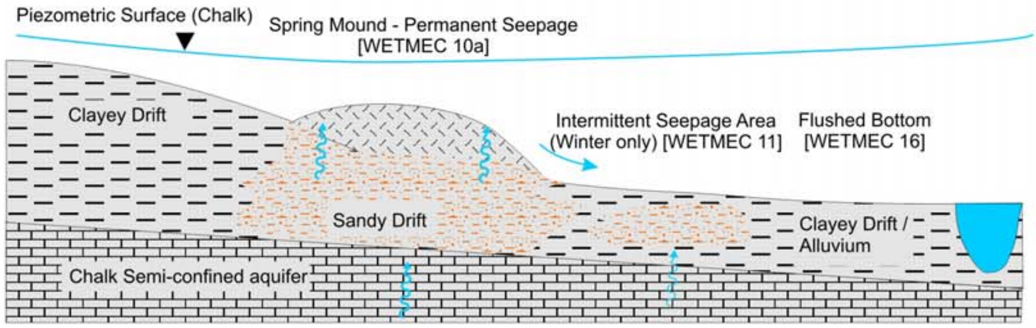


Figure 6.31 Schematic sections of types of Permanent Seepage Slopes (WETMEC 10)

WETMEC 10: PERMANENT SEEPAGE SLOPES
[see also WETMEC 11]

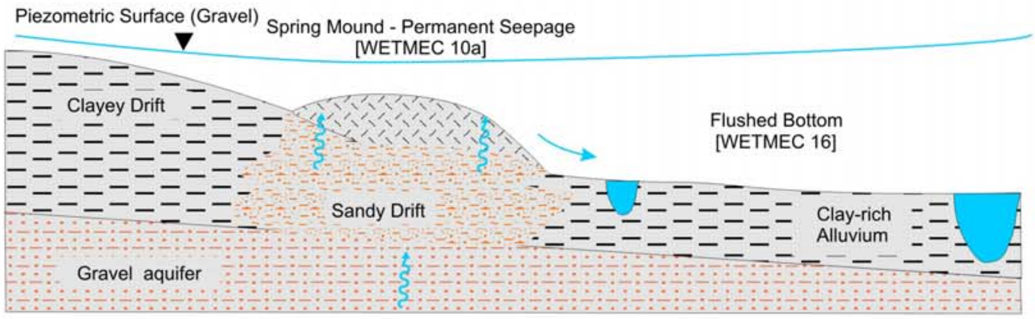
WETMEC 10a: Strong Spring Discharges and Seepages (semi-confined, artesian)
(*e.g.* Badley Moor)

- strong upflow associated with formation of a (tufa-based) spring mound
- outflow trickles downslope across a low permeability deposit (sometimes percolating through a shallow peat 'aquifer')
- valley floor may contain lenses of more permeable material, which support intermittent groundwater upflow



WETMEC 10a: Strong Spring Discharges and Seepages (semi-confined, artesian Drift minor aquifer)
(*e.g.* Clack Fen, Drayton Parslow Fen)

- strong upflow associated with formation of a spring mound (inwashed silt and sand)
- outflow trickles downslope across a low permeability deposit (sometimes percolating through a shallow peat 'aquifer')
- interceptor drain often dug along base of seepage to help create a 'dry' valley bottom



WETMEC 10a: Strong Spring Discharges and Seepages (strong gravitational outflow)
(*e.g.* Sutton Fen)

- strong outflow associated with flow paths in auqifer
- outflow trickles downslope across a low permeability deposit (sometimes percolating through a shallow peat 'aquifer')
- interceptor drain may be dug along base of seepage to help create a 'dry' valley bottom

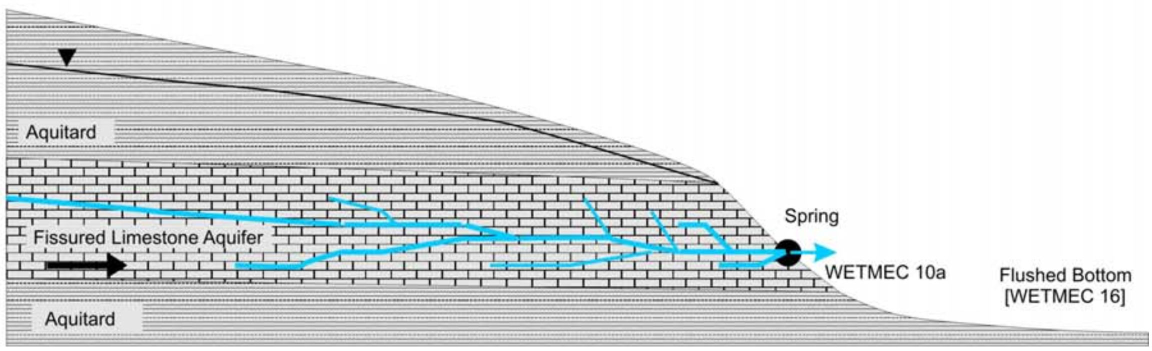


Figure 6.31 (cont.) Schematic sections of types of Permanent Seepage Slopes (WETMEC 10)

WETMEC 10: PERMANENT SEEPAGE SLOPES

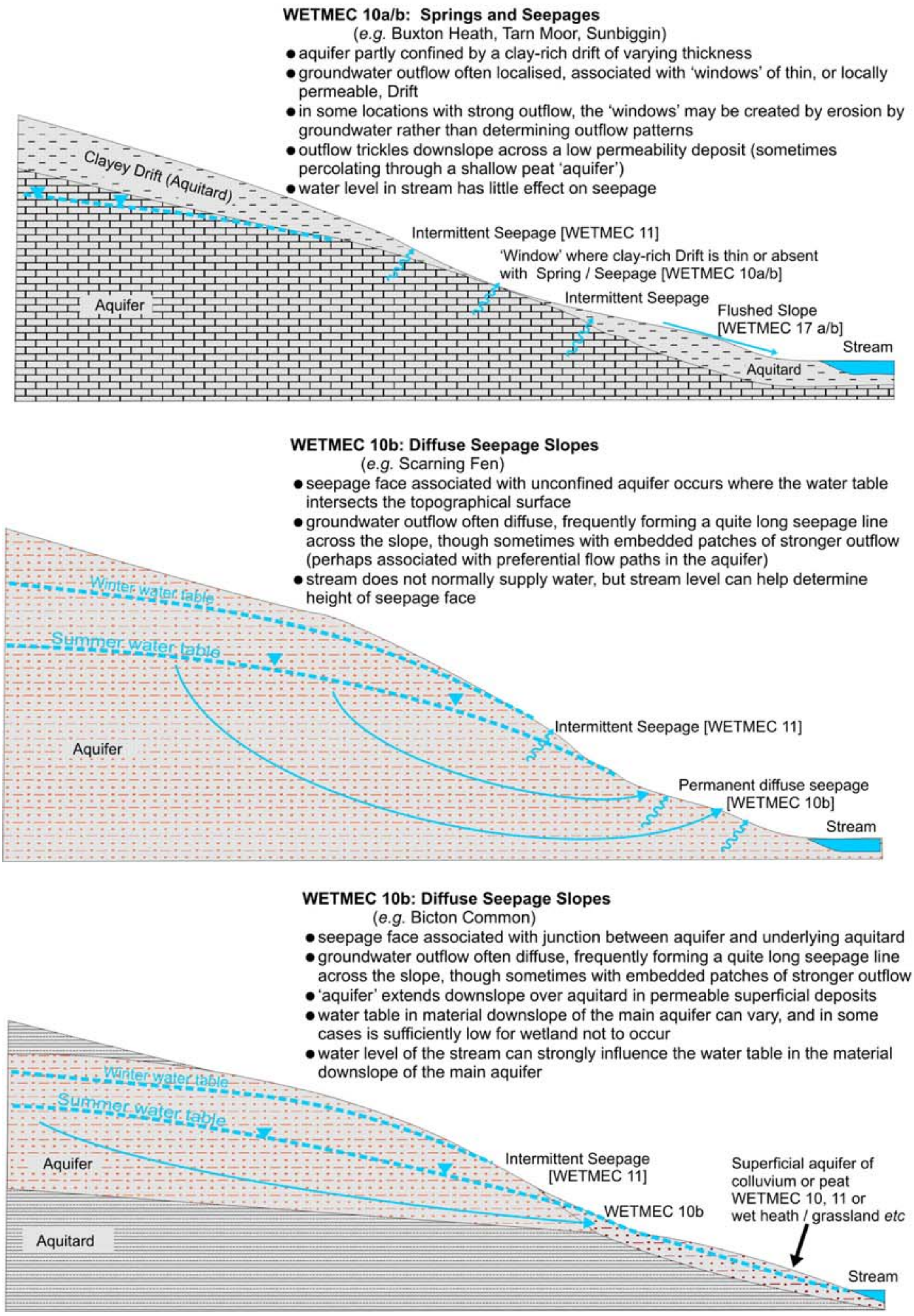


Figure 6.31 (cont.) Schematic sections of types of Permanent Seepage Slopes (WETMEC 10)

6.13.4 Concept and description

CLUSTERS: 17, 18

WETMEC 10 encompasses a range of groundwater-fed samples with a permanently high water table. It relates primarily to groundwater outflows (seepage faces or springs) on obviously sloping terrain, though examples occasionally occupy more or less flat surfaces. Different situations in which this wetland type occurs are shown in Figure 6.31. Examples are often small, sometimes tiny, formed in localised seepages, but some are more extensive and occupy larger areas of valleyheads, especially along the bottoms of gentle slopes. Permanent seepage faces rarely, if ever, constitute an entire wetland site – there are nearly always associated areas of intermittent and part-drained seepage (WETMEC 11) – but they are sometimes the dominant component of some (usually small) sites.

Permanent seepages occur in a variety of topographical contexts, wherever circumstances provide a more or less continuous outflow of groundwater. They are sometimes associated with strong springs, but many strong springs have little or no associated mire development: this may be due to topographical constraints (for example, the springs and outflow streams are in small hollows with little scope for peripheral mire development), or because groundwater outflow is very localised to the spring area (without peripheral seepages). In some instances, improved drainage (natural or artificial) has led to the loss of permanent seepages around some springs and spring streams. The Moors at Bishops Waltham (Hants) has some strong Chalk springs, but no real examples of WETMEC 10, though a quite extensive peat surface occurs mostly above the level of the current groundwater table, suggesting the possibility of some former seepage areas (see WETMEC 17c: Distributed Groundwater-Flushed Slopes).

One of the most widespread contexts in which this WETMEC 10 occurs is as a band along the lower slopes of valleyhead systems, often forming an elongated zone below intermittent seepages higher up the slope, and bordered on the downside either by an axial stream or a soakway/water track (WETMECs 15 or 19) (such as Scarning Fen). This can form part of a distinctive valleyside zonation (Rose, 1953). Not infrequently, seepages along lower valley slopes feed valley bottom mires referable to WETMECs 14 and 16. Occasionally, WETMEC 10 itself occupies quite extensive surfaces on 'flat' valley bottoms (such as Beeston Bog) and unless poached by livestock, some sites are prone to the formation of elevated peaty platforms by the coalescence of tussocks of species such as *Schoenus nigricans* and *Molinia caerulea*, as well as by the accrual of organic debris in the interstices between tussocks. In such circumstances, permanently wet conditions can become restricted to small hollows and runnels, with some or much of the surface becoming elevated and relatively dry (and sometimes rather acidic, even in calcareous sites) through natural seral processes.

WETMEC 10 can also occur as discrete seepage units on valley slopes, rather than as part of a clear valleyside zonation. Large examples of such units are mainly associated with more gentle slopes, but can sometimes occupy quite steep slopes (such as Pont-y-Spig, see Box 6.20). Their surface is sometimes rather uniform, but more often it is dissected by a series of small runnels, sometimes streams, running downslope, often to converge at a single outflow. Small, sloping units of WETMEC 10 are widespread. In many instances they occur as small, wet areas embedded within a drier context (often WETMEC 11). They may occur as isolated units, or form a discontinuous band associated with a seepage line.

The precise topographical context of permanent seepages depends upon the local situation. Examples of WETMEC 10 sometimes occupy marshy bluffs: relatively steep, short slopes, probably created in at least some cases by the seepage-lubricated slippage of material downslope. In some cases the seepage occupies some, or all, of the oversteepened slope; in others it occupies permanently wet conditions at and below the foot of the bluff, perhaps forming a marshy strip between the outflow and an axial stream (though some apparent seepage surfaces in this situation belong to WETMEC 17 (Groundwater-Flushed Slopes) rather than WETMEC 10). In some cases, especially but not exclusively on steeper slopes, the seepage unit may occupy a shallow hollow within the hillside, partly surrounded by drier oversteepened slopes, eaten back by seepage-induced slumping of material. The slumped debris may sometimes partly accumulate within the seepage area, creating a slightly convex underlying surface of mineral material; where this is not the case, the surface is more usually planar or concave. In some locations seepages are associated with distinct seepage steps, apparently created by slumping, which can form elongate terraces more or less along the valley contour (Box 6.22), though active seepage does not necessarily now occur along the length of these.

Box 6.20: Slumping hollow at Pont-y-Spig (Monmouth)

A particularly large and well-developed example of a slumping hollow occurs at Pont-y-Spig. Here, a quite large area of soligenous mire occupies a broad, shallow, elongate spring-fed hollow cut back into a steeply sloping hillside. Part of the hollow is developed below a dry, strikingly oversteepened curving bank which forms an amphitheatre-like upper edge to the mire, and appears to have been created by slippage of material down the water-lubricated slope. Below this the debris slope consists of several irregular, bulging steps downslope, which form a mix of relatively dry consolidated surfaces connected by soakways and seepages. Near the bottom of the main open flushed area, there is a further shorter linear seepage bank along some of the bottom of the hillslope. This forms a very distinct step, which is superficially similar to some of the seepage steps in the New Forest described by Tuckfield (1973) (see Box 6.22). It occurs below a dry oversteepened bank, and has a more or less flat top which is mostly wet, and an extremely steep but short (around two to three metres deep) front slope, which is rather dry except where runnels spill down it from the top to the valley floor.

A distinctive feature of some active seepages is the occurrence of ‘spring mounds’, usually small domed structures within a seepage (Box 6.21). They can normally be distinguished from convex slumped surfaces by their wetness and localised character.

Box 6.21: Spring mounds

Spring mounds are a morphological feature associated with some examples of WETMEC 10, but little is known about their development. Some small examples appear to consist of little more than a vegetation mat over a muddy matrix which bulges upwards, apparently because of the pressure of groundwater upflow, and these can collapse in drought conditions. However, many are stabilised by silts and sand or by concretions of calcite (tufa).

Tufa mounds are formed from strong concretions of calcite, with a variable (and sometimes layered) component of organic material. It is often possible to walk safely across the mounds, but their centre is sometimes little more than a slurry of water and marl. In some examples water discharges from the top of the tufa mound, but in others the top is relatively dry and water outflows lower down, either as a diffuse discharge or from a secondary opening. Most tufa mounds are rather small, but some can consist of more than two metres depth of tufa and can be quite extensive laterally, sometimes grading out into shallower deposits of calcite intercalated with peat. It is presumed that the spatially varying character of these relates to changes in outflow patterns, perhaps created endotelmically by the accretion of calcite, but little study has been made of these systems. The largest examples of tufa mounds encountered were at Badley Moor (Norfolk), associated with groundwater upflow from an artesian Chalk aquifer, through a ‘window’ of transmissive material within a thick (> 20 m) layer of otherwise low-permeability Drift (Lowestoft Till) (Collins, 1988; Gilvear *et al.*, 1989; Gilvear *et al.*, 1994). The artesian head at Badley is reported to be in excess of 4 m agl, but the top of the large tufa mounds are now fairly dry. Smaller, but more numerous and more active tufa mounds occur at Nantisaf (Ynys Môn) and Tarn Moor, Sunbiggin (Cumbria), in examples of WETMEC 10 fed from a Carboniferous Limestone aquifer. The cause of the precise localisation of the tufa mounds at these sites is not known, but is presumed to relate to the specific properties of groundwater outflow from certain fractures in the Limestone. Some tufa mounds are now rather dry. This is evident with some small, discrete examples at Whitwell Common (Norfolk), but also in sites such as Bunwell Common, Aslacton (Norfolk), where a broad tufaceous deposit on the hillslope probably marks the site of a former active seepage discharge.

Spring mounds formed from silts and sands are considerably more widespread than tufa mounds. They are often proportionately broader and shallower than tufa mounds. It is presumed that they are formed from mineral material inwashed into the mound entrained within the groundwater outflow, rather like a vertical delta, but again almost nothing is known about the development of such structures.

Affinities and recognition

This category is composed of Clustan clusters 17 and 18 (see Figure 6.1). Cluster 17 represents samples with quite strong, visible summer groundwater outflow (seepages and springs), and many are based around spring mounds. In some examples, the groundwater is known to be strongly artesian. Cluster 18 represents samples of what are probably weaker seepages. These are not necessarily less wet (in terms of position of the water table) but generally have less evidence of strong, or sometimes any, visible surface water flow.

There is considerable scope for variation in the definition of a ‘permanent’ seepage slope. Here. it is considered to be where the groundwater table is within about five cm of the surface year round, other than in exceptional drought conditions, so that during a normal summer water is visible on the surface or readily oozes underfoot.

Soligenous mires developed over a low-permeability base, irrigated by downslope flow of groundwater sourced from upslope springs and seepages, clustered into WETMEC 17 (Groundwater-Flushed Slopes) rather than WETMEC 20 (Percolation Basins). This partitioning by the multivariate analysis strongly reflects the character of the material immediately below the wetland deposit – samples with a basal substratum rich in sand and gravel have been clustered into WETMEC 10, those over silts and clays into WETMEC 17. However, in some circumstances, the basal material shows a patchwork of variation, and then it can sometimes be difficult – and often of limited benefit – to make a clear distinction between the two types.

The name 'Permanent Seepage Slopes' was chosen to help distinguish this WETMEC from groundwater seepages that occur in more topogenous contexts (such as WETMECs 13 and 14). Examples of WETMEC 10 are soligenous, with high water levels maintained by outflow of groundwater from a mineral aquifer, rather than by topographical constraints on drainage, and the majority are obviously sloping. However, a few examples of WETMEC 10 occur on visually flat surfaces, such as in soligenous pans. These can also have free groundwater outflow and can be distinguished from WETMEC 13 (Seepage Percolation Basins) by this and from WETMEC 14 (Seepage Percolation Troughs), usually, by their very thin peat.

The sub-types recognised for WETMEC 10 are somewhat different to those identified in Phase 1 (Wheeler and Shaw, 2000a). The Phase 1 clustering separated strongly artesian seepages from strong seepages that were not strongly artesian. However, this (important) split was possible only for sites in Eastern England, from which data on aquifer heads were available. This is not the case for most of the other regions considered here and aquifer head data were excluded from the analyses. In the present analysis, both artesian and non-artesian examples with strong spring flow from Eastern England have clustered together into sub-type 10a (Localised Strong Seepage). A further difference from the Phase 1 clustering is that samples from Eastern England that were clustered into the two sub-types of 'small seepage basins' and 'water tracks' have been allocated elsewhere (WETMECs 13 and 14 respectively).

6.13.5 Origins and development

Very little is known about the origin and ontogenesis of most WETMEC 10 sites, partly reflecting the frequent absence of significant accumulations of peat. This makes dating these wetlands difficult, and even where organic deposits remain, pollen grains and macrofossils are often much corroded in the strongly seepage-fed systems. Succow and Lange (1984) recognise a similar problem for dating spring mires in East Germany, though they suggest that for some of them peat accumulation did not really start until about 500 BC. The origin and persistence of the associated outflows is strongly related to long-term changes in the position of the water table in the source aquifer, and the variable controls upon this, but there may also be some endotelmic ontogenic controls. For example, in some instances where the seepages occur lateral to valley or basin bottoms with low-permeability wetland deposits (such as marl, dense peat), it seems likely that some soligenous wetlands may have developed somewhat upslope of the topogenous areas in response to a growing resistance to direct groundwater discharge into the basins (such as Great Cressingham Fen, Norfolk); however, this proposition is largely speculative and lacks good supporting evidence.

Some examples of WETMEC 10 (and WETMEC 17: Groundwater-Flushed Slopes) are associated with erosional features created by slumping on water-lubricated surfaces. Oversteepened banks and bluffs are found in many sites with seepages, especially in valleyhead locations with fairly steep topography, though they do not always (still) have active groundwater discharges. Such 'seepage steps' are particularly prominent in certain New Forest valleys (Box 6.22).

Box 6.22: Seepage steps in the New Forest

Seepage steps in the New Forest have been described in some detail by Tuckfield (1973). The seepage step itself consists of a steep, sometimes near-vertical, face which may or may not be vegetated. Tuckfield (1973) gives a mean height of 2.2 m for the faces examined, and a maximum height of six metres. Groundwater outflows from near or just below the base of this and appears to be the cause of slumping. Wedge-shaped chunks of material, some 0.5 m thick and four to six metres wide, are reported as sliding down from the face to accumulate at the base as a convex debris slope, and it is on this material, below the face, where the main area of wetland is usually developed. The character of the debris slope is determined by the lithological characteristics of the slumped material, and may contain varying and undulating deposits of sands, gravels and clays. Recently formed areas are often irregular, but there is a tendency for ridges of slumped material to become buried beneath a superficial layer of peat.

Seepage steps are widespread in parts of the New Forest. Some are relatively small, isolated structures, but others form long, narrow terraces along the valleysides, more or less along the contour, though they are not necessarily active along their entire length. The most active seepages tend to be near to the valleyhead, where they are close to the drainage stream, and mire often occupies the wet, unconsolidated ground between the face and the stream. Further down the valleys the seepage steps may be further separated from the stream, both vertically and horizontally. These are presumably older and are often less active – even where they are associated with groundwater outflow, the slope below them may be only locally waterlogged.

In some locations, seepage steps are closely associated with groundwater outflow at the junction between an aquifer and aquitard unit (Clarke and Allen, 1986). However, Tuckfield (1973) is at pains to point out that, whereas the occurrence of seepage steps shows a general relationship with lithological variations in the bedrock, this is by no means exact and the height of the groundwater table provides the more direct control. This distinction is particularly significant in the present context. Where the debris slope is composed mainly of permeable material, the outflows have generally been clustered into WETMEC 10, but where the deposit at or near the surface has low-permeability characteristics, the samples have been clustered into WETMEC 17.

6.13.6 Situation and surface relief

The majority (more than 75 per cent) of Permanent Seepage Slopes occur in valleyhead contexts. Some 13 per cent occur on hillslopes that are not part of a valleyhead system, and the remainder occur alongside topogenous wetlands, especially at the margins of floodplains but also on the slopes of some basins.

As the name suggests, the surface is usually sloping, sometimes forming small spring mounds, but can occasionally be more or less flat. The surface may be subdivided by channels and hollows formed by spring flow. Samples were taken from the full range of slope categories (Table 6.34).

Table 6.34 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 10

	Mean	1	2	3	4	5	6	7
Surface layer permeability	4.7		1	15	24	34	26	1
Lower layer permeability	4.4	1	3	15	37	24	16	4
Basal substratum permeability	5.0		5	13	11	39	37	
Slope	2.8	11	32	28	26	3	X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.13.7 Substratum

'Soils' associated with WETMEC 10 are typically thin and often skeletal. They are of variable permeability (Table 6.34), and may be composed variously of sand and gravel, with variable amounts of silt, sometimes clay, tufa and marl, with varying amounts of organic material (usually strongly humified). Some examples have shallow accumulations of peat, typically up to a maximum depth of about 50 cm, though a few deeper examples occur. The peat or other organic material is often quite humified, but this clearly does not provide an effective barrier to groundwater outflow. The basal substratum is also occasionally rich in silt or clay, but is predominantly formed from a more permeable material, usually sand and gravel, and the mean permeability ranking of the basal substratum of WETMEC 10 is the highest of all WETMECs. In some situations, where the substratum is composed of slumped or downwashed material, the basal substratum can be very heterogeneous, with local mixes of sands and clays.

Some surface substratum features associated with WETMEC 10 are described above (Box 6.20: Slumping hollow at Pont-y-Spig (Monmouth); Box 6.21: Spring mounds; Box 6.22: Seepage steps in the New Forest).

6.13.8 Water supply

Water supply to WETMEC 10 is essentially by groundwater outflow from a mineral aquifer. The WETMEC normally occurs downslope of the normal summer top level of a seepage face, or associated with an artesian supply where the aquifer head is substantially above ground level. The seepage may also receive some rain-generated run-off, but in many situations this makes little direct contribution to the summer water table, either because of infiltration into permeable surface deposits upslope of the mire, or because it is intercepted by a catchwater drain along the top end of the system. Virtually no data are available for land-drainage inflows, but there is no reason to suspect that run-off provides a significant water source for maintaining the fen water table in normal summer conditions. Some studies (such as Adams, Gilman and Williams, 1994) have indicated that certain WETMEC 10 mires (such as Scarning Fen, Norfolk) have quite large surface water catchments. However most, if not all, such surface water flows through the mires in streams and ditches, and almost certainly contributes little to the water supply of the seepages.

Some permanent seepages occur on hillslopes, considerably removed from any watercourses, but the majority occur in fairly close proximity (< 30 m distant) to streams and ditches. However, in most cases any proximate watercourses are well below the surface level of the seepages and there is little reason to suppose that they generally contribute much, if any, water to the WETMEC 10 surfaces. They may, however, help determine the water level in adjoining seepages, and deepening of the ditches can lead to drying of the seepages. In a few cases the base of some seepages, often as flattish areas alongside groundwater-fed streams, may be fed by surface flow from the stream (as miniature floodplains alongside a groundwater-fed stream) or there may be lateral recharge into flanking seepage peat deposits and water-table support, but there is generally little evidence for this in the WETMEC 10 samples considered (the one example where this process was clearly evident (Tarn Moor, Sunbiggin) was clustered into WETMEC 7). However, in some sloping sites with (usually winding) streams running downslope, it is possible that some lateral recharge from the stream in the upper part of the slope may help sustain the seepage lower down, but this appears to be more a feature of some WETMEC 17 (Groundwater-Flushed Slopes) flushes and, if it occurs in WETMEC 10 at all, is likely to be associated with sites with a strongly heterogeneous basal substratum.

Where the basal substratum is composed of a variable mix of clays and sands, the distribution of these deposits may determine the local pattern of groundwater outflow from the aquifer. In some circumstances, part of the seepage may effectively be fed by groundwater flow across low-permeability deposits and thus be analogous to the mechanism of WETMEC 17. However, any attempt to separate these mosaics into 'seepage outflow' and 'groundwater-flushed' elements is usually difficult and of little practical value, and the entire seepage system has normally been subsumed into WETMEC 10.

When considered together with WETMEC 11 (Intermittent and Part-Drained Seepages), there is a clear relationship between the character of the basal substratum and the mean summer water table (Table 6.35). There is some suggestion of a similar relationship within WETMEC 10 alone, but the trend is not as clear cut. A complication in examining this relationship is that some lower permeability substrata (sandy clays/silts) are associated with quite high summer water tables. This is almost certainly a consequence of local mixes of material, and the difficulty of making a sensible distinction between them, as noted above.

Table 6.35 Mean summer water table of samples of WETMECs 10 and 11, categorised by the nature of the substratum beneath the wetland deposit (basal substratum)

Basal substratum	Mean summer water table (cm)	
	WETMEC 10	WETMECs 10 + 11
Silt/clay loam	(none)	–13.5
Sandy clays/silts	–1.5	–11.4
Sandy clay/silt loam	–4.8	–7.6
Sandy loam	–2.0	–4.2
Sand/gravel/permeable bedrock	–1.2	–2.0

6.13.9 WETMEC sub-types

Persistent groundwater outflow, such as gives rise to examples of WETMEC 10, can occur in a variety of hydrogeological circumstances (Figure 6.31). Perhaps the most widespread situation is where groundwater outflow from an aquifer occurs at and above the junction with an underlying aquitard, often to produce a spring or seepage line along the base of the aquifer. However, WETMEC 10 surfaces often do not trace neatly the boundary between aquitard and aquifer units. In particular, some occupy locations well above the base of the aquifer, essentially where the groundwater table intersects with the topography of the landscape. This can occur particularly in the headwaters of some small valleys, where oversteepened slopes are associated with the stream channel.

The relationships between groundwater outflow from bedrock aquifer units and mire water conditions are frequently complicated, and sometimes largely obscured, by overlying superficial deposits, and these often determine the local pattern of outflow and of mire development. The most common situation is where surface layers of low-permeability Drift constrain groundwater outflow to 'windows' where the deposit is locally thin or of higher permeability. This can result in a patchwork of WETMEC 10 surfaces scattered across a valley slope. In other circumstances, the boundary between aquifer and aquitard bedrock units can be covered by a low-permeability alluvium, resulting in groundwater outflow at the top edge of this deposit rather than at the base of the aquifer. Downwashed colluvium can sometimes have a similar effect, but this depends critically on the character of the material. For example, permeable downwash (Head) deposits can form a superficial aquifer, in hydraulic connection with the main bedrock aquifer. The effect of this depends upon local circumstances, including particularly the permeability and thickness of the Head. In some cases (such as Bicton Common, Devon) it can extend the seepage downslope below the top of the aquitard unit, in which case it effectively represents a water supply mechanism transitional between WETMECs 10 and 17. In others, the water table in the downwashed material is often or always sub-surface, resulting in a zone of wet heath or wet grassland habitat downslope of the outflow. There may be a mix of these two extremes, with a zone of seepage outflow near the top of the Head deposit grading downslope into drier conditions, with increasing distance from the main groundwater source.

Although these outflow mechanisms are conceptually distinct, they have not been identified as discrete clusters within the multivariate analysis. Rather, two main WETMEC sub-types have been identified which correspond to two clusters at the 36-cluster level. There is a tendency for the different mechanisms identified in Figure 6.31 to be restricted, or preferential, to one or other of these two types.

WETMEC 10a: Localised Strong Seepage

CLUSTER: 17

> *Examples at:* Badley Moor, Barnham Broom Fen, Beeston Back Bog, Bicton Common, Bonemills Hollow (Hornstock Valley), Booton Common, Bryn Mwcog, Clack Fen, Cors Bodeilio, Cors Nantisaf, Drayton Parslow Fen, Foulden and Gooderstone Commons, Great Close Mire, Gritnam Bog, Holt Lowes, Landford Bog, Nantisaf, Nash Fen, Pont y Spig, Sheringham Bog, Stoney Moors, Sunbiggin Tarn and Moors, Sutton Heath and Bog, Syresham Marshy Meadows, Valley Farm Fen, Warwick Slade Bog, Weston Fen

Examples of WETMEC 10a are associated with particularly strong groundwater outflows from the mineral aquifer, often with visible surface flow of water on the seepage face. Many examples are marked by spring mounds, buoyed up by water pressure and stabilised by sands and silts and, in some cases, tufa. In many of these cases the groundwater is probably artesian, in some instances strongly so, with piezometric heads as much as two to four metres above ground level.

A number of strong spring discharges are associated with fissured layers in the bedrock. Figure 6.31b illustrates flow through a dipping Jurassic Limestone aquifer, sandwiched between aquitards (such as Sutton Bog, Shacklewell Hollow). In Chalk aquifers, such discharges appear to be particularly associated with strong lateral flow through fractured layers within the Chalk (such as Totternhoe Stone, Melbourne Rock); this is believed to be the basis for the strong spring supply to a number of sites (such as East Walton Common, Gooderstone Fen). Strong spring flow is also a feature of some small fens in the South Midlands, where outflow of water from sand and gravel deposits embedded within Till often results in the development of this type of wetland, where stream valleys have cut into aquifers (such as Clack Fen, Drayton Parslow Fen).

Well-developed tufa mounds are fairly scarce in fens in England and Wales, and probably mainly occur in contexts where there is strong artesian upflow of groundwater, or where there is strong outflow from fractures in fissured deposits. By contrast, non-tufaceous spring mounds are much more widespread. It is possible that many of these are also associated with artesian upflows, but data on piezometric heads are not available for many sites (see Box 6.21).

It is likely that in many cases, the strong outflow of groundwater helps to ensure that the WETMEC 10 surface is permanently wet, even in drought conditions. Figure 6.31a is loosely based on Badley Moor, where the spring mounds are particularly large and composed of calcite (tufa). In some cases the tops of the spring mounds are rather dry, but it is not known if this is a result of a reduction of groundwater head or because of the development of lateral leakage pathways within the mounds. Moreover, not all spring mounds are associated with permanently wet conditions. For example, in the dry summer of 2003 a spring mound at Bryn Mwcog had collapsed to a flat surface, and the water table was well below the surface. This suggests that some spring mounds are primarily a product of water pressure and are not always stabilised by mineral material.

All strong groundwater outflows are associated with free hydraulic connection with the aquifer, and this can often be illustrated by the nature of the underlying material. For example, along the drift-smeared Limestone margins of Cors Nantisaf, strong spring outflows appear to be located directly over patches of Limestone or a gravel-rich material, whilst adjoining locations smeared with a clay-rich Drift support only weak or intermittent seepages, or none at all. However, it is not clear to what extent natural variation in the Drift determines the location of the groundwater outflows, or whether strong outflows have removed a former constraining Drift cover. At Tarn Moor (Sunbiggin), Holdgate (1955) considered many of the strong seepages to be erosional features, where the Drift overburden had been removed locally by groundwater outflow.

Whereas strong springs and seepages are sometimes associated with a good development of soligenous mire, particularly powerful springs can be associated more with complexes of runnels, pools and water tracks, with fen confined to any seepages peripheral to these. Strong point discharges are sometimes more impoverished floristically than adjoining seepages with lesser flow, possibly due to scouring by rapid water outflows.

WETMEC 10b: Diffuse Seepage

CLUSTER: 18

> *Examples at*: Aylesbeare Common, Beetley and Hoe Meadows, Booton Common, Buxton Heath, Clayhill Bottom, Cors Bodeilio, Cors Erddreiniog, Cors Geirch, Cors Goch, Cors Hirdre, Cranes Moor (Hampshire), Folly Bog, Fort Bog, Greendale Flushes, Hense Moor, Holmhill Bog, Lords Oak, Matley Bog, Roydon Common, Scarning and Potters Fen, Shortheath Common, Southrepps Common, Stoney Cross, Stoney Moors, Swangey Fen, Weston Fen, Whitwell Common, Wilverley Bog

This is the most widespread and extensive form of permanent seepages, occuring particularly on permeable valleyhead slopes where there is gravitational outflow of groundwater where the water table intersects with the surface topography. In many cases the seepage is closely associated with an underlying aquitard, or with a low-permeability lining of the valley bottom (alluvium or colluvium). It can be associated both with unconfined and semi-confined aquifers. This type of seepage can be quite extensive laterally, more so than WETMEC 10a, but small localised discharges do occur, usually reflecting local variation in the underlying mineral ground. For example, at Buxton Heath (Norfolk) small, isolated, diffuse WETMEC 10 seepages occur locally on the valley slopes, embedded within an intermittent seepage zone (WETMEC 11) where there are less clay-rich ‘windows’ in the Drift. This sub-type is most readily distinguished from 10a by the absence of well-defined, strong spring heads and spring mounds (though there may be variation in the degree of flushing along the slope and in a few cases, small spring heads can be embedded within a slope that would otherwise be considered to be diffuse seepage). A zone of diffuse intermittent seepage often occurs above this sub-type, and the seepages may drain down into a water track (such as Roydon Common, Norfolk) (Figure 6.31c).

Some of the most extensive examples of WETMEC 10b occur along the sloping sides of many of the New Forest valley bogs. In many cases they appear to be associated with the junction between the relatively permeable Becton Sands and the less permeable underlying Chama Sands (rather than with the more deeply underlying Barton Clay as has sometimes been assumed). The lithology of some of the New Forest deposits can be quite complicated, and some valleys have more than one aquitard and associated seepage line. Such combinations are sometimes considered to form a distinctive, composite type of mire (see Allen, 2003), but the current analyses suggest they are more simply regarded as a vertically repeated series of diffuse seepages rather than as a separate, composite entity. In some New Forest (and other) sites, groundwater outflow from the main bedrock aquifer on the valley sites can percolate downslope over an aquitard unit through a downwash deposit of fairly permeable Head, which forms a subsidiary superficial aquifer. Where the water table is sufficiently near the surface, this process may effectively extend the seepage face well downslope below the main aquifer–aquitard boundary, but in many cases the downslope water table is lower, resulting in an intermittent seepage (WETMEC 11) downslope of WETMEC 10, or a non-mire habitat such as wet heath or wet grassland.

6.13.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 10 are summarised in Table 6.36. Consistently high water tables are a feature of this wetland type, but they are coupled with considerable water flow and this may help to explain the relatively high oxidation–reduction potentials that are often associated with this unit. For example, mean Eh of WETMEC 10 is almost 50 mV higher than the mean value for WETMEC 6 (229 mV), though both have rather similar mean summer water levels (–3.6 cm for WETMEC 6). Concentrations of reduced phytotoxins are often low in the rooting zone and, for example, S^- concentrations are often below detection limits (Sellars, 1991). This favourable growing environment may help to explain the large number of plant species associated with some examples of this wetland type and the frequent contribution of characteristic dryland species (such as *Briza media*) to the vegetation of wet seepage slopes.

Table 6.36 WETMEC 10: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	0.5	0.1	2.0
Summer water table (cm)	–1.9	–11.0	6.8
Rainfall (mm a^{-1})	807	558	1,831
PE (mm a^{-1})	595	462	646
Water pH	6.0	3.6	8.4
Soil pH	6.2	3.3	7.5
Conductivity (µS cm^{-1})	370	79	928
K_{corr} (µS cm^{-1})	365	31	928
HCO_3 (mg l^{-1})	155	0	455
$Fertility_{Phal}$ (mg)	8.2	3	26
Eh^{10} (mV)	273	38	490

See list of abbreviations in Appendix 1

Many Permanent Seepage Slopes support low productivity vegetation, reflecting both intrinsic nutrient deficiency in the irrigating water and low fertility substrata (such as sands and gravels) onto which the water discharges. The most base-rich examples (usually those associated with discharges from Chalk or Limestone aquifers) precipitate calcite, which appears to have some capacity to adsorb phosphorus and thereby regulate soil fertility and vegetation productivity (Boyer and Wheeler, 1989). This seems to provide a natural hydrochemical mechanism which helps to maintain a low fertility growing environment even in catchments with intensive agriculture. The water feeding some calcite-precipitating examples of WETMEC 10 can contain more than 30 mg l^{-1} nitrate-nitrogen, but vegetation productivity remains small because P concentrations are limitingly low (Boyer and Wheeler, 1989). However, where such controls on nutrient availability are absent, eutrophic conditions may occur.

Some permanent seepages, especially those sourced from Drift aquifers of sands and gravels, are highly ferrugineous, with much precipitated ochre. It might be expected that the abundance of ferric solids could also lead to co-precipitation of phosphorus and concomitantly small rates of productivity, but there is as yet little evidence that this process actually occurs (M. Boyer, unpublished data). This may be because ochre-precipitating seepages tend to be quite strongly reducing in the rooting zone. High concentrations of Fe appear to be toxic to a number of plant species, including some typical wetland taxa, and highly ferrugineous permanent seepages are usually species-poor. Ferrugineous seepages typically provide a mesotrophic habitat.

6.13.11 Ecological types

The distribution of samples of WETMEC 10 amongst the pH and fertility categories is shown in Table 6.37.

Table 6.37 Percentage distribution of samples of WETMEC 10 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	36	19	6
Sub-neutral	19	4	
Base-poor	16		
Acidic	1		

Oligotrophic, base-rich

The most base-rich examples are associated with strong discharges from Chalk and Limestone aquifers. Their low fertility may reflect (a) intrinsically small nutrient concentrations in the irrigating water; (b) calcite–P co-precipitation; and (c) a nutrient-poor substratum. In some sites the irrigating water is N-rich and the systems are essentially P-limited (see above).

Oligotrophic, sub-neutral

This interesting and important group is a particular feature of some samples from Norfolk and the New Forest. The Norfolk examples are mostly fed from Drift (such as Beeston Bog, Buxton Heath, Holt Lowes), but also include the lower parts of Roydon Common where water, apparently from the Sandringham Sands, is base-enriched (possibly through contact with a base-rich Drift). In the New Forest this type is particularly characteristic of some seepages proximate to the relatively base-rich Headon Beds, but this is not always the case (such as Stoney Cross). Other examples of this type have been recorded from Aylesbeare Common (Devon). A feature of all the preceding sites is that their vegetation contains a mixture of calcifuge and calcicole species, but in this regard they contrast with other examples of this same ecological category which, although fed with water of fairly low pH, do not support such calcifuge taxa as *Narthecium ossifragum* and *Rhynchospora alba.* A good example is provided by the seepage slope at Pont-y-Spig (Monmouth). The measured water pH of this site, which does not have calcifuge species, is 6.1; this is less than that from some samples from Stoney Moors (6.5) which have calcifuge taxa. The reason for this discrepancy is not known, but may reside in other hydrochemical properties of the sites. The low fertility is thought to reflect primarily the intrinsic properties of the water source and substratum. There is no evidence for P immobilisation mechanisms and the systems may be either P or N limited.

Oligotrophic, base-poor

This category includes acidic seepages derived mainly from the Lower Greensand, various Eocene deposits and from acidic Drift aquifers. It forms the dominant type of permanent seepage system in the New Forest. The low fertility is thought to reflect primarily the intrinsic properties of the water source and substratum. There is no evidence for P immobilisation mechanisms and the systems may be either P or N limited.

Mesotrophic/eutrophic base-rich

Most examples of this category are associated with discharge of water from calcareous Drifts, in some cases perhaps with a contribution from a Chalk or Limestone aquifer. However, they also include small, fertile seepages fed from the Chalk (such as Barnham Broom Fen). The higher fertilities seem to reflect (a) more nutrient-rich water input (which may sometimes be strongly influenced by agricultural fertilisation); and (b) more fertile substrata, frequently with a quite high silt or clay component. Some examples in South Midlands (such as Clack Fen, Drayton Parslow Fen) are fed from a perched Drift aquifer in glacial sands and gravels. They are (mostly mesotrophic) analogues of chalkwater-fed spring mounds and this probably represents their natural condition (there is no reason to suppose they were once oligotrophic and supported, say, M13 vegetation). At Clack Fen, there is evidence that seepages located below arable farmland are more nutrient-rich than those below pasture (Wheeler, 1983).

Many of the Drift-fed seepages are ferrugineous, some highly so. These latter tend to be rather species-poor and composed of species with high Fe tolerance.

Mesotrophic sub-neutral

The only representative of this category sampled was the Drift-fed permanent seepage areas at Beetley and Hoe Meadows (Norfolk). It is, however, probably quite widely distributed.

6.13.12 Natural status

The main defining feature of WETMEC 10, a more or less permanent groundwater outflow, is a natural feature of the landscape and no examples amongst the sites examined are known to be artificial in origin[1], though it is possible that in some sites removal of overlying peat layers (by turbary) has helped to expose, and emphasise, strong underlying discharges. The

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[1] Some permanent seepages are artificial in origin, for example having developed on the floor of limestone quarries dug down to the groundwater table (such as Dry Sandford Pit, Cothill, Oxon.).

antiquity of this habitat is not well known. Rose (1957) pointed to the occurrence of some late-glacial relict bryophytes in some East Anglian spring-fed fens, and this could reflect a long-term continuity of the seepages through the post-glacial period, with some low-productivity examples persisting more or less free from closed canopy tree cover. However, it is easier to invoke historical continuity as an explanation for species distributions than it is to demonstrate it, particularly in systems that have been subject to peat extraction (both because the necessary palaeobotanical archive has been removed and because it is patently clear that so-called 'relict' species may have a considerable capacity to survive substantial disturbance).

Some Permanent Seepage Slopes have been modified by attempted drainage and by past peat cutting, but in general WETMEC 10 must count as one of the least modified WETMECs as far as the water supply mechanism is concerned. Most of the more base-rich examples are likely to have been tree-covered, but it is suspected that some of the low-fertility examples may have been naturally open, except for very small sites where trees growing on the drier surroundings may have overtopped WETMEC 10. There is little evidence for spontaneous tree encroachment onto many of the base-poor examples of WETMEC 10, except where they have been damaged by drainage and so on, but it is often not clear to what extent this is a product of constraints on tree establishment imposed by the environmental characteristics of the habitat, or of persistent low-intensity grazing by livestock and wild grazing animals.

6.13.13 Conservation value

Almost all herbaceous, oligotrophic examples of Permanent Seepage Slopes, across all base-status categories, have high conservation value and form the basis for SAC habitats (such as "alkaline fens" and "calcareous fen", see Tables 3.3 and 6.4). M13 and M21 are the dominant communities respectively of base-rich and acidic oligotrophic examples, with M22 the main community of base-rich mesotrophic examples. Eutrophic examples were mainly occupied by S25 and S26, with some examples of S4. The examples of M9 included within this WETMEC are allocated to M9-1 (see Part 3), but they have poor affinities with this unit and are perhaps best regarded as M13/M9-1 transitional.

The percentage occurrence in NVC communities of samples of WETMEC 10 is: M13: (30%); M21: (24%); M22: (18%); M10: (9%); M14: (4%); M9-1: (2%); S26: (1%); M24: (1%); S25: (1%); M06: (0.5%); M15: (0.5%); M16: (0.5%); M17: (0.5%); M25: (0.5%); M29: (0.5%); S04: (0.5%). Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 10 is given in Table 6.3.

A total of 156 wetland species have been recorded from samples of WETMEC 10. Thirty-seven nationally uncommon plant species have been recorded: *Bartsia alpina, Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Cladium mariscus, Cladopodiella fluitans, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Drosera intermedia, Drosera longifolia, Epipactis palustris, Equisetum variegatum, Eriophorum latifolium, Hammarbya paludosa, Moerckia hibernica, Oenanthe lachenalii, Parentucellia viscosa, Peucedanum palustre, Philonotis calcarea, Pinguicula lusitanica, Plagiomnium elatum, Potamogeton coloratus, Preissia quadrata, Primula farinosa, Rhizomnium pseudopunctatum, Selaginella selaginoides, Sphagnum contortum, Sphagnum pulchrum, Sphagnum subsecundum, Sphagnum teres, Thalictrum flavum, Thelypteris palustris, Utricularia minor.*

Base-rich and sub-neutral oligotrophic seepages are particularly important in terms of the number of plant species recorded (Table 6.38).

Table 6.38 Number of wetland and uncommon wetland plant species recorded from WETMEC 10, allocated to pH and fertility categories

	Wetland species			Uncommon wetland species		
	Oligo-trophic	Meso-trophic	Eu-trophic	Oligo-trophic	Meso-trophic	Eu-trophic
Base-rich	117	91	44	28	16	1
Sub-neutral	101	66		16	6	
Base-poor	50			4		
Acidic	12					

In unmanaged situations, colonisation by woody plants can lead to development of some form of scrub and woodland, including alder wood in some (mainly mesotrophic) examples. This also constitutes a priority EC Habitats Directive interest feature but in the context of Permanent Seepage Slopes, particularly oligotrophic examples where the herbaceous communities are often considered to be important, any scrub colonisation, even by alder, is most often considered to have nuisance value.

6.13.14 Vulnerability

Whilst the consistently high water tables characteristic of Permanent Seepage Slopes might appear to make them particularly vulnerable to some form of drying-induced damage, many examples of WETMEC 10 have persisted even within intensively farmed landscapes. In East Anglia, many of the Permanent Seepage sites known to Victorian botanists still retain considerable conservational value (Wheeler, 1999b). The small size and difficulty of drainage of many of these systems has probably helped protect them from gross agricultural improvement, especially the oligotrophic examples associated with the low-fertility soils, many of which were designated as Poor's Land at Parliamentary enclosure (Wheeler, 1999b) (and which have received some protection from improvement because of this). Nonetheless, many sites which apparently once supported Permanent Seepage Slopes have been partly drained, though sometimes reducing the area of permanent seepage rather than removing it (such as Flordon Common, Norfolk). Deepening of adjoining streams and ditches is also thought to have contributed to the drying of some, perhaps many, former permanent seepages, though actual evidence for this is sparse and often anecdotal[1]. A few sites are thought to have been converted into agricultural land, but drainage initiatives seem mainly to have damaged the wildlife value of the seepages for rather little economic return.

Groundwater abstraction is widely thought to pose a threat to Permanent Seepage Slopes, though an actual impact has only been demonstrated in a few cases (for example, Harding, 1993) and there are obvious difficulties in distinguishing between natural variation in water tables, effects induced by abstraction, and other causes of drying. Deterioration in vegetation composition is not in itself a reliable indicator of lowered water tables as other processes, especially dereliction, can have comparable effects upon species composition (Wheeler, 1999b).

Enrichment of the irrigating groundwater by growth-limiting nutrients (NPK) is a potential threat to oligotrophic permanent seepages. There is some evidence that enrichment of certain base-rich examples may be mitigated by Ca–P co-precipitation and no examples of calcite-precipitating seepages that have become substantially enriched are known (though this could be due to lack of data). Analogous mechanisms do not appear to operate in less base-rich seepages, and these may be more susceptible to enrichment (although it is

[1] For example, W G Clarke suggests that at Flordon Common in 1924 there had been "a considerable alteration in the flora. The stream was then cleaned out and runs with a very rapid current and this seems to have drained a good deal of the standing water. The pools in which *Utricularia* and *Chara* once flourished have vanished and I was unable to find any *Drosera* on either common, though not prepared to assert that none is present". [WG Clarke, *annot. proofs Clarke (1910)*, *NNRO*, 1924]

sometimes invoked as a hydrochemical mechanism, there is little evidence for significant Fe–P co-precipitation in ferrugineous seepages). Drying of permanent seepages can lead to nutrient release, though again supporting evidence is sparse. The potential for drying-induced enrichment depends critically upon the nutrient capital of the soils. Some skeletal seepage slope soils contain only small reserves of nutrients and give rise to very limited nutrient release even when oven dried; by contrast, deeper peaty soils can be much more prone to nutrient release on drying (Eades, 1998).

Lack of management has probably been the main cause of 'damage' to some permanent seepages. Many of the plant species characteristic of oligotrophic seepage faces are shade-intolerant and tend to be eliminated by the development of a rank, herbaceous vegetation or closed canopy woodland (by contrast, many of the species found in mesotrophic or eutrophic seepages can tolerate considerable shading). However, some oligotrophic seepages, especially those irrigated by base-poor water, may be substantially self-maintaining. Tree colonisation is sometimes suspected of causing the drying of seepages, though there seems to be little factual evidence for this from measurements, nor for claims of "resumed seepage" consequent upon tree removal. There are plenty of examples of Permanent Seepage Slopes within fen woodland as well as in herbaceous fen, even though they have not been included in this project.

Some sites that now support permanent seepages have been subject to considerable past peat extraction (Wheeler, 1999b). It is possible that in some instances this may have helped create, or enhance, some WETMEC 10 surfaces by uncovering groundwater outflows. If so, ongoing peat accumulation may gradually reduce the impact of some discharges upon surface conditions.

Some examples of WETMEC 10 on slippage planes, mostly on quite steep slopes, may be naturally unstable. This can result in slumping of fresh mineral material onto existing areas of mire and in downslope slip of wedges of vegetated mire. This process helps to prevent the accumulation of a deep peat profile and in some cases, may help retard seral eutrophication and prevent significant establishment of woody species. However, it can also cause physical damage to some species populations. There is only limited evidence for this process in examples of WETMEC 10 sampled for this study. It is applicable to some locations in the New Forest, but most were clustered into WETMEC 17. The process has been observed in some locations that were not sampled for the present study, but which appear to be referable to WETMEC 10, such as the sea-cliff seepages at Blackhall Rocks (Co. Durham), where a population of the nationally rare *Pyrola rotundifolia* has been largely lost from at least one seepage because of natural slumping. Elsewhere, some former slippage slopes appear now to be fairly stable and parts of some of the 'best' examples are wooded (such as Pont y Spig, Monmouth).

6.14 WETMEC 11: Intermittent and Part-Drained Seepages

6.14.1 Outline

This category covers drier areas in groundwater-fed wetlands, mostly over shallow peat, which function either as intermittent seepages or which have permanently sub-surface, but high, water tables. Many examples are partly drained, and some may once have been permanent seepages. Most examples are sloping. If flat, they are often not obviously in topogenous valley bottoms or basins, but can occupy gently undulating terrain (such as Foulden Common). Schematic sections are provided in Figure 6.33.

6.14.2 Occurrence

> *Example sites*: Bonemills Hollow (Hornstock Valley), Booton Common, Bransbury Common, Bryn Mwcog, Bunwell Common (Aslacton Parish Land), Buxton Heath, Cors Hirdre, Cors y Farl, Dernford Fen, Drayton Parslow Fen, East Walton Common, Flordon Common, Folly Bog, Forncett Meadows, Foulden and Gooderstone Commons, Great Cressingham Fen, Greywell Fen, Holly Farm Meadow, Middle Harling Fen, Ormesby Common, Pashford Poors Fen, Pilch Fields, Scarning and Potters Fen, Sheringham and Beeston Regis Commons, Southrepps Common, Sutton Heath and Bog, Swannington Upgate Common, Thriplow Meadows, Thursley Common, Whitwell Common, Wilverley Bog

Numerically, this is a very important WETMEC category. Many of the largest examples and many of the samples in this project (Figure 6.32) occur in Eastern England, where in some cases they represent drier derivatives of once wetter stands. The smaller number of examples from other regions may partly reflect sampling constraints.

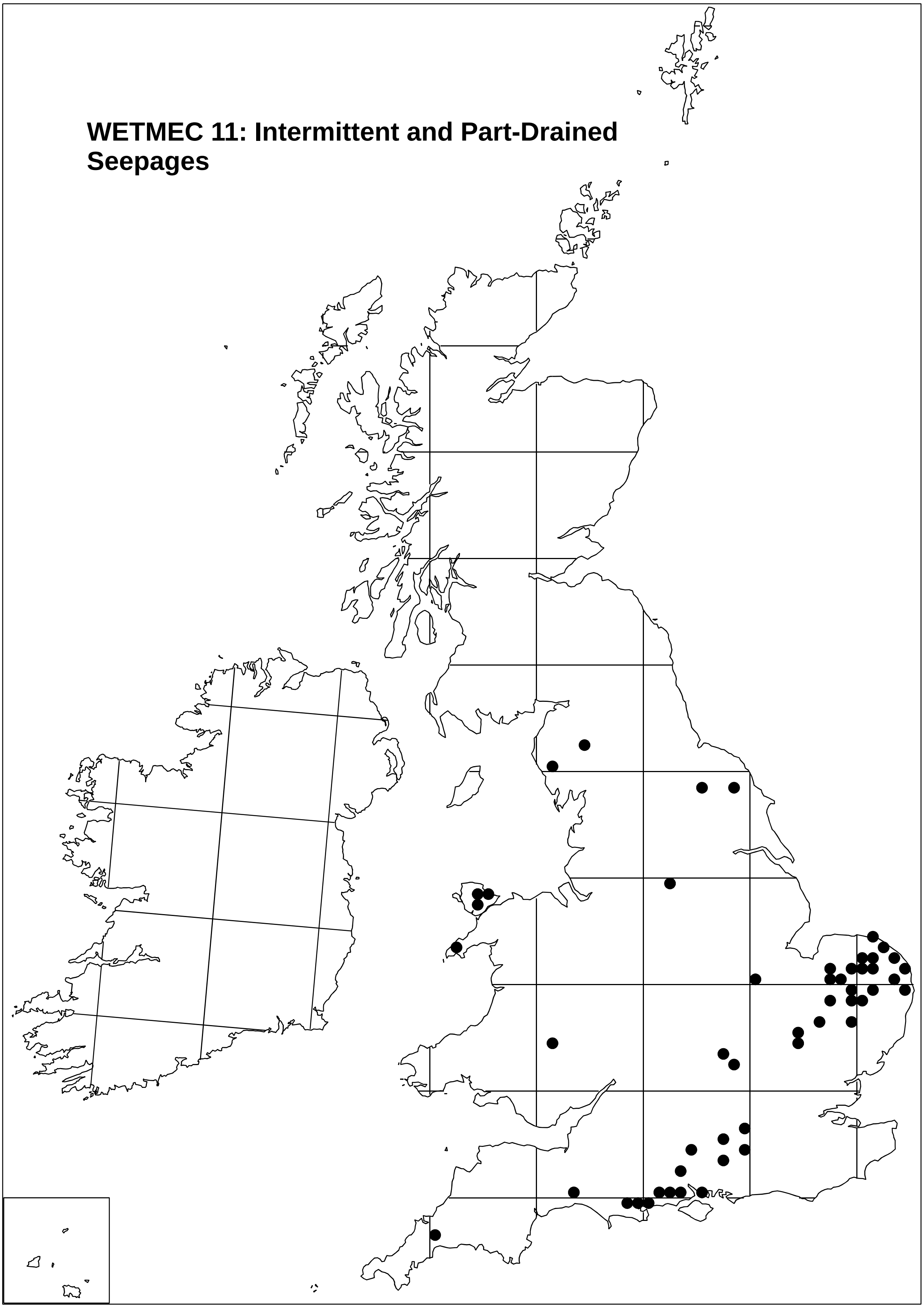


Figure 6.32 Distribution of examples of WETMEC 11 in sites sampled in England and Wales

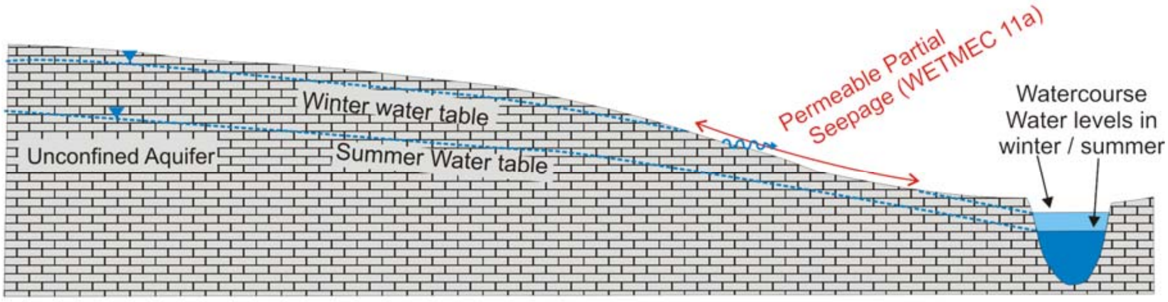
6.14.3 Summary characteristics

Situation	Mainly valleyheads (a few hillslopes), sometimes margins of floodplains or basins.
Size	Often small (< 1 ha), but some quite large examples occur.
Location	Widespread, but mostly sampled from Eastern and Southern England.
Surface relief	Most sloping, some more or less flat. Sometimes with channels and hollows formed by spring flow.
Hydrotopography	Soligenous.
Water: ***supply***	Groundwater (from semi-confined or unconfined bedrock or drift aquifers).
regime	Water table variable but well below surface in summer or year round.
distribution	Upward or lateral flow through substratum, sometimes flow in seasonal runnels.
superficial	Some examples have shallow temporary pools and seasonal runnels; some are crossed or bordered by water-filled drains or dykes.
Substratum	Mineral-enriched peat or thin, strongly organic mineral soils, often with sand, silt, marl or tufa. Basal substratum may be sand and gravel (with variable amounts of silt), sometimes clay, tufa and marl.
peat depth	If present, usually shallow (< 50 cm). Deeper examples are usually in part-drained locations (and transitional to other WETMECs, such as 8 and 9).
peat humification	Usually strongly decomposed and well humified.
peat composition	Often too decomposed to identify many macrofossils, but examples can contain much hypnoid moss peat, sedge peat and brushwood peat, with *Sphagnum* peat in some base-poor examples.
permeability	Soils and basal substratum vary from quite high to low permeability.
Ecological types	Range from base-rich to base-poor, eutrophic to oligotrophic, depending mainly on groundwater source and substratum characteristics.
Associated WETMECs	Has been recorded in association with numerous other groundwater-fed WETMECs but is particularly found alongside, or above, Permanent Seepage Slopes (WETMEC 10). Can be the only WETMEC in some sites.
Natural status	Sometimes uncertain, but many examples have been partly disturbed (peat removal, part drainage); water supply mechanism may be natural or a product of (part-) drainage and so on.
Use	Examples usually have no usage or are grazed (sometimes for conservation). Some examples (including oligotrophic types) are closely associated with intensive agriculture on adjoining land. Some have been drained and converted into agricultural land.

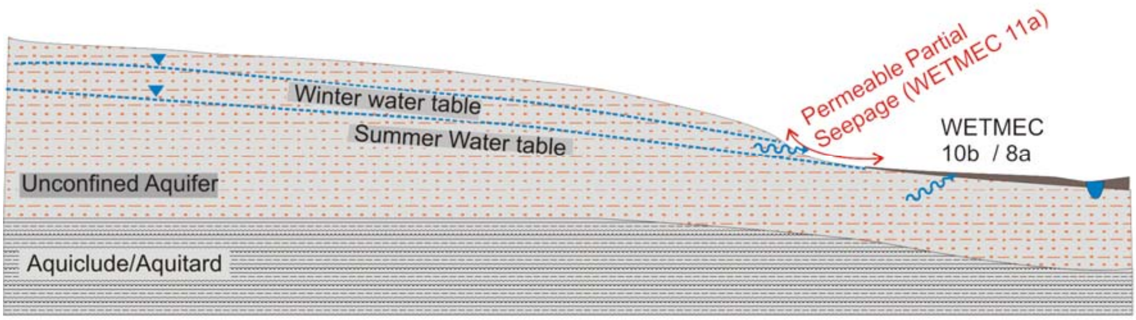
Conservation value	Oligotrophic examples, base-rich to base poor, are generally of high value and include a number of SAC habitats.
Vulnerability	Main threats include: dereliction; further reduction of groundwater level through drainage or groundwater abstraction; agricultural enrichment.

WETMEC 11: INTERMITTENT & PART-DRAINED SEEPAGES
[see also WETMEC 10]

WETMEC 11a: Permeable Partial Seepages
(*e.g.* Bunwell Common Aslacion)
- mire developed entirely over a permeable substratum
- winter outflow of groundwater on valley slopes, but ± permanently shallow sub-surface elsewhere
- watercourse level provides an important control on the water table, and some sites appear to have been permanent seepages (WETMEC 10b) prior to deepening of watercourse channels



WETMEC 11a: Permeable Partial Seepages
(*e.g.* Beeston Bog)
- mire developed entirely over a permeable substratum, but with aquitard at depth
- winter-only outflow of groundwater along much of valley slopes, but with ± permanent seepages along the bottom of the slopes in at least some locations
- water level in valley bottom reflects aquifer level



WETMEC 11a: Permeable Partial Seepages
(*e.g.* Thursley Common)
- winter outflow of groundwater on valley slopes
- some summer-water outflow at junction between permeable material and local aquitard, with local development of a permanent seepage face on the lower slopes
- summer water outflow supplies a valley-bottom mire, developed mostly over an aquitard

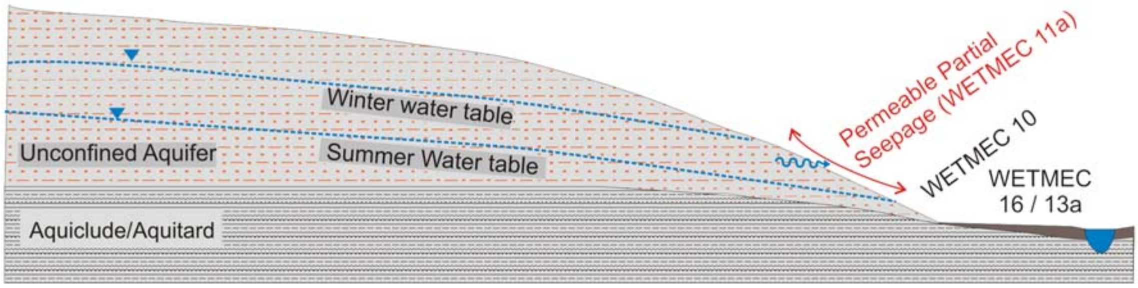


Figure 6.33 Schematic sections of types of Intermittent and Part-Drained Seepages (WETMEC 11)

6.14.4 Concept and description

CLUSTER: 19

WETMEC 11 is, for the most part, perhaps best seen as a drier version of WETMEC 10 (mean summer water table is about 14 cm lower). It occupies a similar range of circumstances, but most of the samples clustered into it were from locations in valleyhead fens where the ground surface is either periodically saturated or where water tables are always sub-surface, but fairly high. Many examples of this wetland type are quite small, but some are extensive and this can form the most extensive, in some cases only, wetland type in some valleyhead fens. Generally, it does not support the species interest of wetter seepages.

Affinities and recognition

Type 11 WETMECs can occur in close association with Permanent Seepage Slopes (Type 10) and some have been derived from these by partial drainage, whilst others appear to be natural. The main difference between WETMECs 10 and 11 is more in the position of the water table relative to the ground surface than in the water supply mechanism, but recognition of WETMEC 11 as a separate unit reflects both the distinctiveness and large number of Type 11 samples.

The water table associated with this wetland type is potentially very variable and this, particularly the distance it falls below the surface during the summer, relates to the type of vegetation that occurs. Conceptually, these summer-dry stands can be divided into two broad categories: intermittent seepages, with a near-surface water table at least in winter; and shallow sub-surface groundwater surfaces, with a high but permanently sub-surface water table. However, this distinction is not sustained by the multivariate analyses, nor do the two categories support markedly different ranges of plant communities. This suggests that, within the range of stands included in this study, the composition of vegetation depends more on the typical position of the summer water table relative to the surface than on its winter level, and that intermittent seepages and locations with a shallow sub-surface water table are best considered together as a single WETMEC.

The cluster analysis (Figure 6.1) shows that samples of WETMEC 11 have strong affinities to WETMEC 12 (Fluctuating Seepage Basins), and the differences between the two units are primarily topographical. WETMEC 12 occurs in small basins where seasonally high water levels are often expressed by surface flooding (which in some deeper basins can persist year round). However, dry sub-types of WETMEC 12 (12d and e) have little substantive difference from WETMEC 11, other than their occupancy of shallow basins, and are transitional between the two.

Some summer-dry areas within groundwater-fed topogenous fens are very similar to flat examples of WETMEC 11, but differ in topographical and other characteristics and, following the cluster analysis classification, are allocated to a separate WETMECs (Groundwater Floodplains (WETMEC 7) and Groundwater Bottoms (WETMECs 8 and 9). However, the functional difference between some examples of these and WETMEC 11, in terms of water supply mechanisms, may be small and the various units intergrade considerably. Sites with wet winter conditions but very low summer water tables (> 1 m bgl) are usually considered to be seasonal wetlands. This type of habitat is not represented in the stands included in the Framework analysis.

The sub-types recognised in this analysis are rather different to those of Phase 1. This doubtless reflects both the wider range of sites recorded in the full survey and the fact that piezometric data on aquifer heads were excluded from the present analysis (as these are mostly available only from Eastern England). Also, some samples allocated to this category in Phase 1 were clustered into WETMECs 8 and 9 in the present analysis, so that WETMEC 11 is now restricted to sloping samples and some more or less flat examples with very shallow accumulations of peat.

6.14.5 Origins and development

Very little is known about the origin and ontogenesis of most WETMEC 11 sites, partly reflecting the general absence of significant accumulations of peat. The WETMEC is clearly a natural feature of many wetland sites and can occupy a characteristic, if rather peripheral, position in valleyhead fen zonations (Rose, 1953). However, some examples have apparently originated from wetter seepages. In some sites with a zone of WETMEC 11 above WETMEC 10, some drying of the seepages has apparently been reflected in a downslope increase in the width of the WETMEC 11 band. In others (such as Bunwell Common, Aslacton), WETMEC 11 has apparently completely replaced WETMEC 10 on a former seepage slope.

6.14.6 Situation and surface relief

The majority (more than 80 per cent) occur in valleyhead contexts. Some four per cent occur in troughs that are not part of a valleyhead system, and the remainder occur alongside topogenous wetlands, especially at the margin of floodplains (nine per cent) but also on the slopes of some basins (four per cent).

Although not often found on steep slopes, most are sloping, with some more or less flat (Table 6.39). Sometimes with channels and hollows formed by spring flow.

6.14.7 Substratum

The soils are typically thin and often skeletal. They contain varying amounts of organic material (usually strongly humified), in the shallower examples mixed with various mineral fractions. Some examples have shallow accumulations of peat, typically up to a maximum depth of about 50 cm, though a few deeper examples occur. Examples on quite deep (> 1 m) peat, or a similarly deep deposit of peat and marl (or tufa) (such as Bunwell Common (Aslacton), Cors y Farl, Flordon Common, Scarning Fen) usually represent examples of WETMEC 11 in part-drained locations. Both the top, and when present, middle layers of peat tend to be more consolidated and humified than in WETMEC 10, and this is reflected in a shift of estimated permeabilities to lower values (Table 6.39). The basal substratum is composed variously of sand and gravel (with variable amounts of silt), sometimes clay, tufa and marl. The mean value for the basal substratum permeability is also lower than for WETMEC 10, but the effect is not as pronounced as with the peat and many examples of WETMEC 11 occur over deposits similar to those which support WETMEC 10 (see 6.14.9).

Table 6.39 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 11

	Mean	1	2	3	4	5	6	7
Surface layer permeability	3.3		12	61	17	10		
Lower layer permeability	3.4	1	4	60	22	13		

Basal substratum permeability	3.9	7	12	14	33	23	12	
Slope	2.3	27	26	35	9	1	X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.14.8 Water supply

Groundwater (from semi-confined or unconfined bedrock or drift aquifers) provides the main source of telluric water. The aquifer is episodically at or near surface, but often low in summer, and in some examples is almost always below the surface (which may be primarily rain-fed). Some examples may receive some rain-generated run-off, but very often much rainfall infiltrates the ground above the wetland, or is intercepted by catchwater drains.

The sites clustered within WETMEC 11 are united by one of its main distinguishing features: a low summer water table. However, this can help obscure some underlying differences in water supply mechanisms. The two sub-types recognised accommodate some real differences in water supply, but other variations appear to be subsumed within them, and in yet other cases the precise mechanisms involved are uncertain. Any ditches and streams associated with this WETMEC appear normally to have a drainage function, though in some sites and circumstances they may occasionally supply water to the adjoining mire.

6.14.9 WETMEC sub-types

Although numerous and rather variable, the samples allocated to WETMEC 11 occupy a single cluster at the 36-cluster level. However, two main sub-clusters can be recognised at the 72-cluster level. These broadly correspond to examples over a fairly permeable substratum and those over more slowly permeable material, and form the basis for two WETMEC sub-types.

WETMEC 11a: Permeable Partial Seepage

CLUSTER: 19.1 (72-CLUSTER LEVEL)

> *Examples at:* Foulden Common, Hemsby Common, Pashford Poor's Fen, Roydon Common, Roydon Fen, Scarning Fen

This sub-type occurs over sands, gravels and sandy loams of varying composition. Its occurrence is essentially determined by interactions between the surface topography and fluctuations of the water table, and its distinction from associated Permanent Seepage Slopes (WETMEC 10) is primarily topographical. It frequently forms a longitudinal zone above permanent seepages (Figure 6.33c), or there may be no permanent seepages at the site (Figure 6.33d).

Some examples are natural, and can form part of a distinctive valleyside zonation (such as Roydon Common, Scarning Fen, many New Forest valley bog sites) (Figure 6.33c), but others are a consequence of aquifer head loss, induced by drainage and, in some cases, groundwater abstraction. These processes can also lead to the downslope encroachment of natural examples of this WETMEC upon wetter mire units (especially WETMEC 10). Some examples are extensive and effectively form diffuse intermittent seepage slopes. Others are small and may, for example, just form a fringe around the top of some permanent seepages (such as Booton Common, Scarning Fen, Norfolk); some occupy dry spring mounds which almost certainly once marked the occurrence of permanent groundwater outflows before disruption of their natural water supply processes (such as Bunwell Common, Norfolk). A few examples of sub-type 11a occur embedded within sub-type 11b, and in this context also probably represent former WETMEC 10 sites which have become drier due to changes in groundwater outflow into the sites. Diffuse groundwater seepages of this type also occur along the rising slopes on the fringes of some floodplains and basins. In a number of sites, small elevated (either natural or residual) ridges and blocks in old turbaries can also be allocated to this sub-type.

WETMEC 11b: Slowly Permeable Partial Seepage

CLUSTER: 19.2 (72-CLUSTER LEVEL)

Examples at: Buxton Heath, Clack Fen, Cors Nantisaf, Cors Goch, Cors y Farl, Drayton Parslow Fen, Forncett Meadows, Holly Farm Meadows, Tarn Moor (Sunbiggin).

This widespread type of intermittent seepage occurs across the same range of topographical contexts as the permeable sub-type (11a), but its relationship with Permanent Seepage Slopes (WETMEC 10) is less topographically dependent. Examples can occur above, alongside and sometimes even below permanent seepages. The distinctive feature of this sub-type is that the basal substratum appears to be of rather low permeability, and is composed of thin clays, sandy-clays and silts and loams. Where it adjoins, or is punctured by, a permanent seepage the latter invariably occurs over a more permeable basal material (such as sands and gravels). This suggests that WETMEC 11b samples occur in locations where groundwater outflow is constrained by resistance imposed by the substratum, so that seepage only occurs when groundwater heads are particularly high, or not at all. However, as noted for WETMEC 10, in some cases the local absence of a layer of clay-rich Drift may be because it has been eroded away by strong springs rather than being the cause of the localisation of these. In locations where the Drift cover thickens, or becomes of especially low permeability, the slopes cease to support mire and fen vegetation, usually in favour of a form of (wet) grassland. Such (often small-scale) variation results in the typically patchy distribution of habitats and vegetation that occur in and around many soligenous mires, as can be seen along the east side of Cors Nantisaf. As a consequence, examples of this sub-type are frequently not as extensive and uniform as those of the more permeable sub-type, nor do they necessarily show such clear topographical zonations.

In some locations sub-type 11b occurs lateral to, and sometimes between, permanent seepages at levels similar to, or below, that of the permanent seepage. This can be the case, for example, where the permanent seepage forms a spring mound which is largely surrounded by a drier intermittent seepage at a lower level. In this rather curious situation, which is not infrequent, a complicating consideration is that the type 11b seepage may sometimes be partly irrigated by surface flow of water from the spring mound, giving the intermittent seepage area some of the characteristics of a flushed surface. Such effects are usually small scale and although they have been noted in various locations, have only occasionally been sampled (and hence have had little influence on the recognition of WETMECs). There are often strong similarities and spatial relationships between such peripheral intermittent seepages and permanent seepages and where the peripheral seepages form a narrow fringe around, or beside, a permanent seepage slope, they can for simplicity be considered part of the latter rather than as a separate unit.

6.14.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 11 are summarised in Table 6.40. This WETMEC has one of the lowest mean water levels of all the WETMECs (the lowest water table recorded for the unit is 37 cm bgl.) This is reflected in the frequent contribution made by characteristically dryland species to the vegetation of this wetland type, which occasionally supports some rather uncommon dryland taxa, such as *Ophrys apifera*. Species composition shows considerable variation within the WETMEC unit, partly determined by the depth–duration of the position of the water table, which also shows considerable variation both between and within sites. However, with the dataset available it has not been possible to identify consistent ecological and floristic differences between those stands where the water table is permanently sub-surface and those with intermittent (mainly winter) groundwater outflow.

The base-status of this wetland type is determined both by the character of the substratum and that of the irrigating water. Whilst in many sites the pH values of the substratum and groundwater are similar, this is not always the case. In some sites, the soil pH of the Type 11 WETMEC is lower than that of the permanent seepage immediately below it (such as Scarning Fen), or of other proximate sources of groundwater. This may reflect a smaller input of base-rich groundwater into the upper layer of the soil beneath WETMEC 11, a greater proportionate contribution of rainwater, or the influence of a mineral substratum of different chemical characteristics to the groundwater (such as where WETMEC 11 occurs on sands and gravels, but where the main groundwater source is from a Chalk aquifer). Conversely, in other sites pH values of the Type 11 WETMEC are higher than those of nearby permanent seepages. The reason for this is often not known, but in some instances may reflect the calcareous character of the clay component in the soil beneath WETMEC 11.

The fertility of this wetland type is variable. Examples on sands and gravels, or in a few cases chalky marls, are typically of low productivity, whereas those on more clay-rich soils are usually more fertile, presumably reflecting the intrinsic fertility characteristics of the substratum. Casual observations suggest the possibility that the surface of some intermittent seepages fed by N-rich groundwater may be more fertile than comparable examples where the water level is permanently sub-surface, but no measured evidence is known concerning this.

Table 6.40 WETMEC 11: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	0.4	0.1	2.0
Summer water table (cm)	–16.9	–37	0
Rainfall (mm a^{-1})	680	542	2,101
PE (mm a^{-1})	598	435	646
Water pH	6.0	4.1	7.2
Soil pH	6.8	4.6	7.8
Conductivity (µS cm^{-1})	538	90	1,034
K_{corr} (µS cm^{-1})	535	90	1,034
HCO_3 (mg l^{-1})	213	10	416
$Fertility_{Phal}$ (mg)	11	4	23
Eh^{10} (mV)	237	128	327

See list of abbreviations in Appendix 1

6.14.11 Ecological types

The distribution of samples of WETMEC 11 amongst the pH and fertility categories is shown in Table 6.41. Note that this almost certainly reflects a disproportionate preponderance of samples from base-rich sites (mostly in East Anglia).

Table 6.41 Percentage distribution of samples of WETMEC 11 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	23	46	5
Sub-neutral	5	9	
Base-poor	9	3	

Oligotrophic, base-rich

Mainly associated with discharges from Chalk and Limestone aquifers, but also found in association with some of the more impoverished Drifts. Often developed on partly mineral-based soils, where fertility is determined by the character of the substratum, but this sub-type also occurs on part-drained peats. Some examples, particularly those on highly calcareous soils, are P-limited. These may be able to maintain low productivity, even when fed with N-rich water. The most typical vegetation of this type is M24, but some examples of impoverished M13 can also be grouped here.

Oligotrophic, sub-neutral

This sub-type is uncommon and has been recorded mainly from Eastern England. It mostly occurs in sites fed from Drift (Beeston Bog, Buxton Heath, Holt Lowes); on sandy Drift or peat surfaces in sites thought to be fed by Chalk water (Booton Common, Scarning Fen[1]); and on Greensand where the irrigating water from this deposit has become base-enriched (Roydon Common, Thursley Common (western arm)). This unusual type also occurs at other sites not included in this survey and where water sources have not been considered (such as Sugar Fen, Norfolk). Vegetation types represented are mostly M24 and M25, and transition between these two units.

Oligotrophic, base-poor

Widespread in mires associated with rather acidic sands and gravels, but generally undersampled in this project. Outside of Eastern England, examples have been sampled at Bicton Bog, Folly Bog, Thursley Common and Wilverley Bog but this type has been noted at numerous other sites. Within Eastern England this type is generally scarce, perhaps because many former examples have been destroyed. Most examples are associated with discharge of water from base-poor sand and gravel Drifts (such as Buxton Heath, Holt Lowes, Swannington Upgate Common) or from Lower Greensand (Dersingham Bog, Roydon Common). In a few sites, base-poor Type 11 stands occur (or once occurred) upon base-poor Drift (sands and gravels) in close association with base-rich permanent seepages, and at Buxton Heath (Norfolk) it appears that some base-poor Type 11 stands are irrigated by groundwater from a different (perched) aquifer than the more base-rich Permanent Seepage

[1] In both of these sites it is possible that the sub-neutral areas are fed by drift water or a mixture of drift and chalk water.

Slopes (WETMEC 10). In other cases, it seems likely that the WETMEC 11 stands are predominantly fed by rainwater, supported by or mixed with a base flow of calcareous groundwater rather than from a separate, base-poor telluric water source (such a mechanism must almost certainly apply to small, acidic, sandy or peaty islands embedded within some calcareous fens, such as Beeston Bog, Norfolk). These systems may be either P or N-limited. The typical vegetation type is usually a form of M25, but some examples come closest to M15 or, in some instances, impoverished M21.

Mesotrophic, base-poor

All examples of this sub-type were recorded from Cumbria, from intermittent seepages peripheral to larger areas of mire, on shallow peat. It represents an apparently widespread but little sampled mire type, mainly supporting M23 and M25 vegetation. All examples were only weakly mesotrophic (their fertilities were at the lower end of the mesotrophic scale), and this was possibly determined by the presence of mineral soil within the main rooting zone.

Mesotrophic, sub-neutral

A rather uncommon mix of characteristics in the sites examined, mostly associated with the combination of intermittent or sub-surface seepage of Drift water with relatively clay-rich or silt-rich substrata (such as Beetley Meadow, Beeston Bog, Pilch Fields), but sometimes also in sites that are at least partly Chalkwater-fed (such as Booton Common). Typically supports a form of M24 vegetation, grading into M22.

Mesotrophic/eutrophic, base-rich

This is a widely distributed groundwater-fed fen habitat. Most samples in this project were from Eastern England, but others were from various locations. Examples are associated with discharge of water from calcareous aquifers: Chalk, Limestones and base-rich Drifts. The higher fertilities seem to reflect (a) nutrient-rich water input (which may sometimes be a consequence of agricultural fertilisation, at least in part); and (b) intrinsically fertile substrata, frequently with a quite high silt or clay component. The latter condition is perhaps particularly important in examples of WETMEC 11b, which are distinguished from proximate permanent seepages by the higher silt and clay component of their basal substratum. This probably explains the juxtaposition of this ecological type with oligotrophic, base-rich permanent seepages that is found at several sites (such as Bryn Mwcog, Cors Nantisaf). In other cases, it is possible that mineralisation of relatively dry peaty surfaces has increased their fertility over that of wetter seepages, though in general it is easier to invoke mineralisation as an important ecohydrological process in wetlands than it is to demonstrate it (Eades, 1998).

In managed (grazed) situations, the characteristic vegetation of this habitat is a form of fen meadow (*Juncus subnodulosus–Cirsium palustre* fen meadow (M22)). There is sometimes a perception that M22 occurs in wetter conditions than *Molinia caerulea–Cirsium dissectum* fen meadow (M24) but, whilst this is certainly sometimes the case, it is by no means always so and the most consistent difference between habitat conditions associated with the two communities is that M24 is associated with less fertile soils than M22.

6.14.12 Natural status

The natural status of Intermittent and Part-Drained Seepages is often difficult to assess. There can be little doubt that the water supply to many sites represents a modification of their natural condition, as a consequence of drainage (direct and indirect) and a reduction of groundwater tables and pressures, in locations that once supported permanent seepages. However, in other, perhaps many, cases the present groundwater regime more or less represents the natural condition. For example, it is likely that sites such as Buxton Heath and Scarning Fen have always had a zone of intermittent seepage above the Permanent Seepage Slopes, though it may now be broader and extend to lower levels than was once the case.

It would be desirable to establish better the 'naturalness' of some examples of WETMEC 11, if only to avoid initiatives aimed at restoring higher summer water tables in situations that have not naturally supported these. Surrogate evidence for lack of 'naturalness' is sometimes available from drainage documentation, or substratum characteristics. For example, the presence of some 50 cm of peat at the summer-dry Sawston Hall Meadows, and of tufa at Bunwell Common (Aslacton), suggests that these sites were once wetter than is currently the case. Where low summer water tables are a consequence of drawdown or drainage, it may be possible to restore groundwater flow by water engineering, though in examples on deeper peats changes in peat structure consequent on drainage (increased bulk density, reduced hydraulic conductivity) may present more resistance to groundwater flow than would once naturally have occurred. Such soils may also become strongly eutrophic, through drying-induced mineralisation and nutrient release upon rewetting, at least during the early phases of this process. This seems to have occurred at Redgrave Fen, where groundwater flow to the seepages has been restored but oligotrophic conditions have not. [Seepages here are highly eutrophic and anoxic and unsuitable for the redevelopment of their former M13 vegetation (Eades, 1998; Wheeler and Shaw, 2000b)]

Some WETMEC 11 sites have also been subject to peat excavation. Natural examples of this WETMEC would be expected to be wooded.

6.14.13 Conservation value

Intermittent and Part-Drained Seepages are often considered to form a rather dry, unfavourable condition in fens, and to form a degraded version of a once wetter state. In some cases this is almost certainly correct, but for others WETMEC 11 may represent a natural hydrological condition (see above). Moreover, some examples of WETMEC 11 have considerable conservational value, dependent in part upon relatively low summer water tables, and may support a number of SAC habitats (see Tables 3.3 and 6.4).

A total of 118 wetland species have been recorded from samples of WETMEC 11. Fourteen nationally uncommon wetland plant species have been recorded: *Calamagrostis canescens, Carex elata, Cladium mariscus, Dactylorhiza praetermissa, Drosera longifolia, Epipactis palustris, Oenanthe lachenalii, Peucedanum palustre, Plagiomnium elatum, Selaginella selaginoides, Selinum carvifolia, Stellaria palustris, Thalictrum flavum, and Thelypteris palustris.* In addition, some examples may support certain species that are essentially atypical of wetlands but of conservational value (such as *Cirsium acaulon, Ophrys apifera* – both species of calcareous grasslands which occur in certain dry Type 11 WETMEC sites).

Of the above-listed species, *Selinum carvifolia* is particularly uncommon in Britain. Although its autecological requirements are not well known, on the European mainland it is regarded primarily as a *Molinion* (e.g. M24) species and in England it appears to be restricted to the relatively dry WETMECs 11 and 8.

The percentage occurrence in NVC communities of samples of WETMEC 11 is: M22: (42%); M24: (34%); M13: (7%); M21: (7%); M25: (3%); M05: (1%); M14: (1%); M23: (1%); M27: (1%); S25: (1%). This list of communities reflects a bias in the dataset towards base-rich examples of WETMEC 11. Many of the herbaceous, low fertility examples of Type 11 WETMECs occupy sites designated for their conservation importance, partly because of the features associated with this WETMEC. Some examples of *Schoenus nigricans–Juncus subnodulosus* mire (M13) vegetation (included within designated SAC habitat types) occur, but these are mostly in a form with rather few of the species characteristic of this community[1]. In some cases they may represent degraded versions of once richer examples of M13, caused by drying, but others may be a naturally impoverished type of M13 associated with the fluctuating water table found in intermittent seepages. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 11 is given in Table 6.3.

The most characteristic vegetation type of low fertility, base-rich and sub-neutral intermittent seepages is *Cirsium dissectum–Molinia caerulea* fen meadow (M24), which is also included within designated SAC habitat types. Some examples of this appear to have been derived from M13 in response to drying; others are semi-natural. The community contains a variable range of M13 species.

The main herbaceous community of mesotrophic, base-rich examples (*Juncus subnodulosus–Cirsium palustre* fen meadow (M22)) sometimes forms part of SSSI citations, but many Type 11 WETMECs with this vegetation occupy sites with no statutory designation. Eutrophic examples are generally considered to have little conservation value, though they sometimes occur in wetland sites designated for other habitats and species.

Although not strictly part of the WETMEC, in some sites ditches cutting through this wetland type (and sometimes helping to drain it), support species which augment the conservation value of the site as a whole. For example, at Sawston Hall Meadows, ditches provide the main repository for fen species such as *Cladium mariscus.* At Hall Farm Fen, the ditches support some rare invertebrates (such as Norfolk hawker dragonfly *Aeshna isosceles* and shining ramshorn snail *Segmentina nitida*) which contribute to the site's SAC status (under the habitat type "naturally nutrient-rich dykes which are often dominated by pondweeds"), although the meadows themselves (with M22 vegetation) are not of especial conservation value. It is important that this distinction is fully recognised, as the water management required to maintain the ditches and dykes in a favourable state may not be the same as that appropriate for the fen.

The main community of the more base-poor samples of WETMEC 11 is M25, with M23 in some mesotrophic circumstances. Neither of these communities generally has high conservation value.

6.14.14 Vulnerability

The Intermittent and Part-Drained Seepages of WETMEC 11 may be considered less vulnerable to a lowering of water tables than Permanent Seepage Slopes (WETMEC 10), in the sense that the unit as a whole, and its most characteristic communities, occupy a wider (and lower) water table range than permanent seepages. Indeed, some examples of this wetland type have been produced by drying of former permanent seepages. Nonetheless, a substantial further reduction of water level may be expected to have damaging impacts upon the conservation interest of this wetland type, the effect depending on the hydrological characteristics of individual sites, starting conditions, degree of change and composition of the vegetation. It is often difficult to specify meaningful lower water table limits for particular communities in WETMEC 11, and a surprisingly large number of typical wetland plants (such as *Epipactis palustris*) can apparently survive for long periods in dry conditions (water table more than 30 cm bgl), particularly in situations that are oligotrophic and summer-grazed.

[1] Not all examples of vegetation with *Schoenus nigricans* found in intermittent seepages are referable to M13.

Some part-drained examples of WETMEC 11 are long-established and have developed a vegetation cover in balance with the lowered water tables. In such situations, rewetting initiatives do not necessarily result in a quick reversal of species composition, and may sometimes result in little more than the replacement of established *Molinion* species with grassy species such as *Agrostis stolonifera*, at least in the short term. Uncommon species associated with part-drained sites, such as *Selinum carvifolia*, may be vulnerable to conservation-driven rewetting initiatives.

Some intermittent and shallow sub-surface seepages may be prone to surface acidification, because of an increased proportion of, or exclusive dependency upon, precipitation as the water supply to the soil surface. There is some evidence for this in a few examples of WETMEC 11, especially on the peat ridges in some turbaries, but it does not appear generally to be widespread. This may partly reflect a lack of data, but is probably mainly because the soils of many of the base-rich WETMEC 11 sites are very rich in exchangeable bases, which help to maintain base-rich conditions in a rain-fed environment, whilst those of base-poor WETMEC 11 sites are intrinsically acidic. However, the possibility of progressive surface acidification, especially associated with accumulation of organic material, cannot be discounted.

Enrichment of irrigating water by growth-limiting nutrients (NPK) is a potential threat to oligotrophic examples of WETMEC 11, especially those on less base-rich sandy drifts which are N-limited, but little relevant information is available. Drying may also potentially lead to nutrient release through mineralisation, but this problem may be less acute than in other circumstances, because often the sites have long been summer-dry.

Lack of management has probably been the main cause of damage to some WETMEC 11 surfaces. Many of the plant species characteristic of M24 vegetation are shade-intolerant and tend to be eliminated by the development of a rank, herbaceous community or of closed canopy woodland. [By contrast, many of the species found in mesotrophic or eutrophic example can tolerate considerable shading, or are so common that their loss is not seen as a particular cause of concern]. Colonisation by woody species can often occur rapidly in Type 11 WETMECs, and sometimes involves some dryland shrubs (such as hawthorn) as well as by willows. Development of closed canopy woodland may well help to lower WECMEC 11 summer water tables further, though there is little evidence for this based on measurements.

6.15 WETMEC 12: Fluctuating Seepage Basins

6.15.1 Outline

A local wetland type found in shallow ground hollows (ground ice depressions and comparable structures), mostly in valleyhead fens, fed by groundwater and often water-filled. The basins often show considerable seasonal fluctuations in water level, typically ranging from flooded to sub-surface conditions. The hollows are sometimes completely closed, or have an overspill flow only in high water conditions; outflow streams are not a conspicuous feature, though in some cases drains breach the basins. Some essentially provide an expression of the local groundwater table, but others appear to have constraints upon free hydraulic connection with the mineral aquifer. A schematic section is provided in Figure 6.35.

6.15.2 Occurrence

Example sites: Cranberry Rough, East Walton Common, Foulden and Gooderstone Commons, Middle Harling Fen, Pilmoor, Skipwith Common, Thompson Common

Outlier sites: Brown Moss, Whitwell Common

All of the examples occurred in Eastern England, with the exception of one outlier site (Brown Moss) in the West Midlands (**Figure 6.34**).

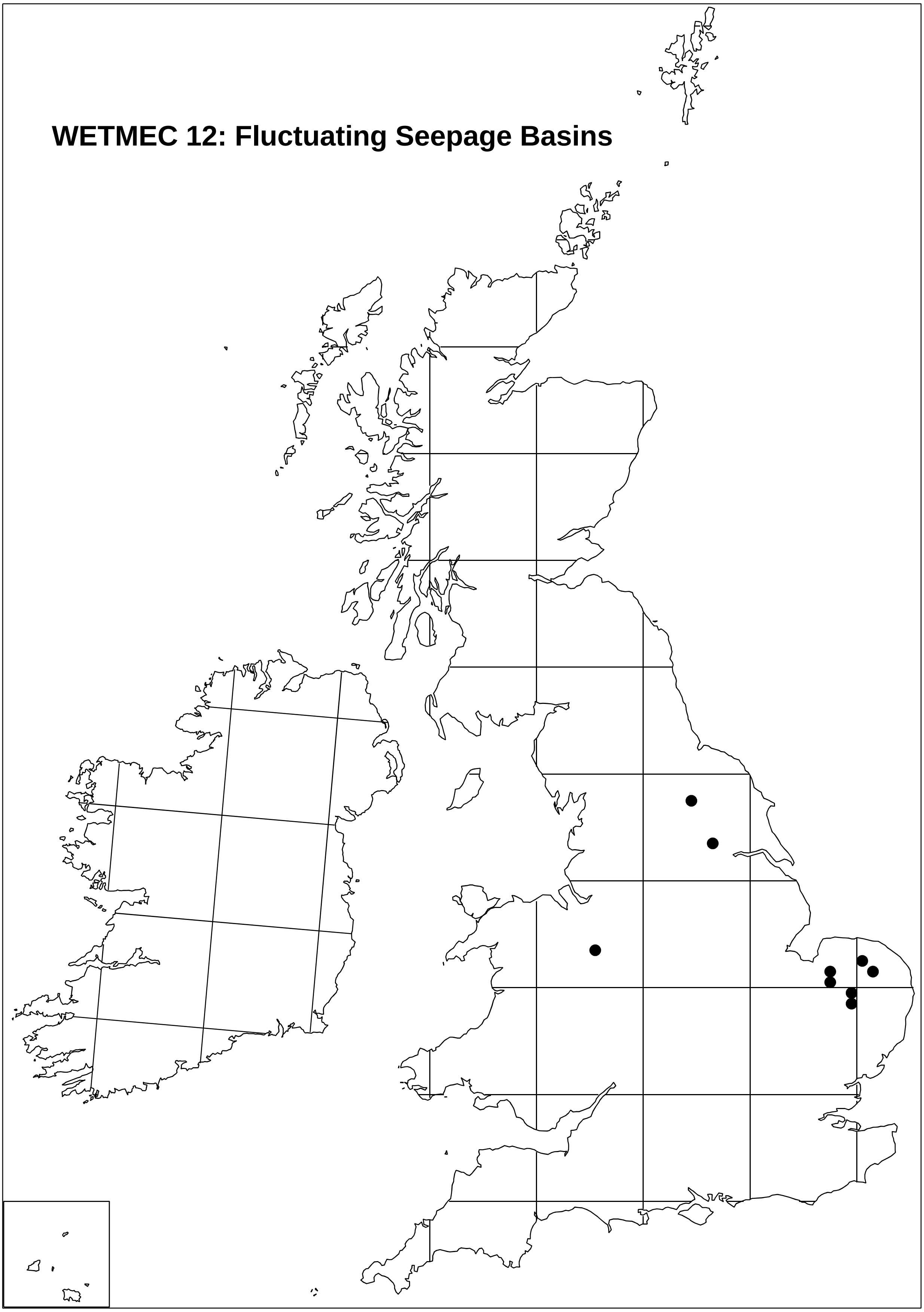


Figure 6.34 Distribution of examples of WETMEC 12 in sites sampled in England and Wales

Summary characteristics

Situation	Either in valleyheads or as small basins within drier ground (sometimes part of a 'pingo field').
Size	Typically small (< 1 ha), but some larger, coalesced examples occur.
Location	Most examples were in Eastern England.
Surface relief	Shallow basins, often with (shallow) standing water for some or all of the year, or filled with almost flat, more or less even accumulations of unflooded peat.
Hydrotopography	Topogenous, shallow basins.
Water: ***supply***	Groundwater (from semi-confined or unconfined bedrock or drift aquifers). In some cases aquifers may be small and local. Some basins have small surface water inflows.
regime	Water table is variable depending on topography and aquifer level; fluctuates strongly.
distribution	Upward or lateral flow into basin, perhaps sometimes seasonal outflow from the basin. Some basins may show little water exchange with the aquifer and there may not be a strongly dominant direction of water flow.
superficial	Shallow pools with fluctuating water surface. Sometimes a seasonally or permanently sub-surface water table.
Substratum	Shallow peat and organic material, sometimes over thin lake muds. Base may be a sand, silt, or clay-like material.
peat depth	If present, mostly shallow (< 50 cm).
peat humification	Usually well-humified and rather amorphous, but occasional exceptions.
peat composition	Few data available. *Carex* peat is a main component in some basins.
permeability	Hydroseral infill may be quite permeable, but many deposits are more consolidated. Basal substratum varies from sandy material to clay.
Ecological types	Range from base-rich to acidic, eutrophic to oligotrophic, depending on groundwater source, substratum characteristics and, in some cases perhaps, small surface water inflows.
Associated WETMECs	Basins may be adjoined (or surrounded) by Intermittent And Part-Drained Seepages (WETMEC 11), but some occur as isolated units. Permanent Seepage Slopes (WETMEC 10) and Seepage Percolation Basins (WETMEC 13) occasionally occur in the same sites as WETMEC 12.
Natural status	Basins are late-glacial landscape features, but the status of their contents is uncertain. Peat *may* have been removed from many sites. Some have been modified by drainage and perhaps by a reduction of aquifer levels.
Use	Mostly too wet to have any substantial use, though some are partially grazed. A few may once have been cleared and used for fish ponds.

Conservation value	Well-developed vegetation zonation is notable in some sites; tend to be quite species-poor but may support SAC habitats. Some rare inverts.
Vulnerability	Threats may include: dereliction and hydroseral succession, reduction of GW level through drainage, GW abstraction and perhaps evapotranspiration; a few may be vulnerable to enrichment from small surface water inflows.

WETMEC 12: FLUCTUATING SEEPAGE BASINS

WETMEC 12: Fluctuating Seepage Basin
(*e.g.* Foulden Common)

- water level in 'basin' is essentially an expression of the level of the water table in the aquifer, and fluctuates with this
- basins may have no natural surface inflows and outflows, or the outflow has been dug (or deepened)
- the degree to which basins dry out depends partly on their depth in relation to the aquifer water table - deeper examples may have some permanently open water, except in exceptional conditions.
- some basins may be situated upon low permeability material so their water table is not always immediately responsive to fluctuations in the groundwater table.

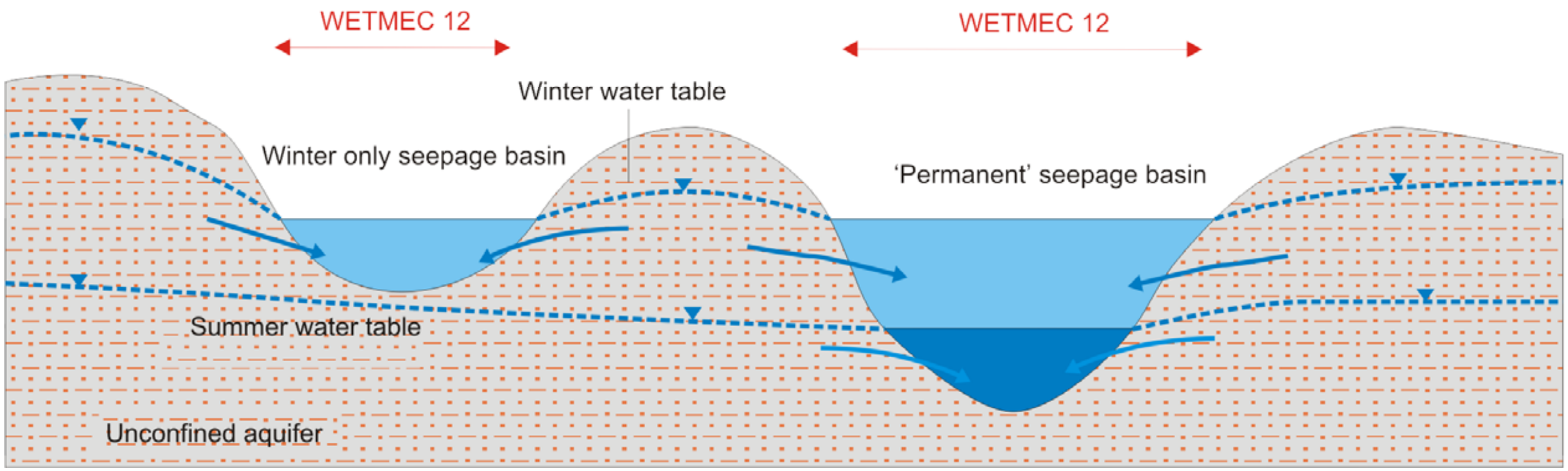


Figure 6.35 Schematic section of a fluctuating seepage basin (WETMEC 12)

6.15.3 Concept and description

CLUSTER: 20

WETMEC 12 essentially includes the infill of small, groundwater-fed hollows which are normally embedded within relatively dry land (grassland or woodland), or sometimes within examples of Intermittent and Part-Drained Seepages (WETMEC 11). Water levels in the basins typically show strong fluctuations and in some sites at least (such as Foulden Common), the fluctuations are of similar magnitude and related to those of the aquifer, but in many cases the relationship between the water level in the basins and the mineral aquifer is not known with certainty. However, the distinctive ecohydrological feature of WETMEC 12 is not the magnitude of water table fluctuation, which may be comparable with that in some examples of WETMEC 11, but its interaction with the topography of the shallow basins. In many instances, this results in a seasonal phase change between a flooded state and sub-surface water tables over all or part of the basin.

The hydrodynamics of the basins are variable and relate to the degree of water level fluctuation, basin depth (relative to the water table) and morphology (especially the capacity of the basin to contain standing water). Basins with markedly different summer water levels (and vegetation) can occur, sometimes in close juxtaposition. Some contain standing water for much or all of the year; others, such as those which do not cut much beneath the normal maximum groundwater table, or which cannot hold much water because of natural or artificial breaches, have sub-surface summer water tables year round. There is little substantial difference between these latter basins, hydrologically or ecologically, and Intermittent and Part-Drained Seepages (WETMEC 11). The basins most likely to contain permanent standing water are usually the largest (Watts and Petch, 1986), and appear generally to be the deepest, though small deep basins do occur. The deepest sites can contain some two metres of standing water in summer.

Some of the best examples of WETMEC 12 occur as clusters of numerous small hollows in some locations in Norfolk. These appear to be ground ice depressions and are often, though perhaps not always correctly, referred to as 'pingo fields' (Thompson Common, East Walton Common, Foulden Common). The depressions may be single and complete or coalesced in complex formation. Some rather similar partial, complete or coalesced, small, shallow ground hollows occur in a number of other valleyhead fens, including Chippenham Fen, Dernford Fen, Swannington Upgate Common, Weston Fen and Whitwell Common, but not all are necessarily referable to this WETMEC. Examples of WETMEC 12 in small ground hollows also occur at Pilmoor and Skipwith Common (Yorkshire), and a small peat-filled hollow at Brown Moss (Shropshire) has been clustered here, though as an outlier to the group. The WETMEC occurs in some larger basins of apparently different provenance (such as Middle Harling Fen). Breckland Meres may also represent an extreme example of this WETMEC, but has not been studied here.

Affinities and recognition

WETMEC 12 is based upon a distinctive, single cluster of the multivariate analysis (Cluster 20) (Figure 6.1) which is most closely related to Permanent Seepage Slopes (WETMEC 10), and particularly, to Intermittent and Part-Drained Seepages of WETMEC 11. Water level fluctuations within the basins are quite strong and comparable with those found in WETMEC 11 (with which the basins are often associated), and the difference between the two units depends mainly on the topography of the basins. In WETMEC 12, water level fluctuations are often expressed either as a phase change between standing water and sub-surface conditions or, in some cases, as seasonal variation in the depth of standing water in the basins, which does not necessarily fall significantly sub-surface. By contrast, in WETMEC 11 wetlands these variations are mostly expressed as changes in water table depth below the surface. This provides a disproportionately large ecological distinction between the two WETMECs in the sense that: (a) fluctuations in the depth of standing water may have much less effect upon vegetation composition of the pool or swamp than comparable fluctuations of below-surface water levels; and (b) fluctuations which involve a significant phase shift in water level, from flooded to below surface, may have a greater impact on the type of vegetation that occurs than sub-surface fluctuations of similar magnitude.

Fluctuating Seepage Basins do not normally occur in association with Permanent Seepage Slopes (WETMEC 10), but in some locations can occur close to Seepage Percolation Basins (WETMEC 13). The differences between WETMEC 12 and WETMEC 13 basins remains to be fully clarified, and requires further investigation. Some WETMEC 13 basins may have a stronger groundwater supply than WETMEC 12 (many Type 13 basins have a more or less permanent outflow stream, whereas Type 12 basins do not, or only show seasonal outflow). Another important difference is that WETMEC 13 surfaces are buoyant or strongly quaking, a difference from WETMEC 12 which may relate partly to differences in basin morphometry. In some circumstances WETMEC 13 basins may experience a similar absolute magnitude of water level change to WETMEC 12, but fluctuations of water level relative to the buoyant surfaces are much less.

6.15.4 Origins and development

Many, but not all, of the shallow basins occupied by WETMEC 12 appear to be part of a late-glacial patterned land surface. These are often referred to as pingos, though there is some debate about their status and a more generic term such as ‘ground ice depressions’ may be preferable (Sparks, Williams and Bell, 1972). The majority contain only a fairly thin (less than one metre deep) deposit of peat, and this is often humified. In some cases it is underlain by a layer of lake muds, and is hydroseral in origin. The stratigraphy of Pilmoor, which has rather little open water, provides a clear example of hydroseral colonisation of lake muds by *Carex elata*, followed in places by the seral development of scrub and, in others, a *Sphagnum*-dominated surface. Other examples have a clear hydroseral-like zonation of vegetation around a (usually shallow) central pool (such as Thompson Common).

6.15.5 Situation and surface relief

The majority (around 70 per cent) of Fluctuating Seepage Basins occur in valleyhead contexts, usually as small, shallow depressions within drier ground, or within intermittent seepages (WETMEC 11). The remainder occupy small basins that are not part of a wider valleyhead system. Many examples are in shallow ground ice depressions.

Many of the basins contain shallow standing water, which generally deepens gently towards the centre, often resulting in a clear centripetal zonation of vegetation types. However, some peat-filled basins have surfaces that are almost flat and even (Table 6.42).

6.15.6 Substratum

The soils are typically peaty but thin (the maximum depth recorded was less than one metre). The peat is often amorphous but not necessarily well consolidated, and some deposits consist more of loose organic material than true peat. The basal substratum is variable, from a silty sand in some locations to a quite stiff clay in others (such as Brown Moss), which appears to represent an underlying aquitard. Some of the more sandy-based substrata were difficult to core with the hand auger used and in some cases at least, there was evidence for concretions within the sandy material. Some basins contain a shallow (> 50 cm) accumulation of gyttja-like material. Substratum permeabilities are correspondingly variable (Table 6.42).

Table 6.42 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 12

	Mean	1	2	3	4	5	6	7
Surface layer permeability	4.4			15	39	39	4	4
Lower layer permeability	4.0		11	31	12	35	12	
Basal substratum permeability	3.6	4		46	35	15		
Slope	1	100					X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.15.7 Water supply

In some Fluctuating Seepage Basins, the behaviour of the water table appears to be directly related to that of the mineral aquifer (such as Foulden Common), but in others there is a lag in the response of the basin water table or other indications of independence. Some basins are lined with low-permeability deposits (such as thin layers of clay or 'sealing layers' of organic material) or there may be impedence layers within the Drift which could function as local aquitards and which may be important in reducing the rate of water exchange between the basins and mineral aquifer.

The source of the groundwater in Fluctuating Seepage Basins is not always evident. HSI/ECUS (1999) observed that the relationship between the water in the pingos at Thompson Common and the underlying Chalk aquifer was not clear. Gilvear *et al.* (1989) proposed that some pingos were located within an aquitard, fed from below from a leaky aquifer, but it is not known on what evidence this proposition was based. At Foulden Common, there appears to be fairly free hydraulic connection between at least some of the ground hollows and the Chalk/Drift aquifer. However, depressions embedded within the deeper, sandy Drift contain less base-rich water than those more directly associated with the Chalk. This points to hydrochemical stratification in the uppermost layer of the Chalk/Drift aquifer or to some degree of hydraulic isolation of some of hollows from the aquifer.

In the three sites for WETMEC 12 outwith East Anglia (Brown Moss, Pilmoor and Skipwith Common), the depressions all appear to be within shallow Drift deposits (sands and gravels) underlain by a clay aquitard. Wet conditions seem mainly due to the lack of surface drainage and the topography of the hollows. At Skipwith Common, "*although the wet hollows are sustained by lateral groundwater inflow from the surface sand, the surface sand is acting as a storage reservoir for rainfall inputs to the site, and is not thought to receive any significant groundwater inflow from the area surrounding the site*" (HSI, 2004–5). This is probably also the case at Brown Moss and Pilmoor. Open water within the hollows is likely to receive lateral inflow from the surface sand layer, and may be in hydraulic continuity with the water table. The pattern of groundwater flow within the sand layer is likely to mimic topography, but rates of water exchange may be small and perhaps without a strong dominant flow direction. In all cases the sand and gravel aquifer may be quite thin, and therefore vulnerable to any variations in recharge, drainage initiatives, abstraction and perhaps increased evapotranspiration.

6.15.8 WETMEC sub-types

No coherent and interpretable sub-clusters were identified within CLUSTAN cluster 20. It is likely that the nature of the hydraulic connection between the basins and aquifer could provide an important subdivision of this WETMEC, but data currently available are insufficient for this purpose. An informal subdivision can be made based on the range of water level fluctuations and position of the summer water level, though accurate delineation of categories requires more information than is currently available. The following informal units were proposed tentatively and provisionally in Phase 1. They do not necessarily equate to an entire depression and can occur in combination. For example, some hollows show a clear zonation from the centre outwards of WETMEC sub-types 12a > 12b > 12d. However, some depressions are largely, if not entirely, composed of a single sub-type.

WETMEC 12a: Fluctuating Seepage Basins with permanent standing water

Stands with permanent surface water in most years, though fluctuating in depth. Vegetation depends on water depth and depth–duration. Permanent open water typically has aquatic plants (such as *Chara* spp., *Ranunculus trichophyllus*). Swamp (especially *Cladium mariscus* swamp (S2) and *Phragmites australis* swamp (S4)) generally occurs in (often peripheral) areas with shallower water, though in a small number of cases *Phragmites* can form an unstable hover over open water.

WETMEC 12b: Fluctuating Seepage Basins with winter standing water, summer water table sub-surface or near surface

In some years there may be residual surface water in summer; in others the water table falls sub-surface, but the substratum remains fairly wet (it may become relatively dry during drought years). Vegetation depends upon the depth and duration of the winter water level, usually swamp (S1, S2, S4) in the deeper parts and fen meadow (*Juncus subnodulosus–Cirsium palustre* fen meadow (M22)) in drier peripheral areas. The wetter examples of this sub-type may support some of the more amphibious aquatic plants, such as *Hippuris vulgaris* and *Hottonia palustris*.

WETMEC 12c: Fluctuating Seepage Basins with shallow winter standing water, summer water table sub-surface or near surface

This is similar to sub-type 12b, but winter water levels are less deep on account of the topography of the basin and the level of natural or artificial outfalls. Often supports fen meadow vegetation (M22), especially the *Carex elata* sub-community (M22c). The *Sphagnum*-based examples at Skipwith Common and Pilmoor may also be assigned to this sub-unit, though the *Sphagnum* surfaces themselves are probably free from standing water year round.

WETMEC 12d: Fluctuating Seepage Basins, winter 'wet', summer 'dry'

Areas with shallow sub-surface water tables in winter and deeper sub-surface water tables in summer. Vegetation depends on range of water levels. Wetter examples may support M22 or M24 whilst 'dry' examples may effectively be non-wetland. Apart from their occurrence in ground basins, there is little or no conceptual difference between these and Intermittent and

Part-Drained Seepages (WETMEC 11). The small area of *Sphagnum* mire at Brown Moss can be allocated to this unit.

WETMEC 12e: Fluctuating Seepage Basins with winter standing water, 'dry' by early summer

These depressions dry out considerably during the summer and support 'inundation communities' with species such as *Agrostis stolonifera, Mentha aquatica* and *Rorippa palustris* (and sometimes *Hottonia palustris* in summer-moist examples).

6.15.9 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 12 are summarised in Table 6.43. There has been little investigation of the ecological characteristics of Fluctuating Seepage Basins – even water depths have been recorded only occasionally. The vegetation, and other aspects of the biota, is almost certainly dependent upon the degree of fluctuation of the water level as well as the summer level, but there are insufficient reliable data to permit a rigorous analysis of this. Of two of the most widespread communities found in the swampy basins, *Cladium mariscus* swamp (S2) can occur in deeper water than *Carex elata* swamp (S1), but we have no clear evidence that *C. elata*-dominated (S1) depressions are necessarily more strongly fluctuating than *Cladium*-dominated (S2) examples, as was suggested by Haslam (1965).

Table 6.43 WETMEC 12: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	0.3	0.1	0.9
Summer water table (cm)	–3.1	–33.5	20
Rainfall (mm a^{-1})	631	596	718
PE (mm a^{-1})	606	578	614
Water pH	5.5	3.6	7
Soil pH	5.2	3.8	7.2
Conductivity (µS cm^{-1})	332	53	713
K_{corr} (µS cm^{-1})	317	–34	713
HCO_3 (mg l^{-1})	71	0	146
$Fertility_{Phal}$ (mg)	18	2	42
Eh^{10} (mV)	170	21	256

See list of abbreviations in Appendix 1

Watts and Petch (1986) suggested that the species richness of the ground hollows at Thompson Common is related to their water regime (

Table 6.44). Their data appear to relate to entire hollows, so the high richness associated with permanent pools is probably due to their greater habitat range (swamp and fen as well as open water). These authors also showed that at Thompson the wettest hollows (with permanent pools) were the largest, whereas those which tended to become dry by late spring were generally the smallest. [It seems likely, but is not known, that the largest examples are also the deepest – Watts and Petch did not report basin depth]. The largest hollows also supported most plant species, again probably because of the greater habitat range contained within them.

Table 6.44 Relationship between water regime and number of plant species in ground hollows at Thompson Common

Water regime	n	Mean number of plant species
A. Permanent pools	8	26.9
B. Always some residual water	44	16.9
C. Dry by September (1985/86)	52	9.4
D. Dry by May (1985/86)	12	8.9
E. Always dry	2	13.5

Slightly modified from Watts and Petch (1986). Categories A–E may each encompass one or more WETMEC sub-types.

Although water quality measurements are sparse, these wetlands span the range from base-rich to acidic[1]. Both base-rich and sub-neutral types occur over Chalk but – although rigorous data are not available – it seems probable that the sub-neutral examples are in hollows embedded mainly or completely within a sandy drift, and are fed primarily by water from within this, whilst the base-rich examples may have more direct contact with chalkwater[2] (Table 6.45). Base-poor and acidic examples are associated with thin Drift (sand and gravel) aquifers that apparently lack hydraulic connection to bedrock aquifers. In some base-poor examples (such as Brown Moss, Skipwith Common) the base-poor sands seem mostly to act as a storage reservoir for rainfall, which feeds into the hollows to produce base-poor conditions in the pools, though rates of water exchange may be small and without a strongly dominant flow direction. However, at Pilmoor, also thought to be fed from a thin Drift aquifer, the water in the non-*Sphagnum* areas is relatively base-rich (Table 6.45). The reason for this is not known, but may relate to the underlying clay deposits, which at this site are near the surface and sometimes exposed in 'holes' in the surface sands. At this site, the acidic conditions which support the *Sphagnum* surface may simply be a consequence of elevation above the influence of the relatively base-rich telluric water.

Table 6.45 Mean (n = 5) hydrochemical data from standing water in Fluctuating Seepage Basins at Foulden Common (Norfolk), Pilmoor and Skipwith Common (Yorkshire)

	pH	Conductivity (µS cm^{-1})	Alkalinity (mg l^{-1})	Notes
F1	7.8	833	556	*Cladium* pingo, W of road [Chalk fed?]
F2	6.8	235	94	*Phragmites/Typha* pingo, E of road [Drift fed?]
F3	6.4	237	68	*Carex elata/J. effusus* pingo, E of road [Drift fed?]
P1	5.4	322	89	*Carex elata–C. rostrata–Sphagnum* spp.
P2	5.3	430	63	*Carex elata* swamp in small glade
P3	5.8	336	146	*Eriophorum angustifolium–Sphagnum* spp. (*–Carex elata*)
S1	3.9	139	nd	*Eriophorum angustifolium–Sphagnum recurvum*

Records: Foulden Common [F] (Dec 1999), Pilmoor [P] (Nov 2003) and Skipwith Common [S] (Nov 1987).

[1] The pH values (and fluctuations) in open water are not strictly comparable with those measured from the soil solution of telmatic wetlands, so the base-richness categories used in the framework are not directly applicable to the open water of Type 12 WETMECs.

[2] An alternative possibility is that hydrochemical differences reflect variation in the base status of the drift or constraints on groundwater flow into the basins.

6.15.10 Ecological types

The distribution of samples of WETMEC 12 amongst the pH and fertility categories is shown in Table 6.46. This reflects a preponderance of samples from base-rich sites (mostly in East Anglia). These are mostly mesotrophic in character.

Table 6.46 Percentage distribution of samples of WETMEC 12 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	4	62	5
Sub-neutral		19	8
Base-poor	4		
Acidic	4		

Acidic/base-poor, oligotrophic

This category includes surfaces from two sites: Skipwith Common (Yorkshire) and Brown Moss (Shropshire). The latter is an outlier site and apparently only clustered within this WETMEC because of the lack of better fit elsewhere. In both cases, the low pH appears to reflect the prominence of meteoric water supply to the surface of the vegetation. Although almost completely herbaceous in character, the vegetation sample from Brown Moss has its highest MATCH coefficient with W4c! This is probably mainly a product of the highly impoverished character of this rather dry site; the best herbaceous match is with M6. The Skipwith Common samples are referable to M4, but a feature of the vegetation of some depressions at this site is an abundance of *Eriophorum angustifolium* and some unsampled locations are referable to M3.

Base-rich, mesotrophic

In this ecological type, the pH of standing water is usually above seven. Examples where the water level usually falls sub-surface in summer support fen meadow (*Juncus subnodulosus–Cirsium palustre* fen meadow (M22)) vegetation (often the *Carex elata* sub-community (M22c)) when grazed. Wetter examples generally support some type of swamp, though some of these may also sometimes experience sub-surface water levels. The main community found is *Cladium mariscus* swamp (S2), but *Carex elata* swamp (S1) also occurs. Open water may support such aquatic species as *Chara hispida* and *Potamogeton coloratus.*

Sub-neutral, mesotrophic

Wet examples of basins of this ecological type can also support *Cladium mariscus* swamp, but *Carex elata* swamp is more frequent, sometimes with much *Menyanthes trifoliata* and grading landwards into a narrow fen fringe of *Carex rostrata–Potentilla palustris* tall herb fen (S27). *Sparganium minimum* sometimes occurs in small pools. Also within this unit are some samples from Pilmoor, Yorkshire that are rich in *Carex elata* but with a superficial cap of *Sphagnum*. The stands are referable to M4 and M5, but water pH and peat trophic status is relatively high, the former reflecting more the telluric water supply to the former (now buried) S1 vegetation rather than the *Sphagnum* surface.

Base-rich, eutrophic

The main vegetational distinction between this type and the preceding is that eutrophic basins tend to be more strongly dominated by vigorous reed (*Phragmites australis*). In general, the cause of the more nutrient-rich conditions is not known. Natural possibilities include a greater proportion of silt and clay in the lining of the basins. In some cases depressions may receive, and be enriched by, land-drainage water (such as edge of Skipwith Common). Drier, ungrazed marginal areas may be a form of *Phragmites–Eupatorium* fen (S25).

6.15.11 Natural status

Many, but not all, of the shallow basins occupied by this WETMEC appear to occupy ground ice depressions. The hollows themselves are thus long-established landscape features, but the status of their contents and water supply mechanisms is much less clear. Some examples (particularly those with more permanent standing water) contain invertebrates which are considered to be late-glacial relict species, perhaps pointing to long-standing habitat continuity. Little has been reported about the stratigraphy and substratum within the Fluctuating Seepage Basins, but an interesting feature is that intact basins often do not have substantial accumulations of peat or sediments. As most of the depressions are shallow and ancient, accumulation of a peat infill, at least up to the level of the mean summer water level, might have been expected. Possible explanations for the absence of this are: (a) fluctuating water levels may have been inconducive to peat accumulation; (b) peat has been removed from the depressions; and (c) the high water tables are relatively recent in origin[1]. We have no evidence for these possibilities, though hydroseral colonisation of some basins by swamp is occurring at present, suggesting that shallow open water may not be a stable state in at least some basins. Even at Pilmoor, where the basin is largely full of peat, this is relatively fresh and quite well preserved and more like a recent deposit than one that has accumulated for some 10,000 years. Overall, it is difficult to avoid the view that many of the hollows have been dug out, presumably for peat, at some stage. At Thompson, some pingo pools are thought to have been former fish ponds.

The natural state of the vegetation in WETMEC 12 basins is also not known with certainty (swamp *versus* herbaceous fen *versus* fen woodland). It is likely that trees growing on the drier surroundings could have overtopped the smaller basins, but if these are hydroseral systems the natural state of the basins themselves would seem mostly likely to be fen woodland, presumably upon fairly consolidated peat. However, at Pilmoor surface acidification and *Sphagnum* invasion has occurred as a late-successional process and the possibility that in some of these sites the natural climax vegetation could be a small ombrotrophic bog, as occurs in some ‘pingo ruins’ in the Netherlands, cannot be dismissed.

Some basins are completely closed, but others have outfalls that flow in high water conditions (some of which may have been dug or deepened). In some sites, a reduction of groundwater levels may have occurred in recent decades, but existing information does not permit clear discrimination between such effects and the natural fluctuations in water level that affect these sites.

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[1] Upwelling chalk water has also been suggested as a possible explanation for some East Anglian examples, but this seems generally to be unlikely as there is little evidence of substantial upflow of groundwater into WETMEC 12 depressions.

6.15.12 Conservation value

A total of 84 wetland species have been recorded from samples of WETMEC 12. Twelve nationally uncommon wetland plant species have been recorded: *Calamagrostis stricta, Carex appropinquata, Carex elata, Cladium mariscus, Epipactis palustris, Eriophorum latifolium, Peucedanum palustre, Philonotis calcarea, Plagiomnium elatum, Ranunculus lingua, Stellaria palustris, Thelypteris palustris.*

The percentage occurrence in NVC communities of samples of WETMEC 12 is: M22: (23%); S02: (15%); S25: (15%); S01: (11%); S27: (7%); W04: (7%); M04: (3%); M05 (3%); M13: (3%); S04: (3%); W02: (3%). Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 12 is given in Table 6.3.

Some examples of WETMEC 12 have considerable conservational value, and may support SAC habitats (see Tables 3.3 and 6.4).

The main swamp plant communities associated with these basins (S1 and S2) are very localised in Britain (especially S1), but both are species-poor and their two main species (*Carex elata* and *Cladium mariscus*) are fairly widespread (much more so than the two communities). In general, the special botanical interest of these basins are species that are not specifically associated with the main swamp communities, such as the aquatic plant *Sparganium minimum* and the rare grass *Calamagrostis stricta.* However, the habitat provided by the basins, in particular the shallow mesotrophic pools (base-rich and sub-neutral), is scarce in Britain, and some basins provide some of the finest examples of hydroseral-like zonations (open water – swamp – fen), which gives them an ecological value that is difficult to express just in terms of species or habitats.

The vegetation of the drier depressions is usually a form of *Juncus subnodulosus–Cirsium palustre* fen meadow (M22), or an 'inundation community'. These communities are not especially notable *per se*, though their occurrence alongside the wetter depressions, contributing to an 'ecological series', may enhance their perceived value

The occurrence of M4 in some examples of WETMEC 12 is of considerable ecological interest and conservation importance. The samples of this community are from Pilmoor and Skipwith Common, near York, but whereas the Skipwith basins seem mostly to be naturally base-poor, at Pilmoor the M4 surfaces have developed serally from a more base-rich *Carex elata* swamp (S1).

Many of the examples of WETMEC 12 are partly grazed. Grazing is particularly a feature of drier grassland between the ground depressions, but some livestock (cattle and horses) make ingress into the wetter areas in summer, sometimes penetrating into the drying swamps or even into the pools. The depression margins are mostly regularly grazed, and the grazed fringe can support populations of *Calamagrostis stricta* and *Sparganium minimum*. It seems likely that grazing incursions may limit scrub colonisation around some of the basins, with the curious effect that in some basins the main stands of scrub occur in the wettest, central locations, beyond the normal reach of grazing animals. [Where this is the case, woody plants are growing on the tops of tussocks, above the normal water level]

Some of the wet ground depressions support a rich invertebrate fauna, with numerous uncommon species (such as Desmoulin's snail *Vertigo moulinsiana*). Some may be glacial relict species (such as the RDB3 water beetle *Hydroporus glabriusculus*), though different ponds may have quite different faunas, even in the same site (Irwin, 1987), probably reflecting hydrological, hydrochemical and management differences. Irwin (1987) considers that the fluctuating water levels (which characterise this WETMEC) "must play a major part promoting the wealth of rare invertebrate species" at Thompson Common. The ground ice depressions at Thompson Common and East Walton Common are particularly rich in notable Coleoptera compared to East Harling Common, Foulden Common and some other sites (Foster, 1983), but it is not known if this reflects hydrological or other differences between these sites.

6.15.13 Vulnerability

The groundwater-fed basins of WETMEC 12 are potentially vulnerable to drainage and a reduction of aquifer levels. However, the relationship between the water table in the basins and that of the mineral aquifer may be complicated. For example, HSI/ECUS (1999) considered that at Thompson Common the relationship, if any, between the water in the pingos and the Chalk aquifer was neither obvious nor, probably, direct. There is a clear need for further investigation of the water supply mechanisms to these basins before an informed assessment can be made of their likely vulnerability to a reduction of aquifer levels. Moreover, in the wetter examples with standing water year round, a reduction of water levels may be expressed mainly as a reduction in the depth and area of standing water which – depending on the values and thresholds involved – may have only limited ecological repercussions. Nonetheless, it is clear that these basins can be, and have been, drained artificially to produce examples with sub-surface summer water tables and quite different (and generally less valuable) ecological characteristics than examples that retain summer standing water.

Examples of WETMEC 12 fed from thin Drift aquifers without known connection to a bedrock aquifer may be particularly vulnerable to general drainage initiatives around the wetland sites, and perhaps to increased evapotranspiration. This may help account for the currently rather dry condition of the small mire basin at Brown Moss. The surroundings of the Pilmoor SSSI, and perhaps the site itself, have experienced considerable drying (Rob, 1947) and this may have lowered the groundwater table in the residual area of mire. Sites such as Pilmoor may thus be particularly vulnerable hydrologically as well as ecologically to scrub encroachment.

Although some of these basins (particularly the drier ones) are partly grazed, the more swampy examples are largely unmanaged, except perhaps for some marginal grazing. It is possible that the swampy basins will gradually become colonised hydroserally and much changed (drier) in character. This begs the question, raised above, of the current status of these basins and the reason for the persistence of open water within them, but it is possible that the basins will need to be cleaned out periodically to maintain standing water and hydroseral gradients. Some tree colonisation has occurred in certain basins, but additional shading can also be created by tree growth on the drier ground around the basins, especially on sites that are so small that trees growing around their edge can form a canopy across them. The extent to which this is perceived as a problem depends partly on the objectives of conservation management. Such shading may have been the natural state of many of these basins, and *Carex elata* swamp (S1) vegetation can survive such conditions. Watts and Petch (1986) report that heavily shaded pools on average contain less than half the number of plant species of unshaded pools, but it is not clear how much of this difference relates to differences in pool size and morphology rather than just the presence of shading (the larger, deeper pools with most habitats and species are also the least likely to be comprehensively shaded). Nonetheless, some very densely shaded pools are almost devoid of plants and tree removal can be associated with an increase in species richness.

Some shading of former S1 vegetation has occurred at Pilmoor (Yorkshire), but another cause of loss of S1 at this site has been seral overgrowth by *Sphagnum*, to produce an unusual species mix (Box 6.23).

Box 6.23: Acidification of WETMEC 12 surfaces at Pilmoor (Yorks)

The main remaining area of wetland at Pilmoor occupies a shallow basin on Drift in the Vale of York. Habitats include quite mature birch woodland, with substantial stands of *Rhododendron ponticum*, patches of heath and several wet sumps in the peaty sand with wetland interest features. The main area of open mire occupies a broad depression within a larger area of *Betula pubescens–Molinia caerulea* woodland, *Sphagnum* spp. sub-community (W4c) and is also subject to some encroachment by birch scrub. In some central areas, including the shaded margins of some pools, *C. elata* is particularly prominent and these stands could be regarded as wooded derivatives of *Carex elata* swamp (S1), but there are no particularly good examples of this community at the site, though it was almost certainly once the dominant feature of the depression. Much of the remaining open vegetation at this site is essentially a form of *Carex rostrata–Sphagnum squarrosum* mire (M5), expressed as an unusual (possibly unique) variant with relict *Carex elata* tussocks puncturing the *Sphagnum* surface.

Stratigraphical cores show that the wet sump was once a shallow pool, thinly lined with clay and occupying a shallow depression within a deposit of sand. This accumulated some lake muds and developed serally into a *Carex elata–Menyanthes–Equisetum* swamp. At some, probably quite recent, stage the surface of this vegetation became colonised by *Sphagnum*, either infilling former gaps between *C. elata* tussocks to create a less tussocky surface than is typical of *Carex elata* swamp, or locally overgrowing the *C. elata* tussocks.

The development of *C. elata* swamp in this shallow depression appears to be comparable with the development of *C. elata* communities in ground hollows in Norfolk (such as Foulden Common, Thompson Common), but the subsequent development of a *Sphagnum*-rich surface may be unique to this site. It seems unlikely to be a consequence of contrasting climatic conditions, as precipitation and potential evaporation values are fairly similar (Pilmoor ppt: 617 mm; PE: 600 mm; Foulden Common ppt: 625 mm; PE: 613 mm). Nor do differences in the hydrochemical characteristics of the basins (Table 6.45) provide a very convincing explanation: whilst water retrieved from Pilmoor (November, 2003) was less base-rich than water collected in December 1999 from a *Carex elata* pingo embedded within sandy drift at Foulden Common, the differences were not great. It seems likely that the real difference between the two sites is that at Pilmoor the telluric water table is consistently low, where the *surface* of the vegetation mat is supplied by proportionately more precipitation than is the case at Foulden, so the surface may now be effectively ombrotrophic. It is possible that this development may have been stimulated by the apparent long-term reduction of water tables in the vicinity of Pilmoor, reported by Rob (1949).

Oligotrophic and mesotrophic pools are potentially vulnerable to nutrient enrichment, especially through inputs of land drainage water. It is possible that the dominance of reed in a large depression in the south-east corner of Skipwith Common may be a product of surface water inflow from adjoining fields, although in general this site seems to be water shedding.

6.16 WETMEC 13: Seepage Percolation Basins

6.16.1 Outline

This category is essentially a groundwater-fed topogenous wetland, most often with a quaking or buoyant surface, in which high water tables are maintained near the vegetation surface for much or all of the year. Some (particularly small) examples may receive groundwater upflow across the basin width, but others appear to be fed mainly by lateral groundwater flow through, or below, the loose surface layers, and across a more consolidated wetland deposit of peat, marl or gyttja. The basins often have an outflow that is visible year round, but there is usually no visible water flow within the stands (Figure 6.37).

6.16.2 Occurrence

Example sites: Blackend Spinney Fen, Booton Common, Bryn Mwcog, Cors Geirch, Cors Goch, Cors Hirdre, Cors y Farl, Cothill Fen, Denny Bog (west), East Walton Common, Great Cressingham Fen, Greywell Fen, Tarn Moss (Malham), Newham Fen, Newton Reigny Moss, Parc Newydd, Shortheath Common, Smallburgh Fen, Sunbiggin Tarn and Moors, Upton Fen and Doles, Wilverley Bog

Outlier sites: Silver Tarn, Wybunbury Moss

A widespread but generally uncommon unit found scattered throughout the survey area. The Wybunbury Moss outlier samples are anomalous in that they represent a buoyant ombrogenous system (WETMEC 2) in which surfaces loosely referable to WETMEC 13 have become established locally in response to partial drainage and penetration of telluric water. The distribution of examples in sites sampled is shown in Figure 6.36.

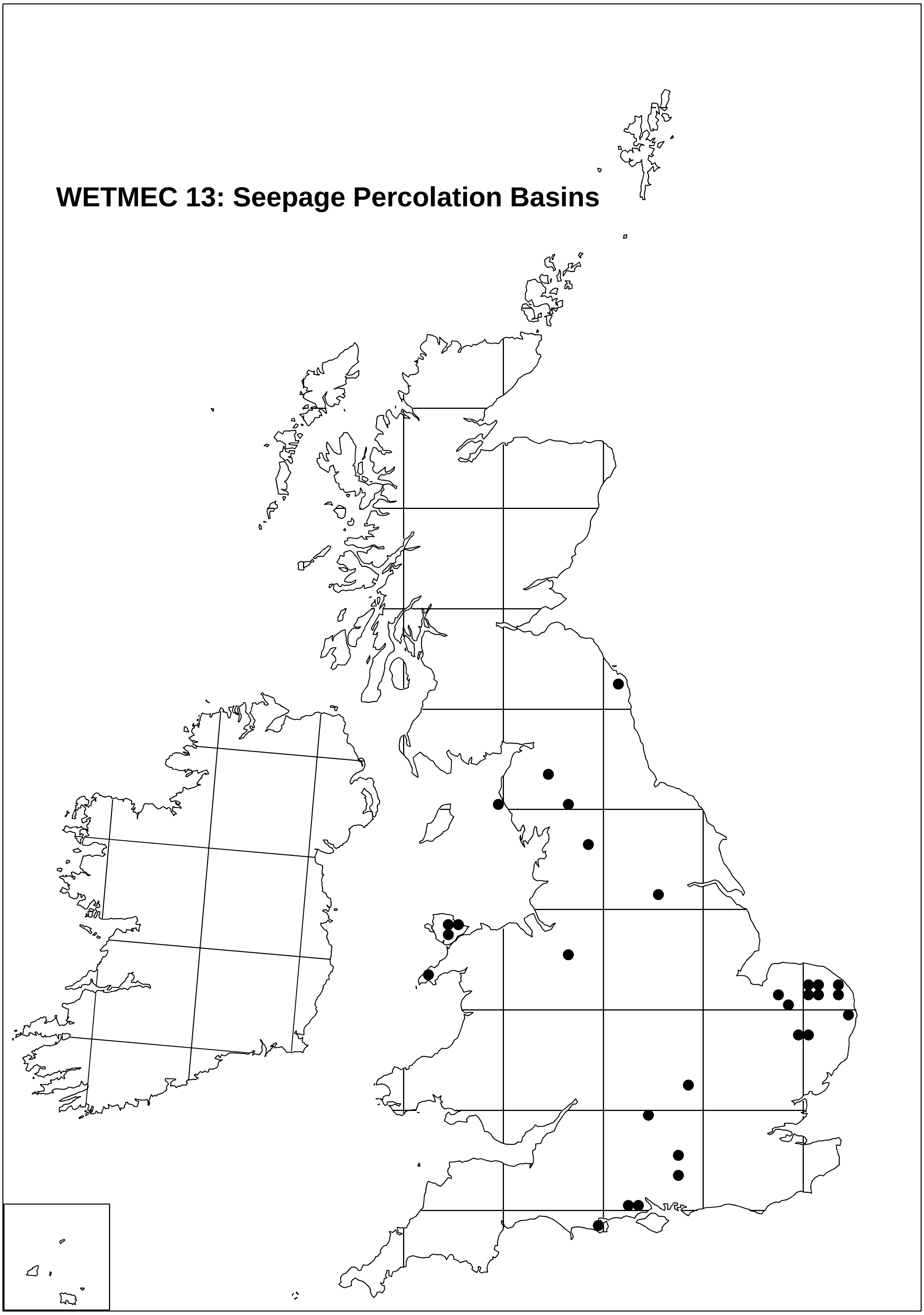

Figure 6.36 Distribution of examples of WETMEC 13 in sites sampled in England and Wales

6.16.3 Summary characteristics

Situation	Basins, valleyhead basins, river floodplains (mostly margins), soligenous seepages (rare and very small).
Size	Mostly small (<10 ha) basins; some tiny examples embedded in seepages.
Location	Widespread in survey area, but generally uncommon.
Surface relief	Even (appears more or less flat, but gently slopes to river or outfall).
Hydrotopography	Rheo-topogenous.
Water: ***supply***	Groundwater.
regime	Water table typically near surface, especially where the surface is buoyant, but can be quite variable.
distribution	Upflow or lateral near-surface flow.
superficial	May contain shallow pools or adjoin a groundwater-fed water body.
Substratum	Unconsolidated muds or peat (sometimes over lake marl). Peat sometimes has bands of calcite but not normally much other mineral material. Sometimes floored by a sandy deposit, but mostly underlain by silts/clays.
peat depth	Sometimes shallow but often deep (2–4 m).
peat humification	Upper layer is buoyant or loose and fresh, often a hydroseral infill. Underlying peat varies in humification. Where present, thick basal peats are typically strongly humified and solid.
peat composition	Variable. Loose upper layers most typically herbaceous–moss peat (mainly hypnoid mosses, or *Sphagnum* in less base-rich contexts), but may also be sedge, reed or brushwood peat. Moss peat is sometimes quite thick. In floodplains, basal peats are often dense brushwood peats.
permeability	Surface layer mostly of high to moderate permeability. Basal substrata often of moderate to low permeability.
Ecological types	Range from base-rich to base-poor, eutrophic to oligotrophic, depending mainly on groundwater source and substratum characteristics. Most examples are base-rich/sub-neutral and eutrophic/mesotrophic.
Associated WETMECs	May be adjoined by WETMEC 10 or WETMEC 11 sites on marginal slopes. Tiny examples are sometimes embedded within seepages. In floodplains, can grade riverwards into WETMEC 5 or WETMEC 6 sites.
Natural status	Some Seepage Percolation Basins appear to be more or less natural, but many examples are associated with reflooded turbaries.
Use	Many are former peat workings. A few support top-quality reedbeds. Some are unmanaged. Some former examples have been converted to farmland, at least in part.
Conservation value	Important mainly for oligotrophic/mesotrophic semi-floating vegetation (SAC habitat) and reedbeds (mainly birds and invertebrates).

Vulnerability	Main threat to some floodplain examples has been indirect drainage (river deepening), but also vulnerable to reduction in groundwater supply. Many examples are subject to dereliction and hydroseral succession. The latter can be associated with consolidation or acidification of buoyant surfaces.

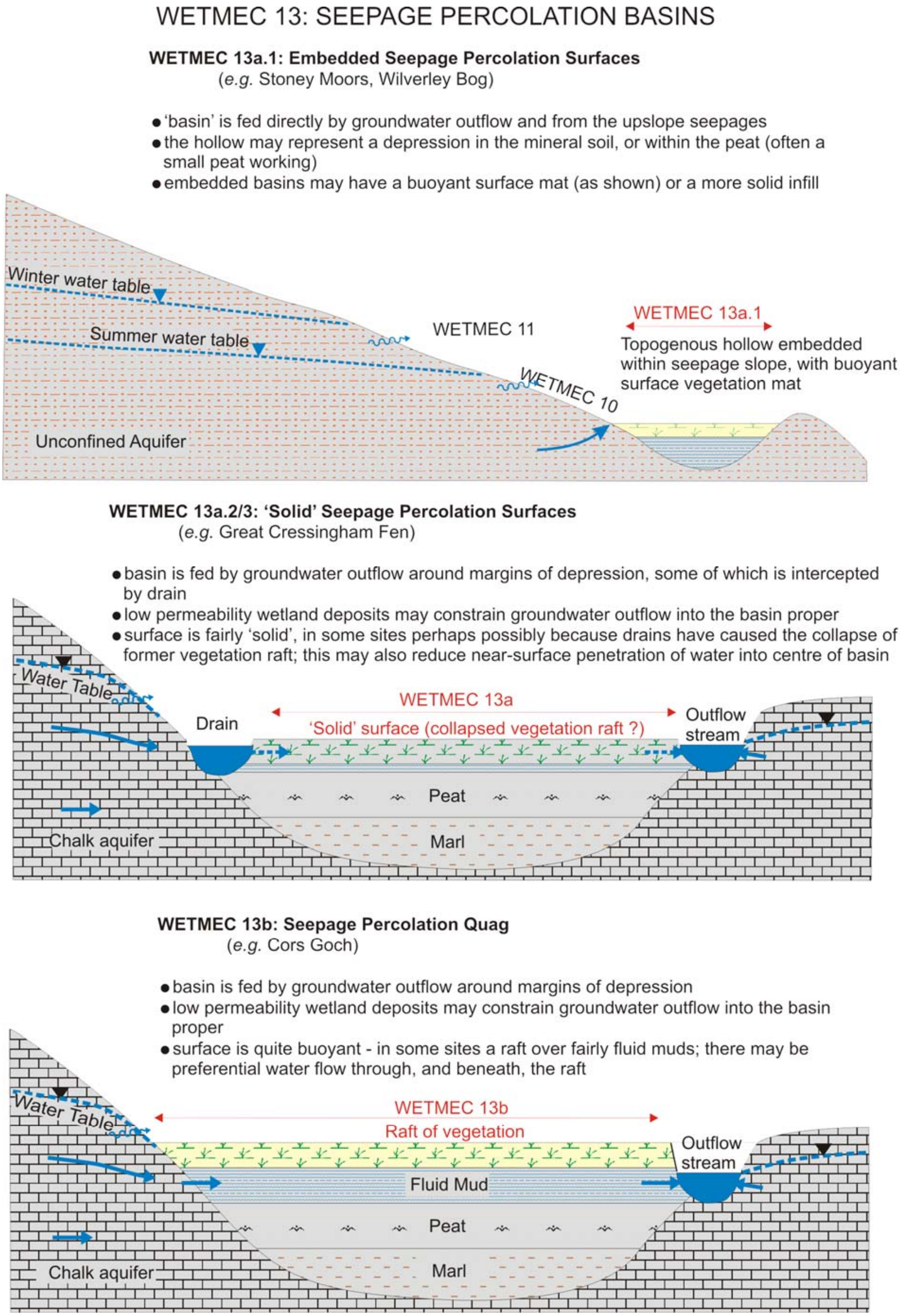

Figure 6.37 Schematic sections of types of Seepage Percolation Surface and Seepage Percolation Quag (WETMEC 13)

6.16.4 Concept and description

CLUSTERS: 21, 22, 23, 24

This variable type of wetland occurs primarily in topogenous depressions, usually ground hollows, pingos, valley bottoms and sumps (sometimes former turbaries) within certain other wetland types, and near the upland edge of some floodplains or large basins where groundwater inputs occur. Small examples can occur in depressions embedded within soligenous seepage complexes. Its character can be seen clearly in situations where a topogenous hollow is fed by strong springs discharging around the margin. Unless the spring flow is intercepted by drains, the groundwater appears to percolate through the topogenous wetland, particularly over or near the surface, or along sub-surface preferential flow paths such as beneath buoyant vegetation mats (most often in reflooded, part-terrestrialised) peat workings, to a (natural or artificial) outfall.

Seepage percolations can also occur at the edge of floodplains, sometimes beneath soligenous seepages on the adjoining upland slopes, feeding down across a gently sloping valley bottom into a surface water unit (WETMEC 5) near the river course. Smallburgh Fen (Norfolk) provides the most intact known example of this. More often the zone of fen nearer the river has been drained, leaving the seepage percolation unit as a remnant close to the upland margin which discharges into a drier topogenous unit or into a drainage system (such as Arne Moors, Upton Fen, Thelnetham West Fen).

Seepage Percolation Basins may contain one or both of two rather different elements: (a) a seepage surface which receives direct groundwater outflow from the mineral aquifer; and (b) a phreatic unit, which does not directly receive seepage but which is fed by lateral flow of discharged groundwater, usually near to the surface. This latter unit occurs in situations where there is resistance to upward groundwater flow, because of low-permeability peat, marl or clays within the substratum, and is not a feature of all sites. Resistance to sub-surface flow by the wetland substratum constrains the area over which this supply mechanism can maintain wet surface conditions. Most examples of WETMEC 13 have quaking or buoyant surfaces, often formed from a loose hydroseral infill of rhizomes and peat. In some cases this appears to be natural, but many examples have developed within reflooded peat workings. It is thought that preferential water flow occurs through or beneath the surface mat. In some instances, the groundwater reaching such turf ponds is distributed from the point of outflow by the surface water system (dykes) (such as Upton Broad) (van Wirdum *et al.,* 1997).

Although fed by groundwater flow, unlike a soligenous seepage face which is kept wet primarily by a high rate of water supply, the wetness of a Seepage Percolation Basin is also a function of its topography and in some cases, water levels can be regulated by detention of the groundwater (and any other inputs) by sluices or natural outfalls, as well as by rates of supply. Thus flow rates are likely to be slower, and accumulated water deeper, than on a soligenous slope or in Seepage Percolation Troughs (this provides a basis for distinction from seepage faces that sometimes occur on the bottom of open basins).

Affinities and recognition

WETMEC 13 is a quite variable unit, based upon four closely related clusters from the multivariate analysis, each of which corresponds to one of the sub-types recognised. The unit is essentially a topogenous equivalent of a permanent seepage slope (WETMEC 10), differing primarily in that the high water table is maintained by topogenous constraints and the loose quag surface. The two WETMECs frequently occur together. This is most obvious and characteristic where the lower slopes of a basin are occupied by WETMEC 10 and the bottom by WETMEC 13, but in some instances the relationship is inverted, as when small depressions within WETMEC 10 form tiny examples of sub-type 13a basins. [In Phase 1 such samples clustered with permanent seepage slope samples, but in this analysis they were clustered within WETMEC 13]

The difference between WETMEC 13 and WETMEC 12 (Fluctuating Seepage Basins) is analogous to the difference between a permanent seepage slope and an intermittent seepage, primarily that the water level in a Seepage Percolation Basin is usually more stable than that in a fluctuating basin. This may be because the groundwater table is itself more stable, with higher rates of lateral groundwater flow than in WETMEC 12 basin, but another control is that the surface of a seepage percolation fen is often partly buoyant, so that vertical mobility of a raft or expansibility of a loose peat infill provides some buffering against water level change. The loose peat and mud beneath the surface layer may also provide a sub-irrigation pathway. Capacity for raft formation depends partly on basin morphometry, and is a particular feature of deeper basins.

WETMEC 13 also shows affinities with WETMEC 14 (Seepage Percolation Troughs) and 15 (groundwater-fed soakways and water tracks). A main distinguishing feature is that the latter are linear and usually sloping features, with clearly directional flow (when visible), but the two categories can be difficult to distinguish in some flat, linear situations. Moreover, patches of WETMEC 13 sometimes occur embedded within WETMEC 14, in locally wet sumps (such as Cranes Moor), which may sometimes represent hollows created by peat excavation. An additional difference is that WETMEC 13 typically has deeper peat, and very often a more buoyant surface and looser sub-surface layer, than does WETMEC 14. WETMEC 13 also has strong affinities with WETMEC 20 (Percolation Basins) and differs mainly in the absence of significant surface water inflows into WETMEC 13.

6.16.5 Origins and development

The development of WETMEC 13 surfaces is variable, reflecting the variable circumstances in which it occurs. The WETMEC occurs in small basins which are often referred to as pingos (such as East Walton Common), but is not particularly common in these (which more usually support WETMEC 12). It more typically occupies somewhat larger basins (such as Cors Goch; Great Cressingham Fen). Although these do not constitute the commonest situation for WETMEC 13 in the current dataset, these have some claim to represent the most characteristic, and in some instances perhaps natural, situation for this wetland type, as they represent the main circumstance in which it occurs elsewhere in Britain. Some details of the development of WETMEC 13 surfaces in basins are available for Cors Goch and Great Cressingham Fen (Box 6.24).

Some examples of WETMEC 13 occur along the edge of bigger wetland basins and floodplains, apparently in locations with particularly strong groundwater outflow from a mineral aquifer. In some instances, much of the former wetland further from the margins has been drained and converted into farmland, as at Newham Fen (Box 6.25). One of the most interesting ontogenic examples of WETMEC 13 occurs at Smallburgh Fen (Norfolk) (Box 6.25), where it occupies the marginal zone of a small floodplain. The pattern of development and juxtaposition of WETMECs at Smallburgh corresponds quite well with the development of some types of *Durchströmungsmoore* in small river valleys in Northern Germany, as described by Succow (1988), and is one of the few such examples amongst the study sites. This may be because in many cases river valley wetlands have been partly drained and modified, and the former occurrence of WETMEC 13-type surfaces within them is difficult to assess. On a semantic point, the epithet 'Seepage Percolation Basins' may be inappropriate for the river valley *Durchströmungsmoore* of Succow (1988), but all of the examined examples of WETMEC 13, including Smallburgh Fen, are in a basin context.

Although drainage initiatives may have reduced the area of WETMEC 13, in some instances (such as Newham Fen), many of the known examples of WETMEC 13 occur within reflooded turbaries, some in locations which almost certainly never naturally supported this wetland type.

Box 6.24: Examples of WETMEC 13 development in basins at Great Cressingham Fen (Norfolk) and Cors Goch (Ynys Môn)

Great Cressingham Fen

Parts of Great Cressingham Fen, examined by B.D. Wheeler and R.P. Money (unpublished data) provide a good example of the development of this wetland type, and perhaps one which has not been subject to turbary. It represents a developmental sequence from marl lake which appears naturally to have stabilised in an herbaceous community, locally rich in mosses and with relatively few woody plants, rather than in fen woodland (monocot-moss peat has replaced an early phase of carr). This is illustrated by the following representative core taken near the SW corner of the mire:

Depth bgl	Characteristics
0 – 10 cm	Loose and unsampled
10 – 110 cm	Herbaceous monocot-moss peat, more humified below 45 cm
110 – 160 cm	Well-humified, black, rather amorphous peat with some monocots and wood
160 – 420 cm	Khaki marl

The first two phases of wetland development (a marl-precipitating lake colonised by swamp and carr) can be interpreted as normal terrestrialisation, but the third phase (monocot–moss peat) is generally less common in Eastern England. Various explanations are possible, the most likely being that it represents a development of hydrological mechanisms in which the groundwater discharge which originally supplied the lake has, due to the accumulation of low-permeability lake and perhaps peat deposits, become more focussed into lateral near-surface flow across the deposit, thereby creating a consistently wet environment suitable for the development of a largely herbaceous, moss-rich fen. The site is now fed by strong springs which discharge above the level of the fen, but these are now largely intercepted by a catchwater drain. In consequence there is probably now relatively limited lateral flow of water across the site, the extent of a buoyant surface is relatively small, and ungrazed locations are readily invaded by woody plants.

Cors Goch

The stratigraphy of the north-east basin of Cors Goch has been examined by Gilman and Newson (1982) and T. Huggins (unpublished data). It consists of a deep (nine metre) hollow, partly lined by a basal layer of lacustrine clay. In the shallower margins this clay is covered by one to three metres of marl and thence by two to three metres of peat, but in the deepest parts the marl is replaced by a deep deposit described as detritus mud or gyttja, with bands of marl and peat. This has largely become capped with two to three metres of peat, but in places comes close to the surface and some of the present pools may have direct continuity with the late-glacial lake. There is little evidence in the stratigraphy of carr development, but the present buoyant surfaces show patchy scrub encroachment, mainly associated with small, acidifying patches. These latter suggest that, at least in the climate of Môn, these calcareous basins may naturally develop ombrogenous surfaces (and raises the possibility that the present surface character could be a product of former turbary). Studies in the Scottish Borders (Tratt, 1998) suggest that many of the calcareous basin mires there (which seem to be referable to WETMEC 13) are essentially reflooded eighteenth century peat and marl workings which probably mostly had ombrogenous surfaces before they were excavated; in some sites, this seems rapidly to have redeveloped.

Box 6.25: WETMEC 13 development at Newham Fen (Northumberland) and Smallburgh Fen (Norfolk)

Newham Fen

Newham Fen (see also WETMEC 8) represents the remnant of a once larger wetland complex (Embleton's Bog), most of which occupied the site of a long-terrestrialised, large late-glacial lake basin. The current patch of WETMEC 13 occupies the site of a shallow and non-persistent water body (Newham Lough) which was not part of the original late-glacial lake, but which seems to have formed where groundwater outflow from an adjoining esker discharged into the wetland (Wheeler and Shaw, 1998). It seems likely that the accumulation of peat within the main lake basin may have helped to restrict drainage of discharge water from the eastern margin and may have contributed to the maintenance of a series of small, spring-fed pools. It is not clear to what extent the occurrence of a larger body of open water (Newham Lough) is natural or a partial consequence of deliberate management as a fish pond (Wheeler and Shaw, 1998). In the nineteenth century Newham Lough showed a strong tendency for terrestrialisation, but it is difficult to assess to what extent this was determined by natural autogenic accumulation of peat, the absence of fish pond management or the drainage of the main area of Embleton's Bog to the west of the Lough. However formed, the former pools and swamp became largely converted to calcareous quag referable to WETMEC 13.

The provenance of groundwater supply to this site is uncertain. A borehole close to the mire (Kershaw, 1997) indicated that the uppermost layer of Drift had some water at 2.4 m bgl but that it confined lower sand and gravel layers which were more significantly water bearing. The Drift is underlain by the Middle Limestone Group bedrock, which provides a multi-layered aquifer. At least three sandstone beds held a good water supply, and an aquifer at 94 m bgl was quite strongly artesian, with an estimated head of some 2.2 m agl (Kershaw, 1997). However, it is not clear to what extent the bedrock layers are interconnected hydraulically, or with the Drift aquifer. Newson *et al.* (2002) raise the possibility that unmapped faults (associated with a mapped ENE–SWS fault just south of the fen) might facilitate the upwelling of a deep bedrock aquifer.

Smallburgh Fen

Smallburgh Fen (Norfolk) occupies a small floodplain of a tributary stream of the River Ant (Broadland). The stratigraphy of this site (Wheeler, Shaw and Wells, 2003) is indicative of a small terrestrial lake basin, with deposits of gyttja and lake marl. It is not known whether the topographical constraints which permitted a water body to form and persist in this side-valley location were created mainly by peat accumulation on the River Ant floodplain downstream, or if it was accommodated within a shallow mineral basin. In the north part of the fen near the Dilham stream, the initial lake deposits were replaced largely by sedge peat, whereas in the south near the land margin monocot-moss peat was prominent, forming a banded profile with shallow marl layers. Although wood fragments occur scattered in the profiles, there is no stratigraphical evidence for extensive fen woodland throughout the ontogenesis of this mire, even in the northern part of the site which is currently covered by alder carr. The surface of this fen now slopes gently northwards to the Dilham stream. The southern edge appears to be fed by groundwater outflow from the upland margins, and an example of WETMEC 13 occurs on relatively loose peats sandwiched between the upland and the northern part of the mire, which is episodically flooded by the Dilham stream and generally has a more consolidated peat infill.

6.16.6 Situation and surface relief

The majority (around 50 per cent) of Seepage Percolation Basin samples were from valleyhead contexts, usually from quaking sumps embedded within some other type of mire. Twenty-nine per cent were recorded from basins and 15 per cent from marginal floodplain locations. Five per cent were from valley-bottom troughs and two per cent from the margins of some groundwater-fed lakes. The outlier at Wybunbury Moss is in a largely ombrogenous basin site where secondary penetration of groundwater from the northern margin has created conditions analogous to WETMEC 13.

The surface is generally even; it may appear flat, but gently slopes to river or outfall. Most examples were taken from apparently flat locations, but a few were from gently sloping surfaces (Table 6.47).

6.16.7 Substratum

Some examples of WETMEC 13 (those embedded within soligenous seepages) can occur over a shallow, almost skeletal substratum, but the majority have a considerable depth of wetland infill (mean of 2.5 m) (Table 6.48) (the maximum depth (15 m) refers to the rather anomalous basin of Wybunbury Moss). The nature of the infill varies, but many of the deeper basins have a basal deposit of gyttja or marl. The surface layer is often loose, sometimes buoyant and treacherous, semi-floating over liquid muds and peat, or forming an expansible quag (Table 6.47). In shallower examples unconsolidated material may extend to the bottom of the basin (or to the basal muds), but very often – and especially in the reflooded turbaries – it is underlain more by solid peat. The basal substratum is very variable. Some examples – mostly those embedded within seepages – are floored by a sandy deposit, but the majority are underlain by silts and clays, the latter sometimes of lacustrine origin.

Table 6.47 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 13

	Mean	1	2	3	4	5	6	7
Surface layer permeability	5.9		1	4	4	22	40	31
Lower layer permeability	3.8		26	28	13	15	11	7
Basal substratum permeability	3.6	16	33	19	12	13	7	
Slope	1.2	96	4				X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.16.8 Water supply

Examples of WETMEC 13 are thought to be groundwater-fed, though frequently there is only limited surface evidence for this. Small examples embedded within seepage systems are clearly groundwater-fed and in some basin sites (such as Great Cressingham Fen), the basin slopes support seepages and strong springs which feed into the residual topogenous WETMEC 13 areas. However, other sites are notable for the absence of obvious groundwater outflows around the basins. For example Cors Goch, one of the best examples of WETMEC 13, has only a narrow adjoining band of weak intermittent seepages and at the nearby Parc Newydd even these are largely absent. Likewise, there is no visible evidence of groundwater discharges at Newham Fen, where the WETMEC 13 area is bordered abruptly by the sharply rising slopes of a dry esker bank. In the Scottish Border mires, basins which appear referable to WETMEC 13 often have visible evidence of groundwater outflow, both in marginal springs and seepages and directly into the bottoms of the basins. These latter discharges may take the form of deep (more than three metre) spring pools, known locally as ‘well eyes’, which are continuous through the basin infill from the surface to the bedrock. They appear to represent localised discharges from fractures in the underlying Silurian Greywackes. No features comparable to ‘well eyes’ have been observed in any sites examined in this study, except perhaps for a strong spring arising within a small ground hollow at East Walton Common (Norfolk).

In many cases, in the absence of relevant hydrometric data, groundwater outflow into WETMEC 13 basins can only be inferred from their broad hydrogeological characteristics. Uncertainties can arise particularly about groundwater provenance, as at Newham Fen (Box 6.25). Nor is the likely magnitude of groundwater outflow into some basins very clear. Some (such as Cors Goch, Box 6.25) are lined with clay deposits and have an infill of gyttja or marl, which is likely to be of low permeability; in the absence of 'well eye' flow paths, it is possible that groundwater outflow into some of these basins may be modest, and that wet conditions are largely due to the retention of water within the topogenous basins. Nonetheless, the majority of WETMEC 13 basins mostly have some surface water outflow year round.

Some examples of WETMEC 13 may receive little direct surface water run-off, especially where the site is separated from the upland by a catchwater ditch or where, as is the case with some of the pingos, the local surface water catchment is trivial. Other examples doubtless receive some rain-generated run-off and some, such as Newton Reigny Moss, receive inputs from under-drainage from adjoining fields. However, basins which have significant stream inflows have generally been clustered within WETMEC 20 (Percolation Basins), or are transitional to this (such as Silver Tarn, Cumbria).

6.16.9 WETMEC sub-types

WETMEC 13a: Seepage Percolation Surfaces

CLUSTER: 21

> *Examples at*: Badley Moor, Blackend Spinney Fen, Booton Common, Cors Bodeilio, Cors Erddreiniog, Cors Hirdre, Cors Nantisaf, Cothill Fen, Denny Bog (West), Great Cressingham Fen, Greywell Fen, Newton Reigny Moss, Sunbiggin Tarn and Moors, Swannington Upgate Common, Whitwell Common, Wilverley Bog

The distinctive feature of this variable unit is that most examples are located on fairly shallow peat (though this is sometimes underlain by a deeper deposit of marl). Many also have a fairly solid surface, or support soft (rather than quaking) accumulations of peats and organic muds. A few (very small and shallow) examples have a semi-floating surface, sometimes with virtually no solid material between the vegetation mat and the basal substratum. In some regards, these have more in common with examples of sub-type 13b than with the solid examples of 13a, and they have been clustered together within 13a probably because of their shallow depth of peat. Examples of this sub-type, including all of the semi-floating examples, are often embedded as small basins, sometimes reflooded peat workings, within a seepage complex.

WETMEC 13a is perhaps too variable and ill-defined to provide very useful ecohydrological units. However, its segregates at the 72-cluster level, although intergrading, form more discrete and distinctive sub-units:

> **13a.1**: Small hollows embedded within seepage slopes (such as Booton Common, Cors Geirch, Greywell Fen, Stoney Moors, Wilverley Bog) or spring mounds (such as Badley Moor). These are transitional to WETMEC 10 (and in the Phase 1 analysis, samples clustered here were then grouped with the Permanent Seepage Slopes). Some of these can have quite strongly quaking surfaces.

13a.2: Shallow seepage basins on generally thin peat. This includes examples in shallow ground depressions and peaty sumps (such as Blackend Spinney, Cors Bodeilio, Cors Hirdre, Sunbiggin Tarn and Moors, Swannington Upgate Common) as well as shallow basins within turbaries (such as Swangey Fen).

13a.3: Peaty sumps (often old turbaries) on deeper peat infill in broadly topogenous contexts (such as Blo' Norton Fen, Cothill Fen, Great Cressingham Fen, Newton Reigny Moss, Thelnetham Middle Fen). Examples with strongly quaking surfaces are transitional to WETMEC 13b.

Sub-types 13a.1 and 13a.2 are mostly clearly part of seepage systems; their shallow basins may be fed both by lateral flow and upflow. However, the deeper basins of sub-type 13a.3 may have substantial accumulations of low-permeability deposits (such as marl), and groundwater inputs may be primarily by inflow from the margins. For example, at least one of the topogenous basins at Parsonage Moor (Cothill Fen) is thought to be supplied mainly by water flow from the margins, though there may now be upflow in some locations where excavations have penetrated deep into the marl; Great Cressingham Fen[1] also receives inputs from springs and seepages on the slopes adjoining the basin (Box 6.24). Both sites have a considerable thickness of marl in their basins.

The substratum of some examples of sub-types 13a.2 and 13a.3 is probably naturally solid, especially in some of the shallow basins, but in others it may represent former semi-floating surfaces which have either consolidated by ongoing accumulation of peat, or have become 'grounded' because of a lowering of water tables. Some examples of the sub-type 13a.3 are transitional to some of the wetter examples of WETMECs 8 and 9, and it seems likely that some stands allocated to these WETMECs (such as Thornhill Moss, Cumbria) may have provided examples of WETMEC 13 before part-drainage of the valley bottoms in which they occur.

WETMEC 13b: Seepage Percolation Quag

CLUSTER: 22

Examples at: Arne Moors, Bryn Mwcog, Cors Bodeilio, Cors Goch, Cors y Farl, East Walton Common, Tarn Moss (Malham), Newham Fen, Parc Newydd, Shortheath Common, Silver Tarn, Smallburgh Fen, Sunbiggin Tarn and Moors, Upton Broad, Wybunbury Moss

This is the most widespread sub-type and is particularly characteristic of WETMEC 13. It differs from sub-type 13a in that the surface has developed (usually as a quaking raft or an expansible loose infill) over muds and water and in some cases may be actively encroaching upon residual open water. Some wet groundwater-filled hollows in valleyhead locations (such as East Walton Common) are clustered here. These are part of the valleyhead seepage system and have some similarities with sub-type 13a, except that they are generally bigger and have a fen raft and, in some cases, residual open water (Figure 6.37). This category includes some of the biggest and best examples of WETMEC 13, such as Cors Goch. Basins allocated to this WETMEC 13b can contain open water, swamp and fen, sometimes arranged in a more or less concentric hydroseral sequence, especially around the deeper basins. The fen phase typically forms a quaking raft, which may cover the entire former water

[1] Parts of Great Cressingham Fen once (1986) supported a semi-floating vegetation raft and could have been referred to sub-type 13b, but this structure appears to have consolidated.

body in the smaller basins. However, stands at the open water transition have been clustered into a separate cluster (23), which has been allocated to WETMEC 13c.

Some examples of this WETMEC represent wet, quaking or semi-floating sumps within a valleyhead mire system as, for example, at Shortheath Common (Hampshire). Examples also occur in wet sumps, probably reflooded peat workings, on deep peat in some New Forest valley bottoms (such as Cranes Moor).

WETMEC 13c: Seepage Percolation Water Fringe

CLUSTER: 23

> *Examples at*: Barnby Broad, Cors Erddreiniog (Llyn yr wyth Eidion), Cors y Farl, Sunbiggin Tarn and Moors, Upton Broad

WETMEC 13c has many similarities to 13b (Figure 6.37) and a case could be made for considering them as a single unit, but 13c was allocated to a separate cluster at the 36-cluster stage of the multivariate analysis and is treated as a separate category. Essentially it represents the open-water transition margin of WETMEC 13b, and the two may form part of a single vegetation mat, differing only in the distance from open water. However, examples of 13c can occur in the absence of 13b (such as Llyn yr wyth Eidion; Sunbiggin Tarn). Typically 13c forms narrow, quaking mats around open water, semi-floating on fluid muds or lake sediments. The water regime and source is effectively that of the lake, but examples may also receive some groundwater outflow from landward sources. This WETMEC thus occurs around pools which may be fed both by lateral flow from the margins and, in some cases at least (such as East Walton Common, Upton Broad), by upflow into the basin. It is not known whether sites such as Llyn yr wyth Eidion, which occupy a Till-lined basin and contain thick deposits of marl and gyttja, also have significant groundwater upflow.

Vegetation mats at two of the Broadland sites allocated to this unit can support much *Sphagnum,* even close to the water's edge. Presumably this reflects an absence of much inundation with telluric water consequent, at least in part, upon the buoyancy of the mat.

WETMEC 13d: Distributed Seepage Percolation Surface

CLUSTER: 24

> *Examples at*: Broad Fen, Dilham, Upton Fen and Doles

Cluster 24 contains just (some) stands from Upton Fen and Broad Fen (Dilham) and is rather distinct from sub-types 13a-c in terms of its water supply mechanism. A case could be made for considering it an independent WETMEC, but this has not be done in view of its clear similarities, both ecologically and floristically, with some other WETMEC 13 samples. The main difference of this unit from sub-types 13a-c is that the 13d basins are reflooded peat workings located over quite deep peat and/or clay, which do not appear to receive direct groundwater outflow from the mineral aquifer. Instead, they form a phreatic unit which receives surface water sourced in large measure by groundwater outflow, but distributed by the surface water system (dykes). Water feeds into the former turbaries from the dykes, into the residual pools and beneath the rhizome rafts of semi-floating mats of fen vegetation. In the schematic diagram for WETMEC 13d in Figure 6.37 (which is loosely based on the arrangement at Upton Broad and Fens) the Broad basin and rafts of vegetation around it form WETMEC sub-types 13b and 13c, whilst the turf ponds which receive water from this *via* the dyke system constitute sub-type 13d.

There is only limited evidence for the postulated distributed percolation process, but at Upton Fen van Wirdum *et al.* (1997) found no evidence for direct discharge of groundwater into sub-type 13d turf ponds (which were consistently underlain by clay); however, there is evidence for a hydraulic gradient from the dyke system into the turf ponds, at least in summer (A. Baird and R. Money, unpublished data). It is not known to what extent the percolation process is driven by a water gradient across the fen as a whole, or is a more local summer process associated with the WETMEC 13d turf ponds and driven mainly by evapotranspiration losses.

The WETMEC 13d water supply mechanism is not very different from that proposed for WETMEC 6 (Surface Water Percolation Floodplains), except that: (a) the main telluric water source is groundwater outflow; (b) water flow is from the land margins to the watercourses rather than the reverse; and (c) in some sites, there is a tendency for the semi-floating surfaces not to flood with telluric water, creating the potential for considerable acidification and spread of *Sphagnum*.

As with the turf ponds of WETMEC 6, filling and consolidation of the peat in the turbaries may considerably reduce sub-surface water percolation and lead to surface drying in summer. There is possible evidence for this in the rather dry old turf ponds in the Doles at Upton Fen, especially those well separated from dykes, though without further investigation it is not possible to disentangle this process from the effects of water table drawdown across the fen, toward the drained Levels.

6.16.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 13 are summarised in Table 6.48. Seepage Percolation Basins have one of the highest mean summer water levels of all of the WETMECs. The mean value, which is very slightly above the surface, reflects the occurrence of a buoyant vegetation mat, or expansible loose peat infill, the surface of which can move to accommodate some changes in water level. Nonetheless, water levels can be both well below and well above the surface. Low water levels are a particular feature of examples with a solid surface (WETMEC 13a), but even with buoyant surfaces, the position of the surface can vary considerably in relation to the water table: immature quaking swamp surfaces can be permanently flooded, whereas small 'boils' of more mature vegetation can have a surface elevated well above the water table. Interestingly, elevated 'boils', sometimes with a range of more dry-requiring species, can frequently occur over particularly buoyant surfaces in locations which rarely flood. There is evidence for a strong increase in redox potentials upwards in semi-floating mats (Giller and Wheeler, 1986b; Sellars, 1991), related to absence of saturation at the very surface and, perhaps, to photosynthetic oxygenation by moss carpets. Such conditions favour a number of the more anoxia-sensitive species, both wetland and dryland, and almost certainly help to account for the rich diversity of plant species that is sometimes found in the vegetation of WETMEC 13.

Another feature frequently associated with buoyant surfaces is that quite extensive carpets of *Sphagnum* can occur as a more mature seral development, even in sites fed by calcareous groundwater (such as Barnby Broad, Cors Goch, Parc Newydd, Upton Broad). This appears to be due to surface acidification, because the surface of the raft is fed predominantly by precipitation with little influence from the underlying telluric water. This feature occurs particularly in sites with buoyant surfaces and relatively stable (for example, sluice or cill-regulated) water tables, but it can also occur in sites lacking such topographical control on water tables when the vegetation mat is sufficiently buoyant. In some of the calcareous basin fens of the Scottish Borders, Tratt (1998) shows evidence of *Sphagnum* dominance in WETMEC 13-type sites related to the thickness of the buoyant mat (most *Sphagnum* is associated with relatively thin rafts), and that the occurrence of a buoyant raft is related, in some degree, to the morphometry of the basins.

Table 6.48 WETMEC 13: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	2.5	0.1	15.0
Summer water table (cm)	1.4	–16.7	50.0
Rainfall (mm a^{-1})	829	601	1,412
PE (mm a^{-1})	594	467	646
Water pH	6.2	3.9	8.3
Soil pH	6.4	4.3	7.6
Conductivity (μS cm^{-1})	380	38	1,070
K_{corr} (μS cm^{-1})	379	36	1,070
HCO_3 (mg l^{-1})	199	0	725
$Fertility_{Phal}$ (mg)	11	4	28
Eh^{10} (mV)	252	84	437

See list of abbreviations in Appendix 1

Many examples of WETMEC 13 occur in sites where there appears to be quite strong groundwater outflow from a mineral aquifer, though in some cases there is little or no visible evidence for substantial outflow and it is likely that Till deposits lining the basins, along with some of the wetland infill, may considerably constrain groundwater outflow. Many examples are fairly base-rich, associated with Limestone, Chalk or Crag aquifers, but others are in mires associated with more acidic substrata (such as Cranesmoor, Denny Bog, Shortheath Common). The groundwater inputs may help to maintain relatively stable water tables, but with existing data it is not possible to differentiate between the effects of rates of water supply, the buoyancy of the fen mat and (in some cases) sluice controls on outfalls in helping to maintain a seasonally stable water table relative to the fen surface.

The groundwater supply to seepage percolation fens probably helps to explain the relatively low fertility of most WETMEC 13 samples.

6.16.11 Ecological types

Table 6.49 Percentage distribution of samples of WETMEC 13 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	32	35	5
Sub-neutral	5	15	2
Base-poor	4	2	

Oligotrophic, base-rich

This is the characteristic condition of examples of WETMEC 13 irrigated by groundwater from Limestone, and to some extent Chalk, aquifers. It includes most of the examples associated with Carboniferous Limestone, together with Cothill Fen, Arne Moors and low-fertility parts of Greywell, Newham, Smallburgh and Upton Fens. Most of the examples are referable to WETMEC sub-type 13b. Particularly wet examples may support *Cladium* or *Phragmites* swamp, but the most characteristic vegetation type of this habitat is M9, as M9-2 (*Carex diandra–Calliergon* mire) and M9-3 (*Carex diandra–Peucedanum palustre* mire) (see Part 3).

Mesotrophic, base-rich

This type is dominated by samples from Eastern England, fed by Drift or Chalk groundwater or a mixture of the two, but it also includes examples from Old Red Sandstone at Bryn Mwcog. The lower productivity (low mesotrophic) examples may again support S2, M9-2 or M9-3 communities, but there is a greater preponderance of S4 (*Phragmites* swamp) or S27 (*Carex rostrata–Potentilla palustris* mire), particularly in wetter examples, and of *Juncus subnodulosus–Cirsium palustre* fen meadow (M22) or *Phragmites australis–Peucedanum palustre* tall herb fen (S24) in drier locations. The latter mostly occur on examples of WETMEC 13a, or on late successional and rather stable examples of WETMEC 13b (such as Smallburgh and Upton Fens, Norfolk). This category also includes some surfaces at Newham Fen that are thought to be enriched by nutrient inflow.

Eutrophic, base-rich

Only a few examples were encountered of this type. One, at Sunbiggin Tarn, was associated with a formerly large nesting site for Black-headed gull (*Larus ridibundus*) and was apparently subject to guanotrophication. The others were all associated with proximate farmland (parts of Cors Hirdre, Newham Fen, Smallburgh Fen and Whitwell Common). The reason for enrichment is not known with certainty, but at Smallburgh Fen it was clearly associated with two seepages feeding into either end of the main area of WETMEC 13 (Wheeler, Shaw and Wells, 2003).

Oligotrophic, sub-neutral

The category is composed of a small number of samples from two contrasting situations: one was from small quaking surfaces embedded in soligenous seepages at two New Forest mires (Stoney Moors and Wilverley Bog); the other was from highly quaking, *Sphagnum*-dominated surfaces that had developed over more base-rich water at Silver Tarn and Tarn Moss (Malham).

Mesotrophic, sub-neutral/base-poor

This category includes a number of mostly WETMEC 13b samples. Some are not associated with Limestone bedrocks (such as Silver Tarn, Shortheath Common, Upton Fen), but others are (Cors Goch, Tarn Moss (Malham), Parc Newydd and Newton Reigny Moss). Of these, samples from Cors Goch, Tarn Moss (Malham) and Parc Newydd were from strongly quaking surfaces, in some instances with *Sphagnum*, which had developed serally over calcareous water on a semi-floating raft. Those from Newton Reigny were from reflooded peat workings apparently dug into ombrogenous peat.

The reason for the development of sub-neutral or base-poor surfaces in some of the Carboniferous Limestone basins is not entirely clear. In some cases (such as Parc Newydd) it may partly be due to limited outflow of calcareous groundwater into the basin, where the contribution of precipitation is proportionately greater than in other sites. However, a key feature appears to be the occurrence of a strongly buoyant vegetation mat which permits the development of a thin ‘rainwater lens’ perched over calcareous groundwater. The early consequences of this may be the appearance of examples of M9-2 and S27 in somewhat less base-rich conditions than they might normally occupy in limestone basins, but a later consequence (particularly when the groundwater table is relatively stable or the raft especially buoyant) is the ready establishment of patches of *Sphagnum*-dominated vegetation (typically M5), or birch–*Sphagnum* communities (W4), where the flow of groundwater becomes directed primarily beneath the surface. In this situation the mire surface is mainly fed by precipitation, but can remain consistently wet even in dry climatic regions because of the constancy of groundwater supply coupled with the vertical mobility of the mat. In sites fed by calcareous groundwater, this can lead (at least temporarily) to an intimate mosaic of base-rich and base-poor conditions, which constitutes a classic development of 'transition mire', a habitat which can support a number of uncommon plant species (such as *Pyrola rotundifolia*). Transition mire can be a precursor for raised bog, which appears to be the natural climax development from examples of WETMEC 13, at least in the West and North of Britain; the sub-neutral and base-poor patches of WETMEC 13 in sites such as Cors Goch and Parc Newydd may be early precursors of ombrotrophication in these sites. The (now cut-over) ombrogenous peat cap in the Newton Reigny Moss basin appears to have developed serally from an earlier fen phase that may have been referable to WETMEC 13, and it is of interest that this wetland type has re-developed in the reflooded peat workings, where the ombrogenous peat has been dug away.

Eutrophic, sub-neutral

Only a few examples were recorded of this type, all from locally enriched areas of basins that mostly support mesotrophic sub-neutral conditions (Newton Reigny Moss and Silver Tarn). At Newton Reigny Moss, eutrophic conditions can be found at the ends of the peat cuttings adjoining the land margin and, particularly, the axial ditch (which appears episodically to flood into the cuttings). The distribution of eutrophic conditions at Silver Tarn is less consistent, and the contributing sources have not been identified.

Oligotrophic, base-poor

Most of the samples in this category were from the New Forest, from wet sumps embedded within valley-bottom troughs (Cranesmoor, Denny Bog (West) and Wilverley Bog). All supported a version of *Sphagnum papillosum–Narthecium* mire (M21), typically with vigorous tussocks of *Molinia* separated by pools and quaking surfaces with much *Menyanthes* and occasional *Carex limosa.* This ecological type was also represented by a highly buoyant, *Sphagnum*-rich surface at Shortheath Common.

6.16.12 Natural status

WETMEC 13 appears to have been a natural and persistent wetland type in some situations, especially small, groundwater-fed basins. Deposits of moss peat and monocot peat in some calcareous basins may well be indicative of the sustained former occurrence of WETMEC 13 (or close analogue). In some of the current basin locations for WETMEC 13 (such as Cors Goch, Great Cressingham Fen), it is likely that a similar water supply mechanism has prevailed for much of the developmental history of the sites. The same appears to be true, at least near the upland margin, for the more complicated context of Smallburgh Fen, where a WETMEC 13-type basin shows ontogenic interactions with the floodplain of the Dilham Stream. An interesting feature of both the Cressingham and Smallburgh examples is that, following overgrowth of the original marl lakes, there was a quite long phase of moss-rich, herbaceous fen with little tendency for fen carr development. This feature has also been found by Tratt (1998) in a large number of small basins in the Scottish Borders, which appear to be referable to WETMEC 13. It therefore appears that the natural rich-fen state of many of these mires was essentially open and herbaceous, but the processes which maintained this (in contrast to the current tendency for carr development across unmanaged surfaces) are by no means clear.

In the Scottish Border mires, an important successional trend in some (perhaps most) of the small basins has been the development of shallow cupolas of ombrogenous peat, even in some tiny, highly calcareous examples (Tratt, 1998). This may well have been the main climax state of many of the basins in the Borders, though removal of peat and marl has removed most traces of ombrogenous peat in many sites. A similar successional sequence has occurred in some basins in North-West England (such as Newton Reigny Moss), though even here most traces of the former ombrogenous surface has been removed by peat digging. Because of such disturbances, it is not known how widespread bog formation was in other basins, but where it occurred it seems to have culminated in the development of small examples of WETMEC 1 (Domed Ombrogenous Surfaces) rather than WETMEC 2 (Buoyant Ombrogenous Surfaces).

WETMEC 13 surfaces, or analogues, may well have once occurred in contexts in which they either no longer occur, or are developed only vestigially. In parts of Eastern Europe and particularly Russia, natural examples of river-valley wetlands with a water supply mechanism comparable to WETMECS 13/14 occur (Figure 6.38). It can be speculated, on the basis of their situation, peat stratigraphy and their (former) water sources, that the upper Waveney-Ouse fens (see WETMEC 9 account) were once also of this character, prior to drainage and peat extraction. Although subject to considerable peat removal, it is clear that parts of these systems have developed across a series of shallow, early post-glacial marl lakes and have shown a developmental sequence broadly similar to that identified in some WETMEC 13 basin sites. Such surfaces no longer exist in the Waveney-Ouse fens, except in a few reflooded peat workings, which may mimic the original water supply mechanism.

Many of the examples of WETMEC 13 examined in this study occupy former turbaries. Some are in basins which may naturally have supported WETMEC 13 at some stage prior to peat removal (such as Newton Reigny Moss), but others occupy locations (such as parts of floodplains) which may have had rather different water supply mechanisms. For example, Upton Fen (Broadland) occupies the margin of the mostly drained Bure floodplain and there is little stratigraphical reason to suppose that the water supply to this part of the floodplain was naturally dominated by seepage percolation processes. In this site, creation of conditions appropriate for the development of WETMEC 13 include: (a) drainage of former fen between the residual site and the river, and severance of the river connection; (b) shallow peat digging followed by reflooding to create turf ponds which developed into WETMEC 13; and (c) excavation of the broads close to the mineral aquifer and outflow of groundwater.

Assessment of the natural status of WETMEC 13 sites can be surprisingly difficult, and often little is conclusively known about their status. At some sites there is no known evidence for past turbary, though the sites may have been partly drained (such as Great Cressingham Fen). Likewise, the WETMEC 13 pools in the pingos at East Walton Common appear largely undisturbed, except for deepening of the outfalls, but as with WETMEC 12 (Fluctuating Seepage Basins) the question arises as to why such small late-glacial basins are not completely peat-filled. The eastern basin of Cors Goch is often considered to be the largely terrestrialised remnant of a deep late-glacial lake, but abrupt local changes in the height and solidity of the peat surface raise the possibility that this may also have been partly cut over. Newham Lough (in Newham Fen) may, in part, be a natural feature created by groundwater outflow, but it has also been maintained historically as a fish pond, and the present example of WETMEC 13 appears to be a terrestrialisation derivative of this.

Even where deep deposits of peat remain *in situ*, stratigraphical studies do not always provide unambiguous evidence for former turbary. Smallburgh Fen is believed by Parmenter (1996) to have been dug for peat, which is a reasonable suggestion for this location, but Wheeler, Shaw and Wells (2003) were unable to find clear stratigraphical support for this proposition[1]. In the Scottish Borders, Tratt (1998) reported that ombrogenous surfaces now

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[1] The difficulty in this instance is that the loose, wet peat infill which often provides evidence for past turbary is not confined to the surface at Smallburgh: this site has had apparently naturally-wet phases at various points in its development, so that the present unconsolidated near-surface conditions may be neither unexceptional nor 'unnatural'.

occur both in apparently undisturbed basin mires and in basins which had been stripped of virtually all their marl and peat in the eighteenth and early nineteenth centuries. Some of the surfaces in the 'industrial' marl workings visually appeared as natural as those of undisturbed sites, and it was only the (unusually complete) documentation of past excavation combined with stratigraphical studies that permitted an assessment of the actual status of these basins. In the absence of documentary evidence, stratigraphical data alone do not always provide definitive evidence of past digging, and the natural status of a number of sites remains unresolved (such as Smallburgh Fen).

6.16.13 Conservation value

Examples of Seepage Percolation Basins are often considered to have particularly high conservation value, especially base-rich examples, and the vegetation may form the basis for SAC designation (see Tables 3.3 and 6.4). Although individual samples of WETMEC 13 are not always particularly species-rich, in aggregate the WETMEC supports a large number of species. This may reflect the range of situations and ecological conditions in which the WETMEC occurs.

In total, some 164 wetland species have been recorded from samples of WETMEC 13. These include 42 nationally uncommon species: *Calamagrostis canescens, Calamagrostis stricta, Calliergon giganteum, Campylium elodes, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Cicuta virosa, Cladium mariscus, Corallorhiza trifida, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Drosera intermedia, Drosera longifolia, Epipactis palustris, Erica ciliaris, Eriophorum gracile, Eriophorum latifolium, Hammarbya paludosa, Lathyrus palustris, Liparis loeselii, Moerckia hibernica, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Philonotis calcarea, Pinguicula lusitanica, Plagiomnium elatum, Potamogeton coloratus, Pyrola rotundifolia, Ranunculus lingua, Rhizomnium pseudopunctatum, Selaginella selaginoides, Stellaria palustris, Sphagnum contortum, S. teres, S. warnstorfii, Thelypteris palustris, Utricularia intermedia, Utricularia minor.* Some of these occur at only a very small number of sites (such as *Eriophorum gracile* from Cors Hirdre). WETMEC 13 also supports a number of other species that are locally uncommon (such as *Parnassia palustris, Pinguicula vulgaris, Riccardia chamaedryfolia, R. multifida, Sagina nodosa, Scorpidium scorpioides*).

Some of the species listed above have been recorded only from certain WETMEC 13 sub-types. For example, the records of *Hammarbya paludosa* are from small quaking mats of WETMEC 13a.1 embedded within WETMEC 10 seepages. The one site with *Liparis loeselii* is from an example of WETMEC 13d (Upton Broad), though it has been recorded in the past from other sub-types at other sites (such as East Walton Common, Smallburgh Fen). The occurrence of some examples of WETMEC 13 in Broadland accounts for a number of the notable species listed above, including *Lathyrus palustris* and *Peucedanum palustre* as well as *L. loeselii.*

The percentage occurrence in NVC communities of samples of WETMEC 13 is: M9-2: (25%); M13: (21%); S24: (8%); S27: (7%); M05: (5%); M21: (5%); M22: (5%); S02: (5%); M9-3: (3%); S25: (3%); CM: (1%); S01: (1%); W04: (1%); W05: (1%); M02: (0.5%); M14: (0.4%). 'M9' *sensu lato* is the most characteristic community of WETMEC 13, and is the one most often forming base-rich, semi-floating examples (sub-type 13b). By contrast, M13 is rather atypical of this WETMEC, and most often associated with more solid versions (sub-type 13a), especially where these are embedded within seepage systems (such as Cothill Fen, which is transitional to WETMEC 10). In some measure, the occurrence of some examples of M13 within WETMEC 13 is a consequence of the idiosyncrasies of the NVC system. This is because whereas Wheeler (1980b) allocated vegetation samples transitional between M9 and M13 to his *Acrocladium-Caricetum* (subsumed within M9), Rodwell (1991b) chose to place them within M13. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 13 is given in Table 6.3.

Examples of WETMEC 13 within more base-poor systems tend to be fairly species-poor, and are most often referable to M5 or M21. They can, however, support species such as *Carex limosa.* Their surfaces also often have rather limited *Sphagnum* diversity, though both *S. magellanicum* and *S. papillosum* sometimes occur. Curiously, some of the most interesting examples of *Sphagnum*-rich WETMEC 13 occupy acidifying surfaces that are developing hydroserally from base-rich, rich-fen conditions. Such surfaces – which fit well the telmatological concept of 'transition mire' – can support some notable plant species including, amongst the *Sphagna*, *S. contortum, S. teres* and *S. warnstorfii* (though these are rare in the area surveyed and some examples may have only *S. subnitens*). Likewise, in some fens the rare *Pyrola rotundifolia* is particularly associated with the late-successional surfaces of WETMEC 13.

When unmanaged, WETMEC 13 surfaces may be subject to colonisation by woody plants, especially the drier examples. In many sites this leads to the development of sallow scrub (W2) or mesotrophic alder wood (W5) or, when acidifying, to birch-*Sphagnum* scrub (W4). However, in some situations vegetation referable (or analogous) to W3 (*Salix pentandra–Carex rostrata* woodland) can develop which, at Newham Fen (Northumberland) supports a small population of the Coral-root Orchid (*Corallorhiza trifida*). However, W3 vegetation – along with rich-fen *Sphagnum* surfaces – is generally much better developed in some Scottish examples of WETMEC 13 than in those sampled in the present survey.

Reedbeds occur locally in WETMEC 13, but they are generally not botanically rich and none have been sampled in this survey.

6.16.14 Vulnerability

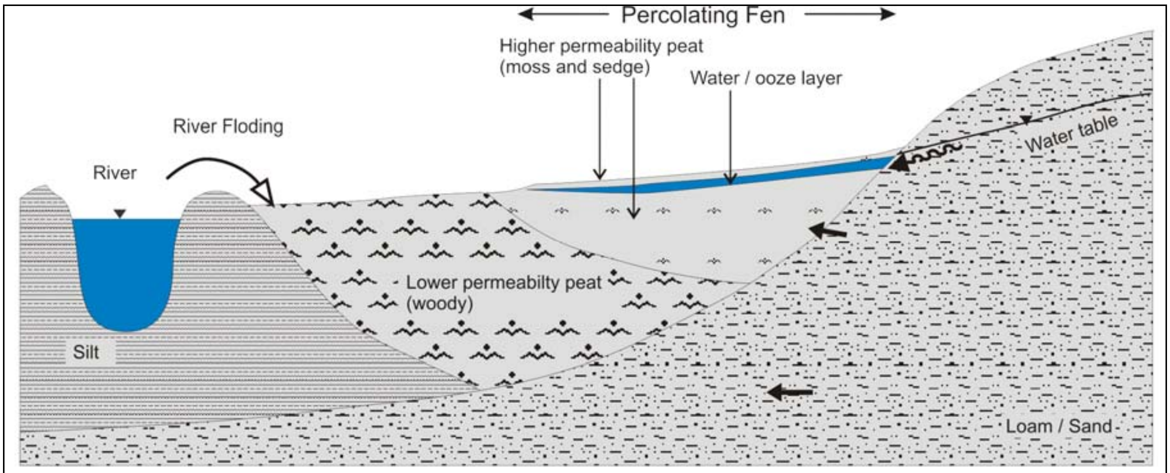
The dependency of WETMEC 13 upon groundwater supply means that it can potentially be affected by a lowering of aquifer water tables. However, because the water table within the WETMEC is usually also determined by constraints on outflow (such as the height of the outfall), in some circumstances it may be possible to manipulate this to maintain near-surface water tables (though with the concomitant potential danger of increasing stagnation). On the other hand, examples of this unit may be particularly vulnerable to any reduction of outflow constraints, which in some cases may include river deepening. Some of the groundwater-fed valley bottoms in the Waveney–Ouse valleys, which may once have been referable to WETMEC 13, seem to have been particularly affected by river deepening and have shown a significant impoverishment of a once-rich wetland resource. Although it is difficult to be certain, sites at the edge of the Crummock Beck floodplain, such as Thornhill Moss (Cumbria), may well once have supported WETMEC 13, at least in part. Drying in such situations can sometimes be associated with a considerable increase in soil fertility, probably through mineralisation processes.

A major internal threat to conservation interest within seepage percolation fens is ongoing hydroseral succession within the basins and turf ponds that support this WETMEC, and the gradual development of conditions more akin to those of solid peat surfaces. Perceptions that WETMEC 13 surfaces are becoming drier may sometimes stem from ongoing stabilisation of the vegetation mats, and peat accumulation, rather than from an actual reduction in fen water tables, because these processes can reduce the buoyancy of the fen mat and the transmissivity of the near-surface horizon. This is known to be a potential problem in reflooded turf ponds that have been allocated to this WETMEC, but its applicability to natural seepage basins is less clear (not least because the natural status of many of the basins is itself not well known).

It is quite difficult to generalise about the importance of vegetation management in WETMEC 13 systems. The deep accumulations of hypnoid moss–monocot peat found in some locations indicate that WETMEC 13 surfaces, or close analogues, have remained herbaceous naturally over long periods but, with the exception of a few examples that are too wet for management to be necessary or possible, most examples of WETMEC 13 are readily invaded by woody species in the absence of management. Of course, whilst removing above-ground biomass, vegetation management does not prevent gradual stabilisation of the substratum (though it may retard this process), and communities such as M9-2 and M9-3 may occupy a transient phase of the hydroseral colonisation of turf ponds (Segal, 1966; Giller and Wheeler, 1986a). This can arise from changes in the properties of the fen mat, or its grounding, which result in lower summer water tables at the peat surface, or from acidification and the expansion of *Sphagnum*-dominated communities over the surface of a still-buoyant mat.

Where examples of WETMEC 13 occur in small basins in intimate association with agricultural land, enrichment can occur either from the leaching of applied fertilisers or from silt inwash. Silt inwash is particularly associated with ploughing of adjoining slopes. Some examples of WETMEC 13 in the basin mires of the Scottish Borders have been considerably affected by silt inwash (Tratt, 1998; Wheeler, Shaw and Wells, 2006), but there is generally little clear evidence for this in the sites examined here (an exception is part of the western basin of Cors Goch).

Nonetheless, some sites do appear to have become enriched. Silver Tarn, which receives some field drain inflows, shows both floristic and phytometric evidence for localised enrichment, though the cause of the localisation is not clear. There is evidence for enrichment of parts of Newton Reigny Moss, both near landward edges and the axial drain. Some deterioration in floristic quality in the WETMEC 13 area at Newham Fen appears to be more a consequence of enhanced fertility than of declining water tables (Wheeler and Shaw, 2004). The cause of enrichment here is not known with certainty, but the fields surrounding the fen, including the esker bank, are improved pasture which has been regularly fertilised. As water from the esker is probably an important water source for the mire, it seems likely that some of the nutrients applied to this field may end up in the mire. However, this may well be a slow process: in a necessarily informal but instructive estimate, Newson *et al.* (2002) suggest that it could take some 20 years for a contaminant to move into Newham Fen through the aquifer from a point in the esker 150 metres distant from the margin. Such a slow response, coupled with uncertainties about the provenance and magnitude of the main groundwater supply to the mire (Box 6.25), makes any assessment of the likely impact of fertilisation a rather inexact procedure.



This diagram is based on an actual section of a natural seepage fed floodplain wetland in the R. Ob valley, W. Siberia, courtesy of E. Lapshina (University of Tomsk). The peat close to the river is regularly subject to river flooding. It is fairly dense and contains mineral material. Strong springs and seepages from terrace deposits which form the upland margins of the wetland feed onto the mire, where a deposit of fairly loose peat has accumulated under their influence. The seepage water is distributed from the main discharge zone through a shallow (0.2 - 1m deep) watery layer, bound loosely by rhizomes, beneath a rather thin, strongly quaking surface. The riverward limit of the quaking layer is rather abrupt and associated with a quite steep peat slope. The slope is drier than the main quaking layer and is typically wooded. It is not certain what determines this limit, or its abruptness. It may be related to some constraint on the lateral extent of groundwater movement, or the limit of normal river flooding, or some combination of the two.

Although there are no examples of this type of wetland in Eastern England, similar structures may have once occurred. It is not possible to find exact matches with the Seepage Percolation WETMEC but, the land margin of the wetland represents a zone of groundwater discharge under pressure, and corresponds to the Semi-Floating Direct Seepage Percolation unit (WETMEC 4b) whilst further from the margin this grades into a phreatic unit which corresponds to the Distributed Seepage Percolation unit (WETMEC 4c).

Figure 6.38 Schematic representation of a natural percolating fen (River Ob floodplain, West Siberia)

6.17 WETMEC 14: Seepage Percolation Troughs

6.17.1 Outline

A WETMEC of gently sloping valley bottoms and troughs, often on fairly shallow peat, irrigated by groundwater supply from marginal seepages and, in many cases, possibly by upflow from beneath the trough. Much of this becomes focussed into preferential surface flow tracks, that is, the soakways and water tracks that constitute the closely related WETMEC 15 (Seepage Flow Tracks). It is likely that there is also some down-trough flow through samples of WETMEC 14, but visible water flow is not normally apparent. Schematic sections are provided in Figure 6.40.

6.17.2 Occurrence

Example sites: Bicton Common, Bramshaw Wood, Chobham Common, Church Moor, Cors Gyfelog, Cranes Moor (Hampshire), Denny Bog (West), Fort Bog, Hartland Moor, Holmsley Bog, Shatterford Bottom, Shortheath Common, Stoney Moors, Warwick Slade Bog

Outlier sites: Silver Tarn (west basin)

Although it occurs more widely, this WETMEC is particularly characteristic of many of the valley bogs of the New Forest and adjoining parts of England, where it can be extensive in some of the broader valley bottoms. The distribution of examples in sites sampled is shown in Figure 6.39.

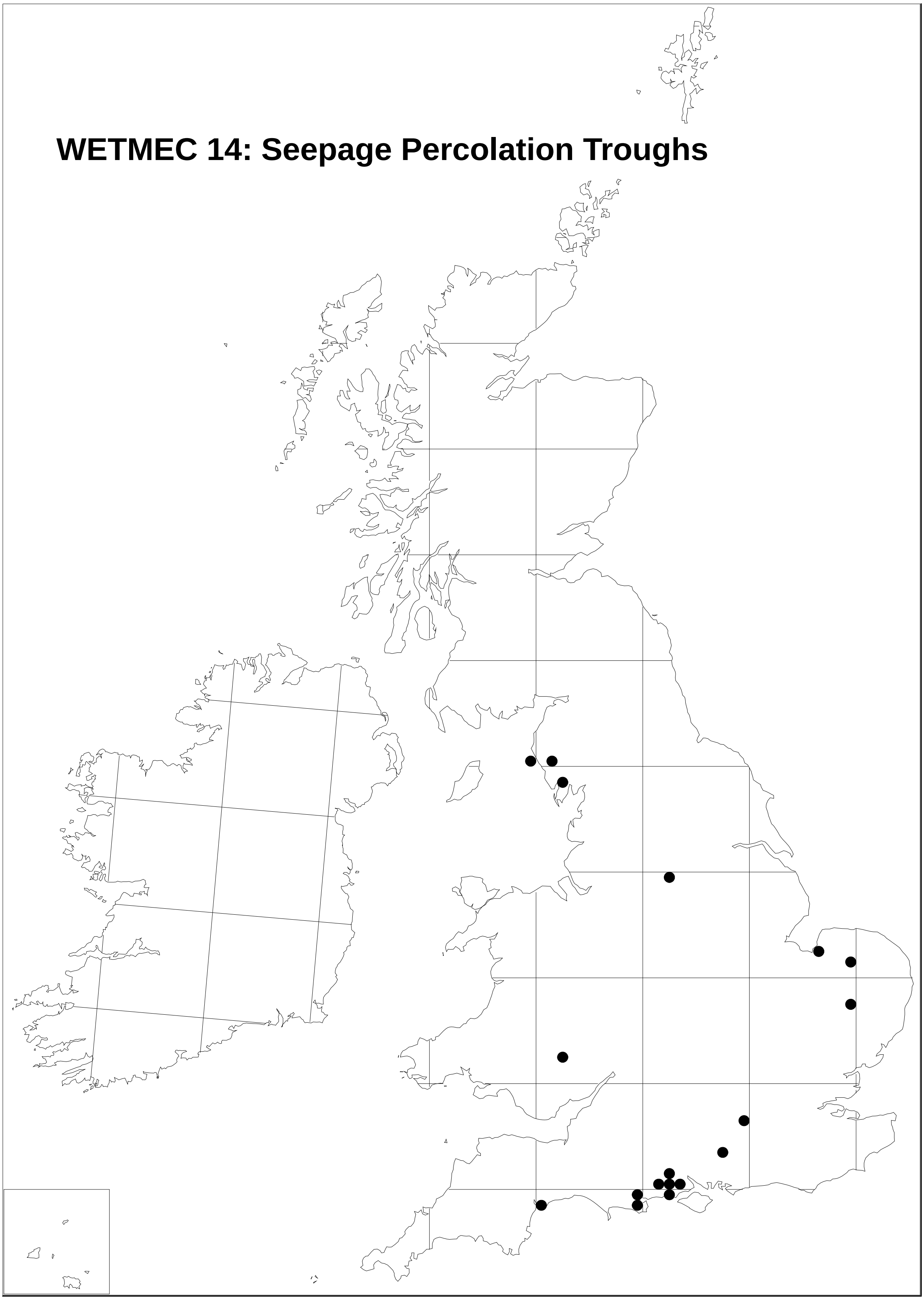
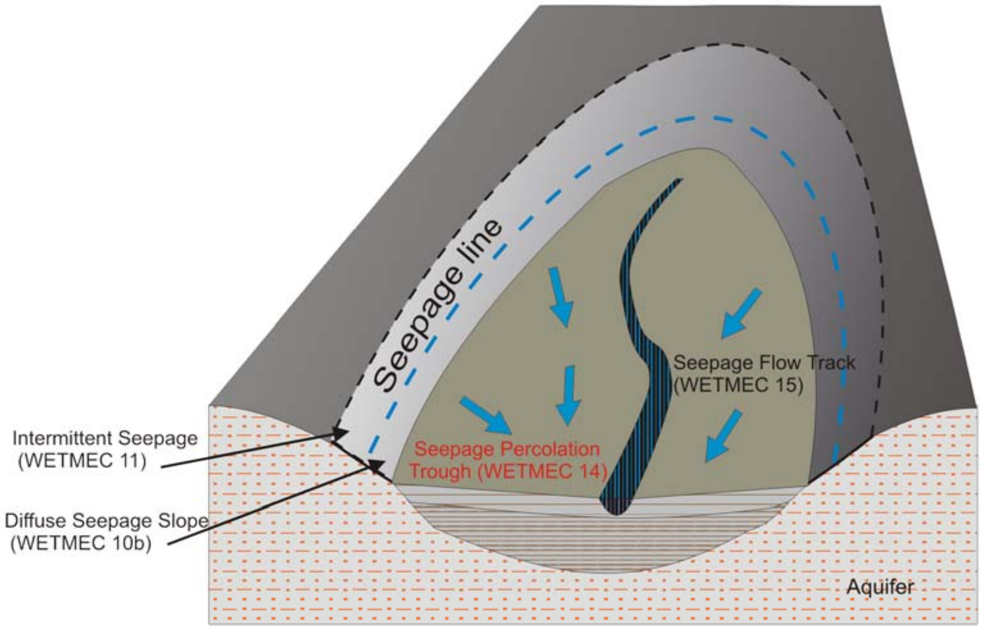


Figure 6.39 Distribution of examples of WETMEC 14 in sites sampled in England and Wales

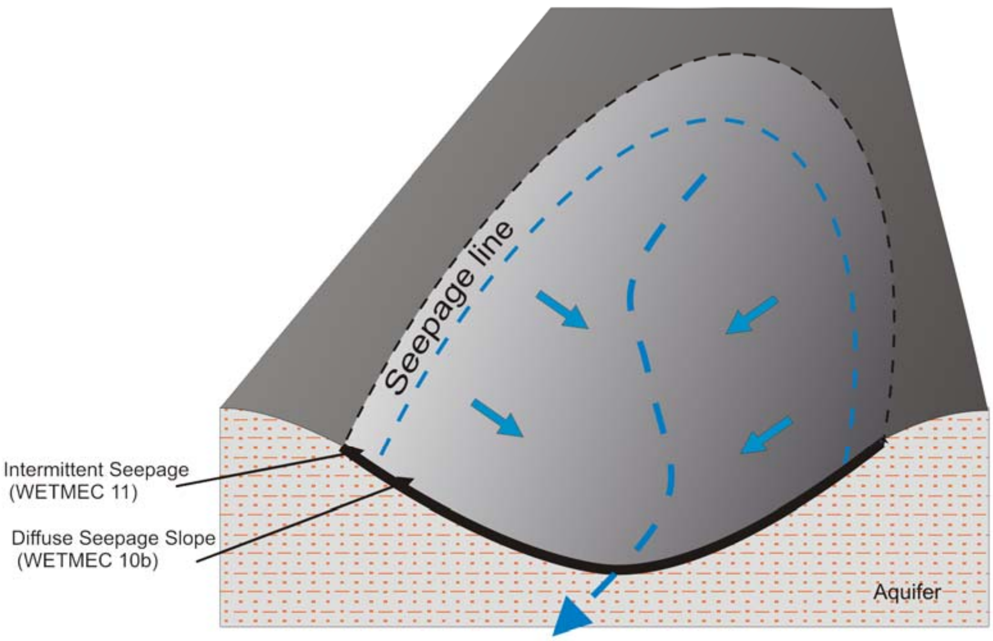
6.17.3 Summary characteristics

Situation	Mostly valleyheads, some troughs, basins and floodplain margins. Occasionally in (large) former peat workings.
Location	Quite widespread. Most examples from Southern England (especially New Forest), but also from East Anglia, Wales and elsewhere.
Size	Flattish mire expanses, gently sloping down the length of broad valleyhead bottoms.
Surface relief	Mostly more or less flat surface (sometimes sloping), in narrow to broad flats and troughs, with a spongy, sometimes quaking surface.
Hydrotopography	Rheo-topogenous.
Water: ***supply***	Groundwater springs and seepages, often outflow from an adjoining groundwater-fed WETMEC. Often some surface water inflow, but probably of little significance to summer water levels.
regime	Consistently wet, with water table at or near the surface for much of the year.
distribution	Longitudinal flow along trough, with some lateral inflow from flanks; probable upflow in some cases.
superficial	Small pools and, sometimes, small water channels.
Substratum	Soft upper layer, most often underlain by a more consolidated surface. Basal material ranges from sands and gravels to silts and clays.
peat depth	Variable; typically < 2 m, but some deeper examples.
peat humification	Usually with a shallow (0.5 m) spongy surface; underlying peat, when present, usually more humified and often solid, especially lower down.
peat composition	Mostly monocot or *Sphagnum* peat. Wood peat in some examples.
permeability	Upper peat variable, but mostly quite permeable. Basal substratum mostly with moderate permeability characteristics.
Ecological types	Oligotrophic, acidic to eutrophic, sub-neutral.
Associated WETMECs	Mostly flanked by other WETMECs, especially WETMEC 10 (upslope) and 15 (downslope); sometimes drains into sumps with WETMEC 13.
Natural status	Many examples appear to form a natural persistent state, but the role of grazing in preventing tree colonisation is uncertain.
Use	Conservation. Light grazing. Some occupy former turbaries.
Conservation value	Species diversity is generally rather low, partly because of the intrinsically small species richness of base-poor mires, but has quite a large species total and includes some nationally uncommon species; may support an SAC habitat.
Vulnerability	Direct and indirect drainage. Groundwater enrichment.

WETMEC 14: SEEPAGE PERCOLATION TROUGHS



(a) Peat filled valleyhead Seepage Percolation Trough. Example shown has loose peat surface (through which most water flow probably occurs) over denser peat, but in other examples almost all the infill may be 'loose'. Other examples may also have a basal aquitard with constrained groundwater upflow.



(B) Valleyhead trough with the Seepage Percolation and Soakway components absent or poorly developed (*e.g.* Scarning Fen). Some of these valleyheads *may* represent former examples of Seepage Percolation Troughs (a), which have been drained and stripped of much of their peat infill.

Figure 6.40 Schematic representation of Seepage Percolation Troughs (WETMEC 14)

6.17.4 Concept and description

CLUSTER: 25

WETMEC 14 essentially occurs along the bottoms of some small headwater valleys. It slopes, normally gently, down along the valley bottom, but is virtually flat or has only very slight slope across the valley, where the predominant gradient is usually longitudinal rather than lateral. The downslope gradient is variable, but is usually less than five degrees.

WETMEC 14 is particularly associated with flat-bottomed headwater valleys or valleyheads where a sufficient depth of peat has accumulated to mask any small topographical irregularities on the valley floor, to form a relatively flat surface. In some sites (such as Cranesmoor, New Forest), larger mineral ridges may puncture the peat surface in places. In less flat-bottomed valleys, WETMEC 14 is either absent or forms a narrow or ill-defined and discontinuous zone near and along the base of the valleyside slope.

WETMEC 14 is often clearly fed by marginal seepages and frequently grades laterally, sometimes almost imperceptibly, into the Permanent Seepage Slopes of WETMEC 10. However, a feature of several WETMEC 14 sites (such as Church Moor, Hartland Moor, Shatterford Bottom) is that wetland conditions are largely confined to the bottom of the valleyhead trough, with little or no development of seepages on the adjoining slopes. In other circumstances (such as Bicton Common, Chobham Common) where there are some (mostly weak) seepages on the steep slopes of the valley trough, these can show an abrupt junction with WETMEC 14 in the trough bottom, giving an impression of some independence between the two units. Many examples occur lateral to axial soakways or water tracks. In particularly narrow valleys, or in circumstances where much of the valley bottom is occupied by a water-track/soakway complex (such as Fort Bog, New Forest; Hartland Moor, Purbeck), WETMEC 14 may form a narrow, or almost non-existent, band between the wet centre and the margins. In these circumstances, it can be difficult to distinguish between surfaces that can be allocated to WETMEC 14 and those referable to WETMEC 15.

Except where the site has been part-drained, WETMEC 14 surfaces are typically very wet, soft and sometimes quaking. However, strongly buoyant or semi-floating conditions rarely occur, except locally around pools or in depressions.

Affinities and recognition

WETMEC 14 (Cluster 25) is closely related to WETMEC 15 (Cluster 26). Both are fed primarily by the flow of water, sourced from groundwater outflow, down along the valley-bottom troughs which they occupy; they differ mainly in the apparent rate of water throughflow and in the presence of surface water. WETMEC 14 does not normally have visible water flow, and water levels are not normally above the surface (except in small pools), but in narrow valleys with a quite high rate of water throughflow (such as parts of Shatterford Bottom, New Forest), it can be difficult to make a sensible distinction between this WETMEC and WETMEC 15. Moreover, both WETMECs often occur together in valley-bottom troughs. Hence, a case could be made for considering Clusters 25 and 26 as sub-types of a single WETMEC. However, Cluster 26 also occurs within some examples of WETMEC 16, and so they have been treated as independent units. Another complication is that in some of the larger valleys, wet quaking sumps in apparent shallow depressions, on or lateral to the main water flow paths, have been clustered into WETMEC 13 (Seepage Percolation Basins) rather than WETMEC 14. Indeed, as the clustering suggests, WETMEC 13 can be conceptualised as occupying surfaces transitional between WETMECs 10, 13 and 15. WETMEC 14 is generally more obviously sloping than WETMEC 13, and in the latter there is a greater tendency for the surface to be underlain by unconsolidated unsampleable material (watery muds and so on).

The main difference between WETMECs 14 and 16 is that the latter occurs over a laterally continuous aquitard (usually clay beneath the peat), whereas the former occurs either over sands and gravels or over a discontinuous aquitard. However, some examples of wet valley bottoms over clay but with deep peat have been clustered into WETMEC 14. Hence the differences between the two WETMECs are not clear cut, and transitional types occur both between the concepts and within some individual wetland sites.

The differences between WETMECs 14 and 18 are considered under WETMEC 18.

6.17.5 Origins and development

Many examples of WETMEC 14 have only shallow accumulations of peat, and the view has been expressed (see Rose, 1953; Newbould, 1960) that some of the mires that support this WETMEC could be relatively recent in origin, a product of increased groundwater levels possibly associated with forest clearance. However, some of the sites with deeper peat undoubtedly have considerable antiquity, as at Cranesmoor and Church Moor (New Forest) (Box 6.26).

6.17.6 Situation and surface relief

Most (92 per cent) samples of Seepage Percolation Troughs were from valleyhead contexts. Five per cent were from troughs associated with basins and three per cent from the margin of floodplains. Some occur in peat workings. The surface is mostly more or less flat, with a spongy, sometimes quaking character, but some samples were from more strongly sloping locations (Table 6.50).

6.17.7 Substratum

Peat depth in this WETMEC is variable, as are its permeability characteristics (Table 6.50). In some examples the peat is rather deep (such as Cranes Moor, around four metres; Church Moor, around 2.5 m; Chobham Common, around two metres), but many examples have shallow peat, often less than one metre deep. In some cases this may be a consequence of past peat extraction. The uppermost peat is typically loose and spongy, but can usually be sampled with a Hiller-type corer (in contrast to the soakways of WETMEC 15, which can rarely be thus sampled).

Box 6.26: Development of WETMEC 14 surfaces at Cranesmoor and Church Moor (New Forest)

Cranesmoor

The peat infill of Cranesmoor is exceptionally deep for the New Forest mires, some five metres deep in places (though most documented cores are shallower than this). Peat stratigraphical studies have tended to focus on the eastern end of the site. Seagrief (1960) provided cores for 'Sphagnum Bog' (around 3.5 m of mostly *Sphagnum* peat), 'Little Bog' (around 1.5 m of *Sphagnum* peat over a similar depth of monocot peat) and 'Flush Bog' (around 3.5 m of a rather muddy monocot peat with wood below about 1.25 m depth). Barber and Clarke (1987) and Clarke (1988) provide details of a core from Sphagnum Bog, which was deeper than Seagrief's, with about 4.5 m of *Sphagnum* peat. The peat is generally underlain by a layer of mud over a loamy sand and cores from Sphagnum Bog have a distinctive white mud. Barber and Clarke (1987) call this the 'Nivea layer', which is thought to be a diachronous deposit formed after some peat deposition had occurred. Clarke's core represents a sequence starting approximately at the Late Devensian–post-glacial transition and continuing to around 4000 BP. It is capped by a thin (roughly 15 cm) layer of more recent peat and the hiatus is considered to represent truncation of the original peat profile by peat digging.

The depth and character of the peat removed by turbary is not known, but Clarke (1988) speculated that some 2.8 m of peat may have been removed and that this may have been, at least in part, ombrogenous (a former small raised bog). Newbould (1960) had previously raised the possibility of ombrogenous peat development at Cranes Moor, but presumed that the climate would have been unsuitable. This latter assumption was questioned by Clarke (1988), but some of the supporting evidence advanced by him in favour of past ombrogenous surface – particularly the distinctive (for the New Forest) residual *Sphagnum* peat and the presumption that the modern Sphagnum Bog area is primarily fed by direct precipitation – may be inadmissible. This is because although water in the rooting zone of the Sphagnum Bog ridge is undoubtedly less base-rich than that in Flush Bog, it appears to be below the level of the Becton Sand aquifer. Furthermore, available hydrochemical data suggest that the water composition of Sphagnum Bog is not significantly different from other *Narthecium ossifragum–Sphagnum papillosum* mire (M21) sites in the New Forest, which are undoubtedly influenced by telluric sources. Nonetheless, these caveats do not remove the possibility that part of the Cranesmoor surface may once have been ombrogenous, especially in this unusually broad valleyhead site.

Church Moor

The stratigraphy of Church Moor has also been examined by Clarke (1988). This has revealed a quite deep infill, with some three metres of peat in places and a sequence from the Late Devensian period. The basal material immediately below the peat is described as "a strongly gleyed silty clay with some gravel". The lowest peat is also quite silty, suggestive of some inwash. Clarke considers that "*for most of the Flandrian until about 5200 BP, conditions favoured decomposition processes and the mire surface was probably relatively dry … An increase in local wetness at c5200 BP is indicated by increased inorganic preservation*."

Church Moor currently consists of open bog with a strip of alder carr along one margin, corresponding to the asymmetric flow track at the site. Clarke and Barber (1987) provide evidence that the main expansion of alder occurred at about 5200 BP and suggest that "*the macrofossil evidence shows that the local mire community and the carr margin have remained stable for the last 5,000 years. The persistence of the vegetation pattern may be due to environmental stability, particularly in the valley mire drainage network, since the stratigraphy of Church Moor shows the stream to have occupied its lateral position along the edge of the mire for much of the Flandrian.*"

The basal substratum also varies in character. In some cases the peat infill is immediately above a permeable bedrock, but in many instances there is a basal layer of superficial material which is either alluvium or colluvium (Head), and in some systems this can be thick and extensive. This material can vary considerably in its lithological characteristics, between sand-rich and clay-rich elements, and in general the lateral persistence of these is not well known. The comment by Clarke (1988) on Church Moor, that "*the basal material immediately below the peat consisted of a strongly gleyed silty clay with some gravel, and is typical of the colluvial sediments which mantle most of the slopes and valleys in the New Forest*" is apposite and probably applicable to many sites. However, other valleyhead troughs are located over extensive basal clays, and samples from these – especially those prone to low summer water levels – have generally been clustered into WETMEC 16.

Table 6.50 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 14

	Mean	1	2	3	4	5	6	7
Surface layer permeability	5.7		3	11	11	3	40	34
Lower layer permeability	4.4		5	37	13	10	29	5
Basal substratum permeability	3.6		24	27	24	16	8	
Slope	1.6	62	19	16	3		X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.17.8 Water supply

Few detailed hydrological data are available from these valley bottom mires, which makes any assessment of their water supply necessarily speculative. However, it is fairly clear that in most, if not all, sites groundwater is the predominant telluric water source. Most sites have little evidence of significant surface water inflows, and any rain-generated run-off may make little contribution to the summer water table of the mires. Some sites undoubtedly receive some land drainage (and where this is enriched by agricultural nutrients, it may have a hydrochemical impact upon the mire disproportionate to its volumetric importance). However, many of the mires occupy headwater locations and tend to source drainage streams rather than be fed by them –streams and water tracks are mainly or wholly endotelmic. Thus, whilst the lower parts of some of the larger mire complexes (such as the Shatterford–Denny Bog complex in the New Forest, or parts of Chobham Common) are fed in part by surface water flow down the valley, much or all of this originates within the mire complex or immediately adjoining it. Water in streams and water tracks, whether endotelmic or exotelmic, undoubtedly often helps to regulate the water table in flanking examples of WETMEC 15. The extent to which surface water from axial streams and so on can be a source of local recharge to WETMEC 15 is not known, but it is clearly not significant for large parts of the surfaces which are well removed from watercourses.

Some examples (such as Warwick Slade Bog, alongside the Highland Water) flank watercourses, but are elevated above them on what may be old river terraces. In other cases, such as Denny West Bog, the lowest parts of the mire are not much elevated above an inflowing stream, sourced in part from the Headon Formation. This forms a drainage ditch through the mire, is thought likely to enhance the base-richness of the inflow (Tubbs, 1986), and may well account for the local development of fen conditions immediately alongside the ditch. There is little evidence that base-rich water affects the main expanse of WETMEC 14 north of the ditch, though the possibility of inflows during episodic flooding cannot be discounted, and may well have been more important before the axial drainage was improved.

Many examples of WETMEC 14 are flanked, at least in part, by visible seepages, sometimes with springs. At Warwick Slade Bog, an active seepage step forms a broad bench about one metre above the general level of the WETMEC 14 mire, along the upland edge. In cases where there are no visible flanking seepages, the troughs are generally incised into permeable deposits (such as at Shatterford Bottom) and lateral flow of groundwater into the trough is presumed – but not known – to occur. In general, the role of basal deposits in constraining water flow is not known. Basal muds and clays may provide considerable resistance to groundwater upflow – in which case certain WETMEC 14 mires may function little differently to those clustered into WETMEC 16, with a predominance of lateral groundwater flow from the edges – but in some cases there is little evidence for such aquitards at the base of the peat, and in others they are demonstrably discontinuous.

In samples with shallow peat deposits (which is most of them), the peat infill is typically rather loose and unconsolidated and may offer little constraint upon water movement. Clarke (1988) considers that the deeper peat deposits (where they occur) may have low hydraulic conductivity and may restrict lateral seepage. It is likely that such circumstances may promote lateral water flow through the spongy surface layers, as through the acrotelm of an ombrogenous bog, rather than prevent ingress of telluric water. Of course, much water movement is probably channelled into the preferential flow paths provided by the soakways and water tracks of WETMEC 15, and it is not certain to what extent across-valley and down-valley flow occurs through the upper layers of WETMEC 14. However, at some sites patterns of electric conductivity variation provide indirect evidence for some lateral flow through WETMEC 14 locations (for example, Newbould, 1960), though the interpretation of such data may be complicated by the occurrence of lithologically distinct groundwater sources (see ecohydrological site account for Cranes Moor in Appendix 3). Thus, functionally WETMEC 14 surfaces appear to be similar to those of WETMEC 13, but with a greater prominence of down-valley flow.

6.17.9 WETMEC sub-types

No WETMEC sub-types have been identified.

6.17.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 14 are summarised in Table 6.51. With the exception of some partly drained examples (such as Silver Tarn), the surfaces of WETMEC 14 are consistently wet, with a water table at or very near the surface for much of the year. Although some sites are slightly sloping, in some cases high water conditions are partly maintained by constraints upon outflow as well as by water supply. For example, at Warwick Slade Bog mineral (presumed alluvial) material alongside the Highland Water appears to constrain water outflow to the river, except along some quite well-defined surface channels. Chobham and Shortheath Commons also have constraints on outflow from the lowermost parts of the system.

Table 6.51 WETMEC 14: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	1.5	0.3	4.0
Summer water table (cm)	0.1	–18	25
Rainfall (mm a^{-1})	837	667	1,100
PE (mm a^{-1})	600	556	668
Water pH	4.8	3.7	5.9
Soil pH	4.9	3.8	5.9
Conductivity (µS cm^{-1})	150	81	289
K_{corr} (µS cm^{-1})	142	49	287
HCO_3 (mg l^{-1})	21	0	90
$Fertility_{Phal}$ (mg)	10	4	49
Eh^{10} (mV)	281	34	509

See list of abbreviations in Appendix 1

Perhaps the most curious feature of WETMEC 14 is its preferential association with base-poor, acidic conditions – few samples have been recorded from base-rich, calcareous sites (Table 6.52). The WETMEC is essentially absent from most of the calcareous valleyhead fens in East Anglia, but the reason for this is not altogether clear. Development of WETMEC 14 essentially requires a relatively broad-bottomed valley of gentle gradient and a good supply of groundwater. It is possible that this combination of features is most readily provided in the small headwater valleys of the heathlands of Southern England, and is not found, for example, in most of the East Anglian valleyheads. Certainly some East Anglian valleyheads tend to be V-shaped, with seepage slopes leading down to an axial stream or water track, and with little scope for the development of topogenous valley-bottom surfaces associated with WETMEC 14. However, parts of some sites such as Flordon Common seem topographically appropriate for WETMEC 14; its absence may be a consequence of long-term drainage and perhaps peat cutting.

6.17.11 Ecological types

Table 6.52 Percentage distribution of samples of WETMEC 14 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich		3	5
Sub-neutral	38	5	3
Base-poor	48	2	

Oligotrophic, acidic/base-poor

Most samples fall into this category: pH less than 5.0 and low fertility surfaces. There is no obvious vegetational distinction to be made between samples in the acidic and base-poor categories, both of which typically support M21 vegetation.

Oligotrophic, sub-neutral

Amongst the samples within this category, some support the same vegetation types as the oligotrophic, acidic/base-poor category, but others have rather different communities, including a rather ill-defined *Molinia–Myrica* community. Most of the samples from the north-eastern (lower) end of the Little Arm at Chobham Common fall into this category, referable variously to *Sphagnum cuspidatum/recurvum* bog pool community (M2), *Carex echinata–Sphagnum recurvum/auriculatum* mire, *Juncus acutiflorus* sub-community (M6d) and *Molinia caerulea–Potentilla erecta* mire, *Erica tetralix sub-community* (M25a). Some samples from Church Moor also fall into this unit, for reasons that are not obvious.

Mesotrophic/eutrophic, sub-neutral

Only a small number of samples fall into this category, from two sites (the southern arm of Hartland Moor (Dorset) and the western outflow basin at Silver Tarn (Cumbria)). The southern arm at Hartland Moor may be enriched by field drainage into the head of this valley, though this is not certain. This may also be the case at Silver Tarn, but the examples of WETMEC 14 at this site are not good representations of the type. Communities present include M22 and M23.

6.17.12 Natural status

The suggestion that valley bogs with WETMEC 14 (and related) surfaces are a product of increased groundwater levels as a result of forest clearance is demonstrably not valid for those sites which have a stratigraphical sequence from late-Devensian deposits, and possibly for very few in total – though forest clearance may have had a hydrological impact upon the mires. Quite profound changes have undoubtedly occurred during the development of some of the mires. For example, a number of sites have basal wood peats which have since become replaced by herbaceous (and often *Sphagnum*-rich) deposits (such as Holmsley Bog (Clarke, 1988); Wilverley Bog (Rose, 1953)) and their present vegetation has few, if any, trees. Clarke (1988) considered that "*little change was detectable in the cores from open mire communities using field stratigraphy alone – only two cores from Holmsley Bog (both containing wood) showed any major differences to the surface vegetation*." Our own data broadly support this view, though with the caveat that one difficulty in assessing the natural status and successional development of some sites is the possibility that more recent peat has been dug away.

In general, there is little good evidence for peat digging in WETMEC 14 mires (see Tubbs, 1986), and the past occurrence of this activity is not really known (Cranesmoor is an exception (Box 6.26)). Rose (1953) pointed out that there was little reason to suspect peat digging in many valley bog sites; it would scarcely have been worthwhile, given that the peat was so thin and unconsolidated as to make excavation of the material both difficult and pointless. The converse view, that these 'worthless' deposits are actually the stratigraphical remains of worked-out turbaries, has not been examined in detail, though the fact that it would imply past peat extraction on a very large scale may perhaps argue against it. In the New Forest mires, surface irregularities which have been interpreted as evidence for past turbary (for example, England Field Unit, 1984) are quite widespread, and are sometimes evident on aerial photographs, but it is less clear whether all areas with loose and shallow peat represent old turbaries. At Stephill Bottom (discussed further under WETMEC 15), Clarke (1988) considered the loose upper layer of peat to be a persistent natural feature of the location.

Nonetheless, a recurrent problem in the Forest and elsewhere is that skeletal stratigraphies with thin, unconsolidated, worthless peats are widespread, much wider than locations for which there is visual surface indication of peat digging. Thus, one has to conclude either that rather few areas have been dug for peat or that very large areas have been worked. Comparative stratigraphical data alone cannot always resolve this, especially in situations where large areas of peat have been uniformly removed, and as a consequence the status of many sites remains enigmatic. In the absence of detailed macrofossil evidence and accurate dating it is not possible to resolve this matter, but on the balance of probability we suspect that peat may well have been removed from many of these skeletal sites.

Many WETMEC 14 surfaces show little tendency for spontaneous tree colonisation, except when disturbed by drainage, and in some cases they appear to be derived from a once more-wooded state. However, it is not clear to what extent woody plants are naturally absent because of unfavourable ecohydrological characteristics or because of low-intensity grazing. It is possible that some surfaces, at least in some of the larger sites, were once naturally ombrogenous but that ombrogenous peat has been removed (see Box 6.26, also WETMEC 16).

6.17.13 Conservation value

Species diversity in WETMEC 14 is generally rather low, partly because of the intrinsically small species richness of base-poor mires. However, it has quite a large species total and includes some nationally uncommon species, and it may support SAC habitat (see Tables 3.3 and 6.4).

A total of 101 wetland species have been recorded from samples of WETMEC 14. This is not a particularly species-rich WETMEC, probably partly because no base-rich samples are included within it – rather it contains a number of base-poor communities (see below), none of which are intrinsically very species-rich. The unit provides one of the main WETMECs for *Narthecium ossifragum–Sphagnum papillosum* mire (M21), and the mires of New Forest in particular provide some of the finest examples of base-poor mire vegetation in Western Europe. The following nationally uncommon species were recorded: *Cladopodiella fluitans, Drosera intermedia, Erica ciliaris, Osmunda regalis, Sphagnum pulchrum, Sphagnum subsecundum, Thelypteris palustris, Utricularia intermedia.* WETMEC 14 also supports a number of species that are generally local or rare in lowland England and Wales, including *Eleocharis multicaulis, Myrica gale, Narthecium ossifragum, Rhynchospora alba, Schoenus nigricans* and *Vaccinium oxycoccos.*

The percentage occurrence in NVC communities of samples of WETMEC 14 is: M21: (77%); M22: (5%); M25: (5%); M04: (2%); M05: (2%); M9-1: (2%); M23: (2%); S27: (2%). The overwhelming predominance of M21 reflects the predominance of base-poor conditions. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 14 is given in Table 6.3.

6.17.14 Vulnerability

The view that survival of the often-extensive tracts of wet WETMEC 14 mire is remarkable is reduced only slightly by the recognition that in some cases, their present condition may be a product of former turbary. Persistence of the habitat is doubtless partly because ‘improvement’ was likely to be both difficult and unrewarding. Nonetheless, some of these valley bogs are potentially amenable to afforestation, and a number have been partly drained. In the New Forest, some valley mire systems were once much more extensive and continuous than is currently the case. In some sites, former drains (Rose, 1953) appear to have become occluded and have all but disappeared (such as Cranesmoor, Wilverley Bog), but in others axial drains are active and erosive. Some of these are the subject of current ditch blocking schemes, using stone gabions and so on. However, these systems are often subject to substantial water throughflow and in the natural state, are likely to have been drained by braided water tracks, grading into sinuous streams.

The vulnerability of these systems to groundwater abstraction is strongly context-dependent. As partly topogenous units, often over slowly permeable deposits, WETMEC 14 surfaces may be less susceptible to a reduction of groundwater head than, say, any adjoining Permanent Seepage Slopes (WETMEC 10) (but see the relevant section for WETMEC 16).

Enrichment of groundwater, including an increase in water pH, is a potential threat to acidic, oligotrophic surfaces. There have been reports of apparent increases in water conductivity at a number of sites (for example, Strauss, 1999) but data are limited and may not necessarily represent real, significant changes. Moreover, the occurrence of the key M21 community over a range of pH and EC values may mean that a small change in hydrochemical characteristics may have little ecological consequence. Perhaps more telling is the apparent spread of potentially vigorous species such as *Phragmites australis* at sites like Crabtree Bog (New Forest), though the cause of this change is not necessarily clear.

As WETMEC 14 surfaces are potentially vulnerable to drainage, it seems likely that there ought to be a WETMEC representing drained examples of this unit. Drained surfaces undoubtedly exist in parts of the New Forest, but have been little-sampled in this project which has concentrated on the better examples of mire. Elsewhere in England and Wales it is possible that a number of partly drained, peaty valley bottoms might once have supported examples of WETMEC 14, but if such systems are represented at all within the *Wetland Framework* they have almost certainly been subsumed within WETMECs 8 and 9. Other examples could now be so dry that they are scarcely recognisable as former mires, and this could go some way to explaining the scarcity of calcareous examples of WETMEC 14, on the basis that there was a greater agricultural return in draining wet calcareous valley bottoms than, for example, oligotrophic, acidic peat.

Likewise, past turbary may have profoundly changed, perhaps beyond recognition, the character of some former WETMEC 14 sites. For example, it is possible that the absence of WETMEC 14 from most East Anglian valleyhead mires is partly due to past turbary. Little is known about peat cutting in these fens, but Wheeler and Shaw (1995b) point out that "*on a (conservative) assumption of 20 right-holders each removing 3,000 turves every year, the equivalent of one metre depth of peat would be removed from one ha of fen every 50 years. As the sites are generally small … it is not surprising that even at Inclosure some had largely been stripped of their peat*." This could mean that topographically appropriate valleyheads, such as Buxton Heath and parts of Scarning Fen, might once have been filled flat across with peat (Wheeler, 1999b), in which case much of their surfaces might well have once been referable to WETMEC 14 rather than to the WETMEC 10 seepage slopes that currently occupy the exposed valley sides. However, such suggestions are largely speculative.

6.18 WETMEC 15: Seepage Flow Tracks

6.18.1 Outline

The term ‘flow track’ is used as a generic term to encompass water tracks and soakways. These represent water flow tracks found on the surface of some mires, which usually form part of the drainage system, but which are variably clogged with elements of mire and swamp vegetation, so that they do not really constitute streams. Water tracks are examples with much open water and represent the transition between mire and true streams. Soakways essentially represent more consolidated water tracks, with less open water, and occur either lateral to water tracks or streams or, in some valleyheads, replace water tracks as the main axial flow path. The two intergrade and can be difficult to distinguish. This is a variable WETMEC, most typical of some valley bottoms but occurring in a wide variety of contexts, mostly on fairly shallow peat. It is irrigated by groundwater supply from marginal seepages and, in some cases, probably by upflow. The substratum consists of very loose peat, at least near the surface, sometimes more or less open water, which forms a preferential flow path for water, sometimes a proto-stream. Schematic sections are provided in Figure 6.42.

6.18.2 Occurrence

Example sites: Bicton Common, Buxton Heath, Chartley Moss, Clayhill Bottom, Cors Geirch, Cors Graianog, Cors Gyfelog (Gyfelog Farm), Church Moor, Cranes Moor, Denny Bog (west), Folly Bog, Fort Bog, Great Ludderburn Moss, Greendale Flushes, Hagthorn Bog, Hartland Moor, Holmhill Bog, Holmsley Bog, Holt Lowes, Lords Oak, Roydon Common, Scarning and Potters Fen, Sheringham and Beeston Regis Commons, Stoborough Heath, Stoney Moors, Strodgemoor Bottom, Thursley Common, Warwick Slade Bog, Wybunbury Moss

Quite widespread. Most examples were from Southern England (especially New Forest), but also from East Anglia, Wales and elsewhere. The distribution of examples in sites sampled is shown in Figure 6.41.

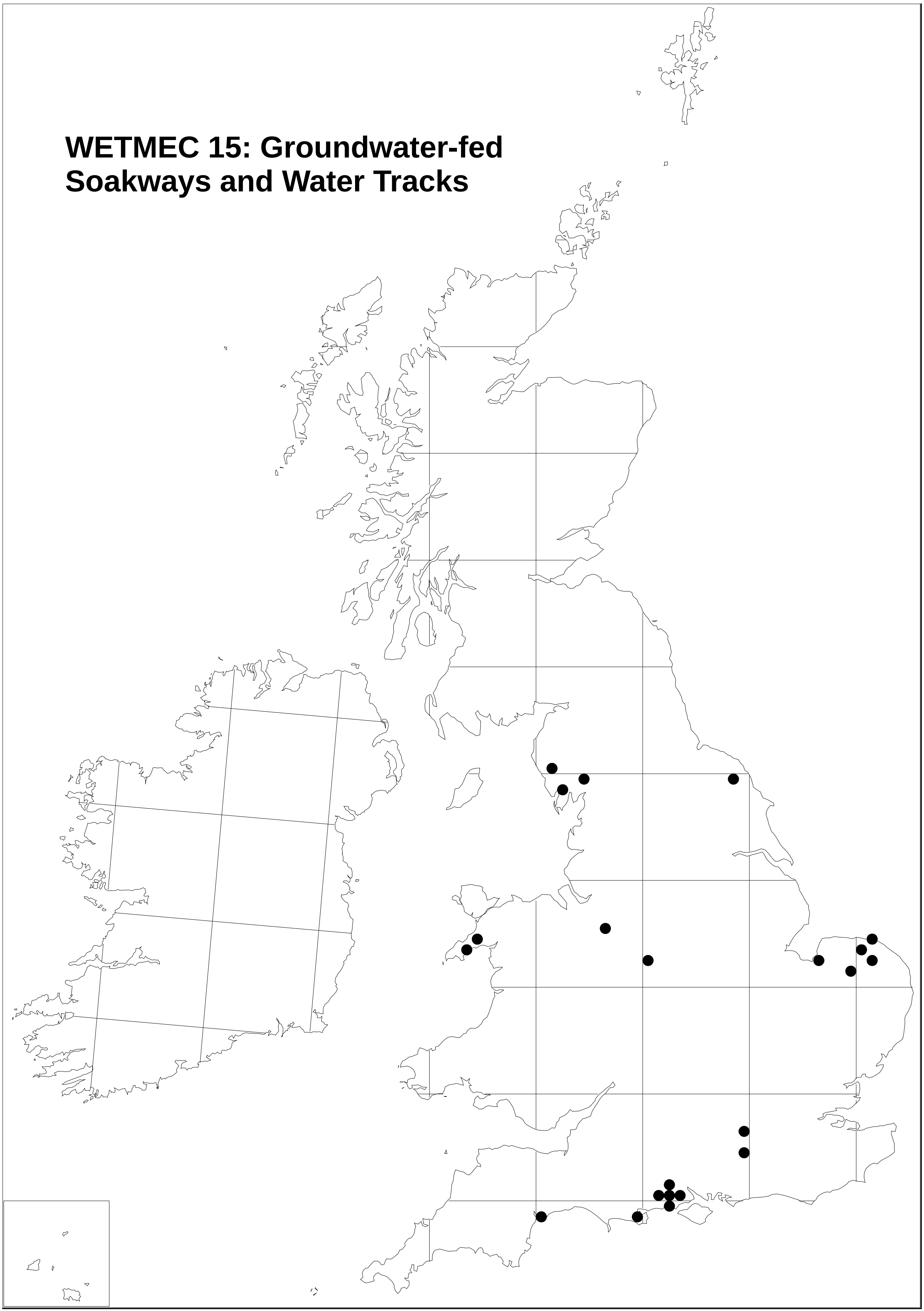


Figure 6.41 Distribution of examples of WETMEC 15 in sites sampled in England and Wales

6.18.3 Summary characteristics

Situation	Mostly valleyheads, some troughs, basins and groundwater-fed laggs (of raised bogs). Some examples in peat workings.
Location	Quite widespread. Most examples from Southern England (especially New Forest), but also from East Anglia, Wales and elsewhere.
Size	Usually fairly narrow linear features, < 20 m width to > 1 km length.
Surface relief	Narrow flats and troughs, soakways with a (often buoyant) more or less continuous vegetation mat, water tracks with much open water. Often with a visible slope.
Hydrotopography	Rheophilous.
Water: ***supply***	Groundwater, partly *via* adjoining WETMECs; often some surface water.
regime	Water table consistently at (or just above) surface.
distribution	Longitudinal flow along trough, with some lateral flow from flanks; possibly upflow in some cases. Water flow often visible.
superficial	Water channels, sometimes braided or otherwise mosaiciform, in the case of water tracks.
Substratum	Most often a buoyant surface (water and liquid muds, sometimes over more solid peat) but sometimes more consolidated. Basal material ranges from sands and gravels to silts and clays.
peat depth	Typically shallow (< 1 m), but some deeper examples.
peat humification	Usually with a shallow (0.5 m) spongy or semi-floating surface (soakways) or open water (water tracks); any underlying peat may be semi-liquid, but can be more humified and often quite solid, especially lower down.
peat composition	Mostly monocot or *Sphagnum* peat. Wood peat in some examples.
permeability	Uppermost peat usually with high permeability characteristics, but may be more consolidated further down. Basal substratum variable, but mostly with moderate to low permeability characteristics.
Ecological types	Oligotrophic, acidic to eutrophic, base-rich.
Associated WETMECs	Mostly flanked by other WETMECs, especially WETMEC 14 or 10 (sometimes 17). Sometimes drains into sumps with WETMEC 13.
Natural atatus	Many examples appear to form a natural persistent state, but some are in occluded drains or flooded peat workings.
Use	Conservation. Generally too wet for easy access. Some occupy former turbaries.
Conservation value	Species diversity is generally rather low but has quite a large species total and a number of nationally uncommon species; examples may support SAC habitats. Sometimes provides a relatively base-rich element within otherwise base-poor mires.
Vulnerability	Direct drainage. Damming can pond back water and adversely affect this and flanking WETMECs. May be affected by changes in groundwater quality.

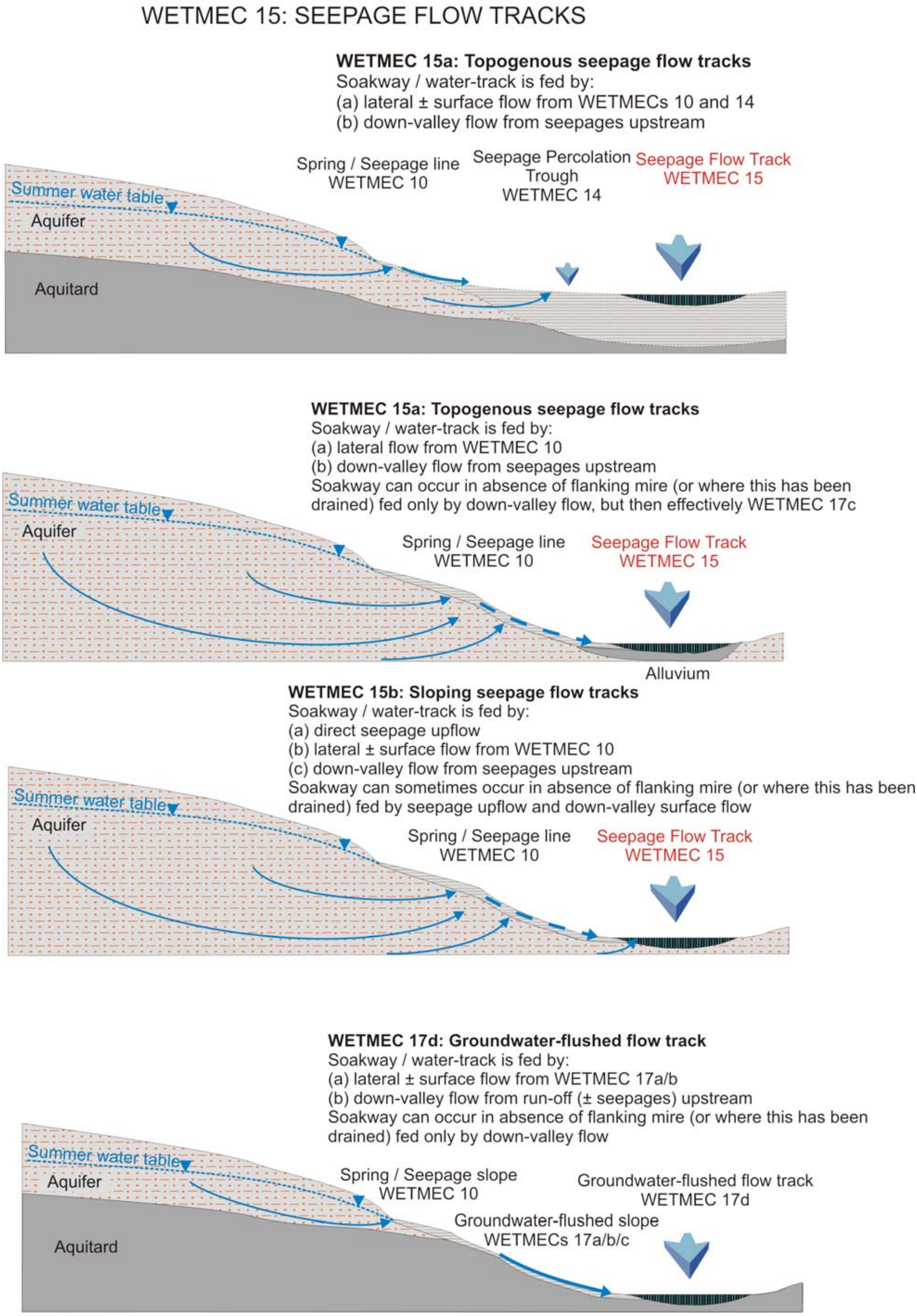


Figure 6.42 Schematic sections of types of Seepage Flow Tracks (WETMEC 15)

6.18.4 Concept and description

CLUSTER: 26

WETMEC 15 essentially represents groundwater-fed wet surface flow tracks in mire systems, and can be divided informally into soakways and water tracks. The difference between these is not clear-cut but relates to the amount of visible surface water, the consolidation of the substratum and, probably, the rate of water flow (usually visible in water tracks, but less so in soakways). Water tracks essentially have greater similarities to streams, whereas soakways have more affinities to mires. Water supply can come from three main directions: groundwater seepage from the margins; groundwater upflow (in examples not over an aquitard); and down-valley (often endotelmic) flow. The latter is often seen as surface water in the water tracks and appears to be their dominant water source. Soakways can have similar sources, but where they occur alongside water tracks they sometimes also experience episodic inputs from the tracks during high water episodes. Depending on the circumstances, this can sometimes lead to inundation of the soakway or simply buoys up the surface to a higher level.

The character of WETMEC 15 is quite variable, and depends strongly on its topographical context. Water tracks are sometimes simple linear features, particularly in narrow, steeper valley bottoms, but they can also form sinuous or braided channels, with soakway (or other mire) elements embedded within them. Soakways sometimes border water tracks, or can occur as the sole axial features. Downstream, water tracks can grade into streams. In some locations water tracks have been accentuated, or removed, by ditching along the drainage axis, whilst in other contexts water tracks appear to be more occluded ditches than natural features. Some occur in visually flat contexts, but most can be seen to be slightly sloping, and in some cases the slope may be greater than five degrees. In narrow valleyheads or in some of the flatter valleyhead systems where outflow drainage is impeded (such as Fort Bog), sluggish water track–soakway complexes can occupy a considerable portion of the valley bottom. In this circumstance, it can be particularly difficult to separate them from examples of WETMEC 14 (Seepage Percolation Troughs), into which they may intergrade towards the margins. Although often regarded as minor telmatological features, in some sites WETMEC 15 surfaces can support much of the main mire interest.

In many sites WETMEC 15 occupies the main drainage axis of a mire, often in a more or less central position, and this forms part of the basis of the classic valley-bog zonation pattern (Rankin, 1911; Rose, 1953) in which (discontinuously) forested water tracks and soakways (roughly Zones 1 and 2 of Rose's scheme) are flanked by *Sphagnum* bog (most usually WETMEC 14). This sequence undoubtedly occurs in places, as at Denny Bog (East), but many examples of WETMEC 15 are not treed, and in some cases they occur along one (or more) of the margins rather than in a central location. In larger, broader sites (such as Cranesmoor) there may be more than one water-track system, occupying different parts of the mire.

In the valley bogs of the New Forest and some other locations, WETMEC 15 can be flanked by WETMEC 14, but this is not necessarily the case. Examples in narrower valleys may be bordered directly by rising seepage slopes (such as Holmhill Bog, Stoney Moors, Widden Bottom, and, outside of the New Forest, Roydon Common, Scarning Fen, Sheringham and Beeston Commons). In some sites, WETMEC 15 has almost certainly been modified by deepening and straightening of the drainage axis, and in some instances (such as Buxton Heath) it has all but disappeared in favour of a small stream. Elsewhere, samples that have been clustered into WETMEC 15 occur in a variety of contexts, sometimes occupying narrow channels below springs and flanked by heath or grassland. Others occupy sluggish channels within, and slowly draining, a seepage slope (such as Cors Geirch (Rhyd-y-clafdy section)). Some examples occur in groundwater-fed laggs around ombrogenous deposits (such as Malham Tarn Moss, Wybunbury Moss), and an unusual case of a groundwater-fed soakway which flows *across* a dome of ombrogenous peat is found at Tarn Moss (Malham), where groundwater from Spiggot Hill flows in different directions across the bog, along three soakways. In this case, the penetration of groundwater along the soakways may have been enhanced (or caused) by the ditches. Some samples from occluded ditches have also been grouped into WETMEC 15. Some, such as Holmhill Bog, appear to represent ditched soakways which, after ditch blocking, are reverting to type, but others may be in ditched locations which did not sustain a natural example of WETMEC 15. A sample for a novel habitat which was clustered into WETMEC 15 is a peat trench dug into ombrogenous peat at Great Ludderburn Moss, now with a throughflow of quite base-rich water, apparently sourced by groundwater outflow.

A small number of samples clustered into WETMEC 15 show little clear evidence for water throughflow. These include samples from the north-western arm of Cors Gyfelog, which shows a fairly clear zonation of WETMEC 15 flanked by WETMEC 14, but the extent to which water flows through this system, comparable to more obviously sloping examples of WETMEC 15, is unclear.

Affinities and recognition

Soakways and, especially, water tracks are often obvious linear features within mires but are frequently more easily seen than defined. Except in the case of some artificial sites (peat-cutting troughs, occluded drains) and other clear-cut examples, it can be difficult to specify in the field their point of transition to an adjoining WETMEC (most often WETMEC 14), and it is equally difficult to draw a clear conceptual line between the two units. WETMEC 15 is closely related to WETMEC 14: both are fed primarily by groundwater flow along the valley-bottom troughs in which they occur, and they differ mainly in the apparent rate of water throughflow and presence of surface water. In contrast to WETMEC 14, WETMEC 15 normally has visible water flow, with water levels normally above the surface, but in narrow valleys with a quite high rate of water throughflow it can be difficult to make a sensible distinction between this WETMEC and WETMEC 14.

WETMEC 15 also shares a number of features with WETMEC 13 (Seepage Percolation Basins), especially the loose upper peats and frequently buoyant surface. In most cases the two are easily separated, because WETMEC 15 is a linear, often obviously sloping, feature whereas WETMEC 13 usually occupies sumps and basins. However, some broad, sluggish examples of WETMEC 15 (as can occur in some reflooded peat workings) are similar and transitional to WETMEC 13.

Some examples of WETMEC 15 occur in close association with seepage slopes and in some cases (such as Sheringham and Beeston Commons) support similar vegetation to these. In the Phase 1 analysis (Wheeler and Shaw, 2000a) the (small number of) water tracks were grouped into a sub-cluster of Permanent Seepage Slopes (WETMEC 10). Functionally, and floristically, such water tracks may be little different to some of the small runnels that occur on many seepage slopes, and the distinction can be primarily one of scale. However, many water tracks have a shallower gradient, deeper water and, often, a more buoyant surface than runnels, which tend to be small, often skeletal water pathways within a sloping seepage system.

It is quite difficult to specify the difference between the two components of WETMEC 15: soakways and water tracks. In the current context, water tracks are distinguished as usually having open water which is frequently visibly flowing, whereas soakways usually have little open water and little obvious flow (at least in normal summer conditions), though they may have an anastomosing network of small runnels. The two units can occur by themselves or together. In the latter case, the soakway normally flanks the water track. Soakways and water tracks thus represent nodal points along a lateral gradient of water depth, water flow and water cover. Soakways often have more mire-like communities than water tracks, though the difference is often only broadly based, because both units can contain mosaics of conditions and vegetation types.

Although examples of WETMEC 15 occur in a variety of contexts, they have all been clustered into a single end group at the 36-cluster level, suggesting that their classification has been dominated by a number of strongly correlated recurrent features, which have over-ridden the influence of other variation. Two WETMEC sub-types have been recognised based on the 72-cluster level, but these do not correspond to a split between the soakways and water tracks, thus reinforcing the desirability of considering them as a single ecohydrological unit, despite their obvious differences.

Examples of WETMEC 15 are similar in many respects to the flow tracks of WETMEC 19. The main difference is that examples of WETMEC 15 are primarily sourced by outflow of groundwater from mineral aquifers, whereas in those of WETMEC 19 rain-generated run-off is more important. The two could readily be united into examples of a single WETMEC, with groundwater and surface water sub-types, but the discrimination suggested by the Ward's Method clustering has been retained here.

6.18.5 Origins and development

Partly because soakways and water tracks are often a minor component of wetland systems, they have been little studied and have sometimes only been fortuitously sampled as part of a wider investigation. As a consequence, little is generally known about these features, including the age and stability of their courses. For example, a stratigraphical section of Pigott and Pigott (1959) at Tarn Moss (Malham) crosses the course of one of the minerotrophic soakways across the bog, but provides no indication of the occurrence of a channel of fen peat. It is thus not possible to establish, from the data available, whether this minerotrophic soakway is a recent feature, perhaps created by drainage initiatives, or a long-lived but narrow feature which was not sampled by the cores of the Pigotts.

Some insights are available about the soakway–water track system at Church Moor (New Forest). Here, the main soakway system does not flow down the centre of this elongate mire, but along the western edge, where it is marked by a strip of alder carr and appears to have had long-term stability of location (see Box 6.26, WETMEC 14). It is not known to what extent the water-track systems show similar stability in other New Forest sites. Some still show good examples of fen woodland along the water track, as at Fort Bog. Peat cores from this site show wood fragments beyond the limit of the present carr, suggesting that the fen woodland may once have been more extensive than is currently the case. Part of this site at least is thought to have been cut over (Clarke, 1988) and the deposit below the present woodland is very unconsolidated and difficult to retrieve, though Clarke (1988) considered that "the stratigraphy shows wood to be present throughout the peat column in the alder carrs"[1].

There is evidence for the disappearance of former woodland in some New Forest locations: Rose (1953) reported a basal layer of alder at Wilverley Bog which was covered by some 20 cm of *Sphagnum* peat, and considered this evidence for "the replacement of alder carr by *Sphagnetum*"; Clarke (1988) provides evidence for the loss of former carr vegetation from

[1] Note that a distinction must be made between the quaking carrs along the water tracks, which are the focus of attention here, and other examples of fen woodland which can occur, for example, on alluvial soils alongside some of the valley bogs, sometimes separating them from adjoining rivers (*e.g.* Matley Bog, Wilverley Bog). As Rose (1953) considered these two latter sites to represent full examples of his zonation, it seems likely that he did not make this distinction.

Holmsley Bog and Stephill Bottom. However, in many cases the woody peat forms a basal layer and its replacement by herbaceous vegetation may be of very long standing; for example, at Stephill Bottom, Clarke considered that the hydrological environment and vegetation character has shown “very little change over the last 3,000 years”. However, Denny Bog (East) just downstream of Stephill Bottom still has some quite extensive, if discontinuous, stands of woody vegetation along the axial water track and it would be of interest to know more about their ontogenic status.

Soakways and water tracks, with their high water tables and unconsolidated infill, would seem an unpromising context for turbary. At Stephill Bottom, Clarke (1988) reported a loose upper layer of peat to 45 cm bgl, rich in *Sphagnum*, over a more consolidated and slightly more humified deposit of monocot peat. However, he rejected the possibility of the wet upper layer representing the infill of a reflooded peat working in favour of its being a persistent natural feature of the mire, dating from about 3000 BP. In the context of a fairly narrow trough, with substantial funnelled water throughflow, this proposition is not unreasonable, but in other circumstances there can be little doubt that WETMEC 15 surfaces are located in former turbaries. For example, at Fort Bog, the rather broad soakway–water track complex appears (along with its populations of the nationally rare *Eriophorum gracile*), in whole or part, to occupy former turbary (Clarke, 1988). A similar situation, where WETMEC 15 occupies much of the valleyhead width relative to the flanking WETMEC 14, is found in parts of Hartland Moor, which is also thought to have been cut over (though little is known about this). The quite large expanse of WETMEC 15 in the north-western arm of Cors Gyfelog may also occupy a reflooded peat working, which could account both for its large extent and its evident affinities to WETMEC 13. On this analysis, turbaries may not have been dug in soakways, but some of the large soakway and water track complexes may well have developed within reflooded turbaries.

Groundwater-fed soakways occasionally form (part of) the lagg alongside some ombrogenous deposits (raised bogs). Examples in the current survey include Malham Tarn Moss (west side), Wybunbury Moss (north side) and, probably, Chartley Moss (west side). Their interest in this context is that the lagg is sometimes considered to be an integral part of the hydraulic concept of a raised bog, but it is clear that such systems, fed by groundwater outflow from a mineral aquifer, are hydrologically distinct and partly uncoupled from the adjoining deposit of ombrogenous peat. Of course, in the absence of the latter, the groundwater outflow might be less likely to be funnelled into a soakway or water track and instead might have spread more extensively into the adjoining mire basin, perhaps as a WETMEC 13 unit.

6.18.6 Situation and surface relief

The great majority of samples (90 per cent) occur in valleyhead systems where they are marked by surface or near-surface water flow, most usually along the main mire axis or alongside valleys, but sometimes also laterally down gently sloping valley sides. Some examples are also known from other topographical contexts, with five per cent from valley-bottom troughs and three per cent from basins. There were also a few samples (one per cent) from groundwater-fed laggs (such as Tarn Moss (Malham), Wybunbury Moss), and some (one per cent) occurred within the dome of an ombrogenous deposit (Tarn Moss, Malham). The latter is a most unusual occurrence and should not be confused with the ombrotrophic soakways which can sometimes be found on ombrogenous deposits (no examples of which were encountered in this project).

WETMEC 15 typically occurs in narrow flats and troughs. Soakways have an (often buoyant) more or less continuous vegetation mat, and water tracks much open water. Many samples were taken from more or less flat areas, but others had a visible gentle slope (Table 6.53).

6.18.7 Substratum

The uppermost substratum layer of peat is normally loose and open, and of high permeability (Table 6.53). In water tracks much open water is visible. The surface is usually unconsolidated and sometimes very unstable and treacherous. In some cases it consists of a buoyant vegetation mat of varying stability, but in other examples plants are rooted in a shallow submerged surface which may be of loose, near-liquid muds or, in some instances, solid peat or mineral material. Peat depth beneath most samples is shallow (less than one metre), but exceptions do occur (such as Cranesmoor where depths in excess of four metres have been recorded). Likewise, the examples associated with ombrogenous deposits can also be on deep peat. Where the peat is deep, the lower peat layers are often much more consolidated than the surface layer material, but in the shallower examples unconsolidated material, sometimes little more than liquid peat, can be found throughout the profile or overlaying a thin basal layer of more solid material.

The basal substratum is variable. At one extreme, examples occur over silt/clay loams; at the other, over sand and gravel. The nature of the basal substratum can vary within the same site and, sometimes, within the same flow-track trough. Incongruities of basal substratum can occur where the troughs run down across bedrocks with contrasting permeability characteristics (see Box 6.27), or variations in the superficial valley infill. In the New Forest examples, this often relates to the occurrence and varying character of Head within the valley.

Box 6.27: WETMEC 15 at Bicton Common (Devon)

Bicton Common is a valleyhead site which supports a number of well-defined flow tracks embedded within other types of mire. The mires corporately occupy some small, quite deeply incised valleys cut into Budleigh Salterton pebble beds over a Littleham Mudstone aquitard. The pebble beds are mostly freely permeable and groundwater outflow occurs from the lowermost pebble bed horizons as a series of springs and seepage faces at the junction of the two deposits on the valley sides. Small valleys within the valleyhead contain water tracks and soakways: in the upper parts they are cut into the pebble beds, which source their water; lower down they are over the Mudstone, where they are fed primarily by longitudinal flow down the trough, together with some groundwater flush (WETMEC 17) input from adjoining Mudstone surfaces. Flow tracks on the pebble beds have clustered into WETMEC 15b, whereas some of those along the Mudstone valley bottom were allocated to 15a. However, the more active, skeletal water tracks towards the head of the valley bottom clustered within WETMEC 17.

Table 6.53 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 15

	Mean	1	2	3	4	5	6	7
Surface layer permeability	6.2			2	5	13	37	45
Lower layer permeability	4.8		6	14	22	23	25	11
Basal substratum permeability	4.0		32	6	15	17	29	
Slope	1.7	54	26	20			X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.18.8 Water supply

Soakways and water tracks are natural drainage features of mires and in many cases much, or all, of their telluric water is derived from adjoining mire units and reflects the character of these. As generic drainage units, soakways and water tracks can sometimes be fed by a wider range of water sources than is the case with some other WETMECs, and can contain a mix not only of surface and groundwater sources but also a mix of different groundwater types. However, all of the samples clustered into WETMEC 15 relate to contexts where groundwater appears to be a main contributor to the summer water supply of the unit. [Soakways and water tracks where there is little evidence for groundwater supply, or where this appears to be small relative to other sources, have clustered in WETMEC 19.]

Some soakways and water tracks clearly originate in springs and seepages, but in others these are less obvious. Some are endotelmic (originating within and adjoined by other WETMECs) whereas for others the source is at, or slightly above, the head of the mire. In a few cases, soakways and water tracks occur alongside streams which originate well above the head of the mire. In some of these the streams may help supply the water tracks and soakways, at least seasonally (and under some circumstances may even feed into flanking examples of WETMEC 14, though normally only on a small scale). However, most examples of WETMEC 15 appear to be fed primarily from flanking upslope sources rather than from adjoining watercourses, at least in normal summer conditions.

Some examples of WETMEC 15 are always very wet but others, especially those in the upper parts of the mires, may become ‘dry’ (showing no surface water) in dry weather. This is particularly, but not exclusively, the case for some examples of WETMEC 15b. In such cases, the vegetation of the temporary flow track may be different both from the flanking WETMECs and from more permanent examples of WETMEC 15 further downstream. In some locations. the flow tracks may extend above their normal limit in the mire in particularly wet weather, and sometimes even beyond the mire itself.

The dominant direction of water movement in water tracks is usually visibly longitudinal, down along the trough in which the WETMEC occurs. Longitudinal flow is also likely along many soakways, but where these flank water tracks or streams, transverse flow from flanking WETMECs to the drainage axis may occur, and may represent the dominant direction of water movement. Open water flow occurs in water tracks; in soakways, flow appears to occur either through loose surface peats or beneath buoyant vegetation mats. Some groundwater upflow from an underlying aquifer may also occur, especially in examples of WETMEC 15b, but the importance of this is generally not known.

6.18.9 WETMEC sub-types

The samples allocated to WETMEC 15 all belong to one cluster at the 36-cluster level of the multivariate analysis. Examination of the 72-cluster level suggests that a more or less consistent subdivision can be recognised, though as this is based on recurrent combinations of variables whose limits do not necessarily coincide, the generation of sub-type diagnostics is not as clear as might be desired. Broadly, the subdivision is into: (a) relatively low gradient systems, often on fairly deep peat, usually over a slowly permeable basal substratum; and (b) steeper systems, frequently on shallow peat or on a skeletal surface, mostly over permeable material, and sometimes part of a seepage complex. However, examples with a mix of characteristics occur and the two types intergrade. Note that examples of more steeply sloping soakways over a low-permeability deposit became clustered within WETMEC 17 (Groundwater-Flushed Slopes).

WETMEC 15a: Topogenous Seepage Flow Tracks

CLUSTER: 26.1 (72-CLUSTER LEVEL)

> *Examples at:* Bicton Common, Buxton Heath, Chartley Moss, Cranes Moor, Denny Bog (west), Fort Bog, Great Ludderburn Moss, Hartland Moor, Holmhill Bog, Thursley Common, Warwick Slade Bog, Wilverley Bog, Wybunbury Moss

WETMEC 15a includes flow tracks along low-gradient valley bottoms, which are often on quite deep peat (relative to 15b). This is the commonest and most characteristic expression of WETMEC 15 in many New Forest valley bogs, and it includes all of the extensive, broad examples of the WETMEC. Most of the lagg and 'artificial' examples of WETMEC 15 (in occluded drains and in abandoned peat workings) have also clustered into this sub-type. It is often underlain by a low-permeability deposit, either a deep consolidated peat or clays and silts, though there are a few exceptions (such as the northern and southern arms of Hartland Moor).

WETMEC 15b: Sloping Seepage Flow Tracks

CLUSTER: 26.2 (72-CLUSTER LEVEL)

> *Examples at:* Clayhill Bottom, Cors Geirch, Cors Graianog, Cors Gyfelog (Gyfelog Farm), Folly Bog, , Greendale Flushes, Hagthorn Bog, Holmsley Bog, Holt Lowes, Lords Oak, Roydon Common, Scarning and Potters Fen, Sheringham and Beeston Regis Commons, Stoborough Heath, Stoney Moors, Strodgemoor Bottom

WETMEC 15b includes a series of soakways and water tracks united by being on shallow peat, or directly upon a mineral substratum. Most examples of the latter are relatively permeable and some examples of WETMEC 15b form part of wider seepage systems (such as Cors Geirch (Rhyd-y-clafdy section), Roydon Common, Scarning Fen, Sheringham and Beeston Commons). A few examples allocated to this sub-cluster are on shallow peat over a low-permeability deposit (such as Holmsley Bog, Widden Bottom) and these have clear affinities with the groundwater-flushed flow tracks of WETMEC 17d. The difference between the two types is that examples of WETMEC 15b have a rather narrow strip of low-permeability material associated with the soakway (such as an underlying band of alluvium) and are fed by groundwater from marginal mires along much of the length of the soakway, whereas examples of WETMEC 17d are flanked by a broader band of low material and are fed mainly by axial flow from springs near the head of the soakway, or by lateral flow from Groundwater-Flushed Slopes (WETMEC 17). Many of the examples are relatively steep-sloping, but this is by no means always the case.

6.18.10 Ecological characteristics

Values of selected ecohydrological variables for WETMEC 15 are summarised in Table 6.54. The dominant ecological characteristics of WETMEC 15, in relation to other WETMECs, is the high summer water table, the presence (in the case of water tracks) of much open water, and the occurrence of longitudinal summer water flow (visible in many water tracks, presumed in most soakways). It forms a strongly rheotrophic habitat, and supports a range of rheophilous species. Some examples of water tracks are protostreams and have as much, or more, in common with flowing aquatic habitats than with mires, but these have not been included in the present study, which has focussed on the more mire-like examples.

As Ingram (1967) observed, water flow is an important, if little studied, ecohydrological feature of some mires, and can have an important influence upon vegetation composition. Flow tracks are often associated not only with (consistently) high water levels but also increased nutrient loadings and, sometimes, better aeration. Nonetheless, increased nutrient loadings along flow tracks, compared to flanking mire habitats, have more often been proposed than demonstrated.

Various workers (for example, Rose, 1953) have suggested that the restriction of fen woodland to axial water tracks in some New Forest valley bogs may be because of a more favourable nutritional environment. Likewise, the occurrence of more base-demanding herbaceous plant species in and alongside some flow tracks is suggestive of locally base-rich conditions. At some sites this has been confirmed by hydrochemical measurements, though differences between the water tracks and flanking surfaces may be fairly small (Newbould and Gorham, 1956; Bellamy, 1967) (Table 6.55).

Table 6.54 WETMEC 15: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	1.1	0.1	10.0
Summer water table (cm)	1.6	–12	13
Rainfall (mm a^{-1})	898	627	2,101
PE (mm a^{-1})	596	526	620
Water pH	5.4	3.7	7.0
Soil pH	5.8	3.8	7.4
Conductivity (µS cm^{-1})	198	58	729
K_{corr} (µS cm^{-1})	194	27	729
HCO_3 (mg l^{-1})	49	0	360
$Fertility_{Phal}$ (mg)	7	3	24
Eh^{10} (mV)	235	52	479

See list of abbreviations in Appendix 1

Table 6.55 Mean values of some hydrochemical and soil variables from samples of WETMEC 15 and proximate examples of WETMEC 14, 18 and 19 in valleyhead mires in Southern England

WETMEC	Water table (cm)	pH (water)	pH (soil)	EC µS cm^{-1}	HCO_3^- mg l^{-1}	Fertility (mg *Phalaris*)	Eh (mV)
14 (Seepage Percolation Troughs)	–0.2	4.7	4.7	155	19.6	6.5	275
15 (Seepage Flow Tracks)	+1.7	5.3	5.6	178	38.5	6.0	238
18 (Percolation Troughs)	+0.4	5.1	5.2	191	19.4	9.8	244
19 (Flow Tracks)	+4.3	5.4	5.5	123	33.9	7.4	196

It is generally unclear to what extent hydrochemical differences between flow tracks and flanking surfaces are a product of enhanced flow *per se* (increased loadings), or a result of an intrinsically different hydrochemical environment within the flow tracks. For instance, although examples of WETMEC 14 may be irrigated from the same groundwater source as the flow tracks, the passage of water through the surface layers of the WETMEC may modify the chemical characteristics of the water to a degree greater than is the case in an open, flowing water track. This may be especially the case when the mire vegetation is dominated by *Sphagnum*, which has a well-documented capacity for protonation (Clymo, 1984). In yet other cases, the axial water track may be fed from more base-rich water sources than some of the flanking seepages (as seems to be the case, for example, at Widden Bottom, New Forest). [This is considered further with respect to Thursley Common (6.18.14).]

Whilst there is clear evidence for enhanced base-richness in flow tracks compared to adjoining WETMEC 14 surfaces, there is no evidence that their phytometric fertility is any higher (Table 6.55). However, it is difficult to make phytometric estimates of fertility on samples of WETMEC 15 substrata, because these are often difficult to collect due to their unconsolidated character. It is therefore not certain how much reliance can be placed on fertility estimates from WETMEC 15.

Ingram (1967) also suggested that water tracks in mires could have somewhat higher redox potentials, because of the water movement. Armstrong and Boatman (1967) have provided some supporting evidence for this, which may be related to vegetation patterns. Both *Molinia caerulea* and *Myrica gale* can be particularly prominent in and close to flow tracks, where *Molinia* sometimes forms very robust tussocks. The growth of both species is clearly favoured by moving water, and this has been attributed to the development of less reducing conditions in the substratum (Webster, 1962a, b; Armstrong and Boatman, 1967). In the present study, cases were found where the redox potential of WETMEC 15 was higher than that of flanking WETMEC 14 but this was by no means always the case and overall, the mean redox potential of WETMEC 15 was *lower* than that of WETMEC 14. This is perhaps consistent with the generally higher water level of WETMEC 15, but it contributes little to explaining the prevalence of *Molinia* and *Myrica* close to water flow paths, and may perhaps point towards a nutritional explanation rather than one simply related to redox potentials.

Whatever the cause of its distribution, the occurrence of fen carr in water tracks in the wettest part of some mires, along the main drainage axis, is noteworthy, not least because classic views of mire zonation and succession (for example, Tansley, 1939) consider tree colonisation to be a feature of drying surfaces. This apparent contradiction is to some extent resolved by the fact that much of the tree growth in water tracks is focussed on the large tussocks of *Molinia* and, in some cases, *Carex paniculata* that occur, and which provide relatively dry microsites. Also, fallen trees often form small tumps of material, suitable for the regeneration of woody plants. Nonetheless, wooded water tracks are often particularly treacherous locations, and it would be of interest to know to what extent this helps exclude grazing animals and thereby promotes the growth of woody plants in these locations.

6.18.11 Ecological types

Ecological types of WETMEC 15 show a strong bias to the sub-neutral/oligotrophic category (Table 6.56). This makes an interesting comparison with WETMEC 14 where the modal category is base-poor/oligotrophic, and reflects the more base-rich character of WETMEC 15, even though it often occurs in the same sites as WETMEC 14 and has a similar source of telluric water.

Table 6.56 Percentage distribution of samples of WETMEC 15 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	5	2	2
Sub-neutral	66	2	2
Base-poor	17	6	

Oligotrophic, acidic/base-poor

This category is much less frequent in WETMEC 15 than in WETMEC 14 (which it often flanks), reflecting the fact that many soakways and water tracks are of higher pH than the adjoining mire surfaces. Examples allocated to this category are nearly all in very short soakways, or near the head of long ones. Some small peat-cuttings which function as small soakways at Cors Graianog are also allocated here. Typical communities are *Sphagnum cuspidatum/recurvum* bog pool community (M2) and *Narthecium ossifragum–Sphagnum papillosum* mire (M21), with some *Hypericum elodes–Potamogeton polygonifolius* soakway (M29).

Oligotrophic/mesotrophic, sub-neutral

This is by far the most frequent ecological type of WETMEC 15, accounting for 66 per cent of all samples. M29 is frequent in this habitat, but undersampled, and most samples have been allocated to M21. However, these are mostly rather atypical of the community and sometimes have much *Hypericum elodes* and *Potamogeton polygonifolius* (transitional to M29), or *Schoenus nigricans* (*Schoenus* trails) or *Molinia caerulea.* The latter stands are transitional to *Molinia caerulea–Potentilla erecta* mire (M25), and have been classified thus by some workers (for example, Groome, 1996) but in most cases MATCH coefficients are greatest with M21. However, some samples are unambiguously M25 or M29. A number of samples from Southern England have been allocated to *Schoenus nigricans–Narthecium ossifragum* mire (M14) and a few from elsewhere to *Carex lasiocarpa–Scorpidium* mire (M9-1). These include examples from the more base-rich sites in the New Forest (such as Stoney Moors, Widden Bottom). The syntaxonomic location of some is not very clear: samples variously have highest MATCH coefficients for M9-1, *Pinguicula vulgaris–Carex dioica* mire (M10), M14 and M29, but some fit none of these categories well.

As fen woodlands have generally not been sampled in this study, the status of the axial carrs in some New Forest sites is not known. Some pH data are available for the carrs, but there are no fertility data: their water is sub-neutral and they are probably mesotrophic or oligotrophic. As they can support a number of fen species that are absent from the adjoining mires (such as *Lysimachia vulgaris, Thelypteris thelypteroides*), it would be of interest to obtain a better characterisation of this habitat.

Oligotrophic, base-rich

Only a small number of samples are referable to this category, all from East Anglia. Some clearly belong here (such as Scarning Fen) and are referable to *Schoenus nigricans–Juncus subnodulosus* mire (M13). However, a number of WETMEC 15 samples from East Anglia (Holt Lowes and Roydon Common) straddle the boundary between this category and the preceding one, and support stands of M14.

Mesotrophic/eutrophic, sub-neutral/base-rich

This category includes just a few samples – a (remnant) soakway at Buxton Heath, alongside the nutrient-rich axial stream, and parts of the groundwater-fed laggs at Wybunbury and Chartley Mosses. The north lagg at Wybunbury appears to receive water partly enriched from road run-off and (formerly) septic tank discharge, but the source of enrichment at Chartley is not known.

6.18.12 Natural status

Soakways and water tracks are natural drainage features of mires. They are particularly associated with sites with high rates of water inflow and with valleyhead sites where the conformation of the landscape creates drainage flow tracks, though they also occur within some relatively flat peatlands.

Some examples of WETMEC 15 may be amongst the least disturbed surface features of mires, difficult to access by all but the most determined grazing livestock and telmatologists. Clarke and Barber (1987) have suggested that the water track at Church Moor has broadly kept its present location and vegetation character for the last 5,000 years, and it may often appear that the current vegetation of examples of WETMEC 15 is fairly natural. However, some examples of WETMEC 15 occupy artificial surfaces in peat workings. In some instances this is clear (such as Great Ludderburn Moss, parts of Cors Gyfelog near Gyfelog Farm), but in others less so. The distinctive zonation of Fort Bog (New Forest) appears to be natural, but some or all of the WETMEC 15 surface at this site apparently occupies flooded peat workings. Likewise, the status of Hartland Moor is ambiguous (Box 6.28), though on balance it seems likely that much of this site has been former turbary.

Box 6.28: Turbaries at Hartland Moor (Dorset)?

The difficulties of detecting past peat removal are exemplified by the flow tracks and flanking WETMEC 14 surfaces that occupy the two headwater arms of Hartland Moor (Dorset). There is documentary evidence for past peat removal at this site by a London firm up until the First World War, and there is visible evidence (on aerial photographs) for peat workings at the eastern (downstream) end of the mire. There is no obvious, similar visible evidence for the two upstream arms and, from that perspective, no reason to suspect peat extraction from them. However, both of the upstream arms have a very loose stratigraphy, essentially a quaking raft of rhizomes and peat over fluid muds, upon a solid mineral substratum. Whereas down-valley water flow undoubtedly occurs, it is not especially rapid and, particularly at the head of the broad northern arm, generally not visible. Given such conditions, it is difficult to see why the headwaters of the mire should not naturally be filled with a quite well-consolidated peat, raising the possibility that these have been subject to peat extraction. However, a corollary of this proposal is that, if peat digging occurred then either it was done so comprehensively as to remove all surface evidence (baulks and so on); or that these have since become flooded and obscured. Peat cutting on this scale would have been a substantial enterprise, and in the absence of documentary evidence it is by no means certain that it occurred, though it provides the simplest explanation for the observed stratigraphical features of the site. As such matters are important to the ecological character of the site, and its ongoing conservation requirements, it would be beneficial if they could be clarified.

6.18.13 Conservation value

As Seepage Flow Tracks are normally embedded within other WETMECs, very often little attention is given to them, although examples may support SAC habitats (see Tables 3.3 and 6.4). Individual samples of WETMEC 15 tend to be rather species-poor, but overall it supports a quite large number of wetland species, including several that are locally and nationally uncommon. Out of a total of 126 wetland species noted in WETMEC 15, there are records for the following nationally uncommon species: *Calamagrostis canescens, Carex lasiocarpa, Carex limosa, Cladium mariscus, Cladopodiella fluitans, Drosera intermedia, Drosera longifolia, Epipactis palustris, Eriophorum gracile, Hammarbya paludosa, Osmunda regalis, Philonotis calcarea, Pinguicula lusitanica, Rhizomnium pseudopunctatum, Sphagnum contortum, Sphagnum pulchrum, Sphagnum subsecundum, Thelypteris palustris, Utricularia intermedia, Utricularia minor.*

In addition, and especially in the context of base-poor valleyhead mire systems, such as many of those in the New Forest, WETMEC 15 provides the locale for a number of more base-demanding species which are otherwise rare, or absent, on these mires (such as *Lysimachia vulgaris, Schoenus nigricans*).

The percentage occurrence in NVC communities in the samples of WETMEC 15 is: M21: (40%); M14: (18%); M29: (12%); M9: (6%); M1: (4%); M2: (3%); M10: (3%); M13: (3%); M4: (1%); M22: (1%); S24: (1%); S25: (1%); W4: (1%); W5: (1%). M21 is the most frequent syntaxon, but there is a bigger representation of communities characteristic of more base-rich conditions than is the case in WETMEC 14, including M14 and M9 (the latter represented by M9-1). In these soakways samples referable to M14 and M9-1 are very similar floristically, and it is not clear whether they really represent different communities. A further complication is that some of the most species-rich patches in base-rich examples of WETMEC 15 can have highest coefficients of MATCH with M10, a community for which this habitat is far from typical. Whatever their vegetation is called, these more base-rich soakways support substantial species diversity, and provide habitats for such rarities as *Eriophorum gracile.* Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 15 is given in Table 6.3.

Some of the soakways and water tracks are wooded. These are mostly outwith the compass of the current project, but some of the more open examples of water-track scrub were sampled in the New Forest mires. These can support a number of fen species that are generally absent from the open mires, including *Lysimachia vulgaris, Osmunda regalis* and *Thelypteris palustris*, and their contribution to the conservation value of these sites would benefit from further examination.

6.18.14 Vulnerability

Examples of WETMEC 15 are vulnerable to direct drainage, and the absence or scarcity of this WETMEC at a number of valleyhead sites may be a consequence of past drainage. Because it is often in the lowest parts of seepage faces, this WETMEC may be less vulnerable to a reduction of aquifer head than some of the flanking WETMECs. Moreover, in some situations a reduction of groundwater outflow may be expressed in slower flow rates rather than lower water levels. Nonetheless, there are reports of examples of WETMEC 15 that are drier than was once the case. At Sheringham and Beeston Commons, it is reported that the water track through the main mire area tends to dry up more frequently than was formerly the case, and its width may be somewhat less, but for reasons that remain to be established.

In some sites flow tracks have been obstructed, either deliberately (for example, bunds at Thursley Common, road construction near Scarning Fen) or inadvertently (for example, blocked culverts at Chobham Common). Others have been dammed because of conservational concerns about low water levels (such as Roydon Common, Tarn Moss (Malham)). This can sometimes lead to loss of the soakway immediately upstream of the blockages by the formation of pools of open water (such as Thursley Common), and can also result in the spread of relatively base-rich water onto less base-rich WETMECs (such as Tarn Moss, where dammed water in a minerotrophic soakway has encroached locally upon the adjoining ombrogenous surface).

As with WETMECs 14 and 16, there have been reports of enrichment of water tracks by groundwater contamination. However, as mentioned above (6.18.10), the interpretation of hydrochemical data is not straightforward. A rather curious example of guanotrophication of a soakway appears to occur at Tarn Moss, where the soakways emanating from Spiggot Hill are apparently enriched in the vicinity of the hillock with droppings from birds roosting on its trees.

Box 6.29: Possible flow track enrichment at Thursley Bog (Surrey)

The southern sector of Thursley Bog is composed of two arms (east and west), separated by a northward-extending broad spur of heathland. Both areas support examples of WETMEC 15, but have somewhat different hydrochemical and floristic characteristics. The western flow track appears to have consistently higher water pH values (around one pH unit) than the eastern flow track, and this is generally reflected in higher concentrations of dissolved Ca, Na, K and, especially, Mg[1], and in the vegetation composition (Greshon, 1989). Greshon attributed the higher pH values in the western valley to its proximity to the underlying Bargate Beds, but hydrogeological data suggest that within the site the Bargate aquifer is confined beneath the Sandgate Beds. Assuming that this is the case, an alternative explanation needs to be found for the observed hydrochemical differences. Possibilities include: (a) local chemical variation within the Folkestone aquifer; (b) enrichment from adjoining agriculture or housing development; and (c) modification of the hydrochemical properties of the groundwater *after* outflow: the groundwater-sourced surface water in the more base-rich western arm is stronger flowing and more open than that in the eastern arm, and it is possible that the more base-poor conditions in the latter could simply be a product of its slower flow and greater interactions with the adjoining *Sphagnum*-based vegetation. At present few data exist on which to assess these possibilities, but water extracted from mineral ground immediately above the source of the eastern flow track had similar pH and EC values to that of the flow track in the western arm, providing some preliminary support for option (c) (B.D. Wheeler, unpublished data).

[1] This assessment is based on a comparison of concentrations from the South Bog water-track and the Neck with those from the inlet of the East Bog into Podmore Pond (which is taken as representative of the eastern water-tracks)

6.19 WETMEC 16: Groundwater-Flushed Bottoms

6.19.1 Outline

Effectively a topogenous equivalent of WETMEC 17 (Groundwater-Flushed Slopes), occurring on valley bottoms, flats and sumps where a telluric water source is fed from the margins across a basal aquitard that is covered by a (usually) rather thin layer of peat. Telluric water comes from springs and seepages which are either located at the margins of the WETMEC or which feed into it through a (short) surface water system. The telluric water supply may sometimes include a run-off or land-drainage component. Some examples are transitional to WETMEC 14 (Seepage Percolation Troughs) in concept and in the field. Schematic sections are provided in Figure 6.44.

6.19.2 Occurrence

Example sites: Bonemills Hollow (Hornstock Valley), Clack Fen, Cors Erddreiniog, Cors Goch, Cranberry Rough, Cridmore Bog, Dersingham Bog, Drayton Parslow Fen, Holmsley Bog, Hyde Bog, Leighton Moss (with Storrs Moss), Matley Bog, Morden Bog, Pont y Spig, Retire Common, Rhôs Gôch (Rhôs Gôch Common), Shacklewell Hollow, Southrepps Common, Swangey Fen, Syresham Marshy Meadows, Thursley Common, Whitwell Common, Wilverley Bog, Winfrith Heath – Whitcombe Vale

This is a widespread WETMEC of valley bottoms and flats, which includes rather small (and often summer-dry) valley-bottom sites together with extensive wet mire surfaces. The distribution of examples in sites sampled is shown in Figure 6.43.

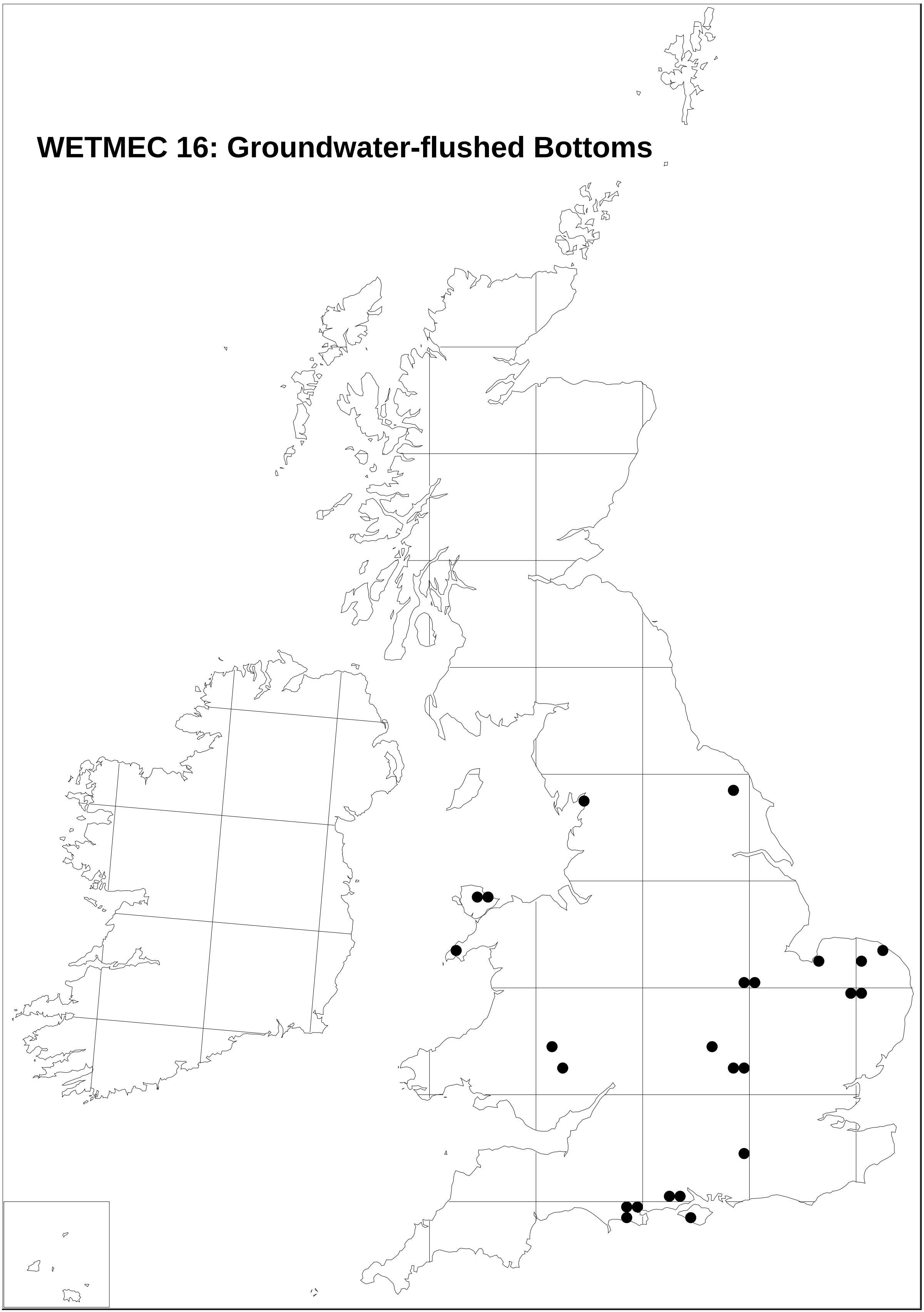


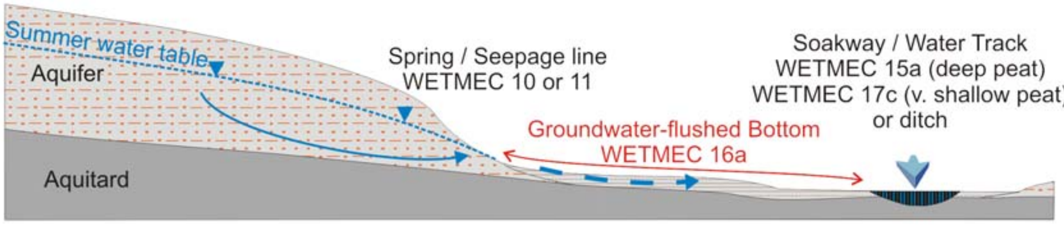
Figure 6.43 Distribution of examples of WETMEC 16 in sites sampled in England and Wales

6.19.3 Summary characteristics

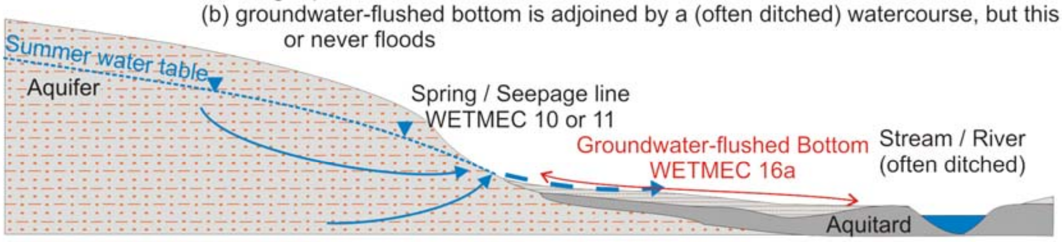
Situation	Majority in valleyheads, some in troughs, basins, floodplains and coastal plains.
Location	Most examples are from Southern England, but also from East Anglia, Wales and elsewhere. More widespread than WETMEC 14.
Size	Small (< 1 ha) to very large (> 120 ha – Leighton Moss), flattish mire expanses, on narrow-broad valleyhead bottoms, basins and flats.
Surface relief	Narrow to broad flats and troughs, sometimes with a spongy, occasionally quaking, surface.
Hydrotopography	Rheo-topogenous.
Water: ***supply***	Springs and seepages, sometimes from an adjoining WETMEC. Often some surface water inflow, but probably of little significance to summer water levels.
regime	Summer water table can be low, but often near surface, and sometimes above surface.
distribution	Longitudinal flow along trough, with some lateral inflow from flanks; no evidence for groundwater upflow.
superficial	Small pools and, sometimes, small water channels in wetter examples, sometimes with evident flow tracks (WETMEC 15).
Substratum	Soft upper layer, sometimes underlain by a more consolidated surface, or solid upper layer of PAL. Basal material typically silts and clays.
peat depth	Generally fairly thin (mean = 1 m), but some deeper examples.
peat humification	Shallow (0.5 m) spongy surface, often little humified when present; underlying peat, when present, usually more humified and often solid, especially lower down.
peat composition	Variable: mostly monocot or *Sphagnum* peat, but amorphous in some examples. Wood peat in some examples.
permeability	Peat permeability characteristics are very variable. Basal substratum has low-permeability characteristics.
Ecological types	Oligotrophic, acidic to eutrophic, base-rich.
Associated WETMECs	Mostly flanked by other WETMECs, especially WETMEC 10, 11 or 17 (upslope) and 15 (downslope).
Natural status	Some examples *may* form a natural persistent state, but others depend on grazing to keep their character.
Use	Conservation. Light grazing. Some occupy former turbaries.
Conservation value	Species diversity is often fairly low, either because of the intrinsically small species richness of base-poor mires or because many base-rich examples are quite productive and rank. However, may support examples of SAC habitats.
Vulnerability	Direct and indirect drainage. Groundwater enrichment.

WETMEC 16: GROUNDWATER-FLUSHED BOTTOMS

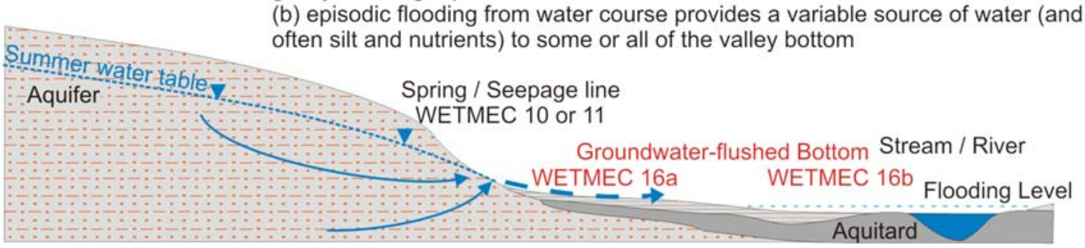
WETMEC 16a: Groundwater-flushed Bottom
(*e.g.* Dersingham Bog, Thursley Common)
(a) lateral flow from seepage line (sometimes with band of WETMEC 10) across gently-shelving aquitard
(b) water flow may collect to form a soakway or water track, or into a drain



WETMEC 16a: Groundwater-flushed Bottom
(*e.g.* Syresham Marshy Meadows)
(a) lateral flow from seepage line (sometimes with band of WETMEC 10) across gently-shelving aquitard
(b) groundwater-flushed bottom is adjoined by a (often ditched) watercourse, but this rarely or never floods



WETMEC 16b: Groundwater-flushed Bottom + Watercourse inputs
(*e.g.* Cridmore Bog)
(a) lateral flow from seepage line (sometimes with band of WETMEC 10) across gently-shelving aquitard
(b) episodic flooding from water course provides a variable source of water (and often silt and nutrients) to some or all of the valley bottom



WETMEC 16c: Groundwater-overflow Bottom (*e.g.* Rhôs Gôch Common)
(a) lateral (sometimes drained) flow from seepages (sometimes with band of WETMEC 10) and springs is distributed into valley-bottom and flats
(b) telluric water supplyis mainly outflowing groundwater but valley bottom is essentially disconnected from the seepage system
(c) wet valley-bottom conditions are maintained by high rates of water supply and by natural or artificial constraints on surface water outflow
(d) combination of condition is particularly associated with gross disturbance of valley bottom (the WETMEC 16c area at Rhôs Gôch may once have been raised bog, removed by turbary

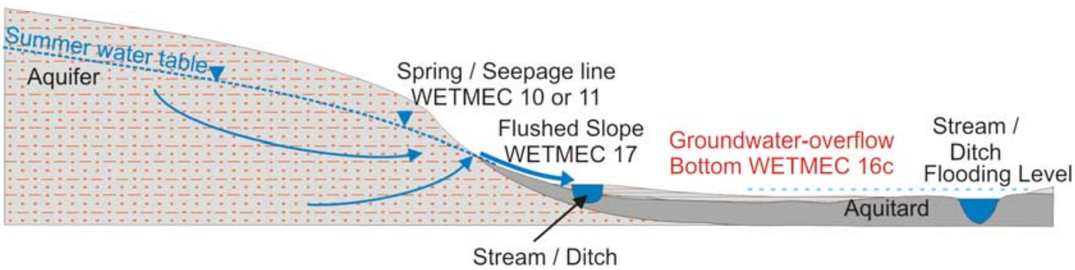


Figure 6.44 Schematic sections of types of Groundwater-Flushed Bottoms (WETMEC 16)

6.19.4 Concept and description

CLUSTERS: 27, 28, 29

This variable WETMEC occurs in a range of topographical situations united by the common features of occupying a flat or slightly sloping surface; a (mostly) thin layer of peat over a well-developed aquitard; and a telluric water supply from the margins. Water supply is often a rather diffuse inflow but, in some larger examples, can become focussed into endotelmic flow tracks. The occurrence of this WETMEC depends on marginal springs and seepages. These may take various forms, from discrete discharges with or without significant mire development, to Permanent Seepage Slopes (WETMEC 10) or Flushed Slopes (WETMEC 17) which grade almost imperceptibly into this valley-bottom unit. In a few cases (WETMEC 16c), the groundwater source is to some extent uncoupled from the topogenous system into which it feeds.

The surfaces included within WETMEC 16 vary considerably in their characteristics and wetness, related *inter alia* to the magnitude (and seasonality) of groundwater outflow into the mire; distance from the groundwater source; and topographical constraints upon drainage. Some examples have artificial constraints on water outflow from the WETMEC (dams, causeways and so on) whereas in others, impeded drainage is associated with a large peaty surface of negligible gradient. In many cases, other than some instances with topographical constraints on drainage, there is a tendency for drier conditions to occur (in summer) with increased distance from the water source (the margins). In such cases, it is likely that locations further from the margins are proportionately more dependent upon precipitation inputs – though few data are available to confirm this, and in some sites the occurrence of soakways crossing the mire can obfuscate any simple relationship.

Depending on the topography of the site, WETMEC 16 can cover much of the valley bottom and be the dominant feature of the site (such as Dersingham Bog, Hyde Bog, Winfrith Heath (Whitcombe Vale)). In other sites, other WETMECs (such as WETMEC 10) may also be prominent. In yet other situations, WETMEC 16 is localised, being the product of a specific, local combination of conditions. For example, at Cors Erddreiniog, the two samples clustered into WETMEC 16 were both more or less on the valley floor between Llyn-yr-wyth-Eidion and marginal seepages. In this location, there is only a thin layer of surface peat (underlain by a wedge of marl), and it accordingly fits the main characteristics of WETMEC 16. Similarly around parts of Cors Goch, some strips of shallow peat between the marginal seepages (WETMEC 11) and the buoyant surfaces of WETMEC 13 in the main basin have also been clustered here.

Affinities and recognition

Some examples of WETMEC 16 are easy to identify: those which consist of extensive, flat surfaces with only a shallow surface layer of peat upon clay or silt, fed by marginal groundwater outflows. Depending on the context, the peat may be either loose and wet or consolidated and often rather summer-dry, but it is usually thin (typically < 0.5 m). One of the greatest difficulties of recognition can be with regard WETMEC 14. In general, WETMEC 14 samples do not occur over a continuous basal aquitard (clay or silt-rich deposits that are probably only slowly permeable) but a few examples do, and are the source of some potential confusion (illustrated and enhanced by the fact that examples of both WETMECs can be found at some sites). Examination of the cluster diagnostics indicates that where the samples are over a low-permeability layer, and the peat is fairly thin (and in some cases rather dry), they have been clustered within WETMEC 16; where they are over relatively deep and wet peats, they have usually been allocated to WETMEC 14, irrespective of the character of the basal layer (such as in parts of Cranes Moor). Examples with a basal layer of sand and gravel have always been clustered with WETMEC 14, irrespective of peat depth and hydration. This variation is a consequence of multivariate clustering in a context where the limits of key variables are not always coincident. Interestingly, the resulting clusters and sample allocations are for the most part intuitively acceptable, but it is difficult to specify clear criteria to distinguish unambiguously the two units.

Another potential diagnostic difficulty is with WETMEC 8, which shares a broadly similar conceptual water supply mechanism with WETMEC 16. The differences here are that WETMEC 8 is usually over deep peat; does not usually have an extensive spongy surface; usually has lower summer water tables; and, very often, has groundwater outflows intercepted and distributed by a ditch system. Also, compared with WETMEC 8, some examples of WETMEC 16 are visibly sloping.

Samples of WETMEC 16c (Cluster 29) are rather distinctive from most samples clustered into WETMECs 16a and 16b, and a case could be made for considering Cluster 29 samples as a separate WETMEC. It has some affinities with certain types of Seepage Percolation Basin (WETMEC 13) and in the Phase 1 analysis (Wheeler and Shaw, 2000a), the Suffolk coast samples were grouped within this category as “a rather unusual variant” of ‘seepage swamped basins and floodplains’. They differ from examples of WETMEC 13 in the stiff basal clays and silts and the shallow accumulations of peat.

Examples of WETMEC 16 can have considerable similarities with WETMEC 18 (Percolation Troughs): samples in both units often have peat of similar depth and character and are underlain by a more or less continuous aquitard. However, the flushed bottoms of WETMEC 16 are fed largely by groundwater outflow from a mineral aquifer at the margins of the deposit, whereas in WETMEC 18 the role of groundwater is less or non-existent, and that of rain-generated run-off is higher.

Some samples from Retire Common form outliers to the main cluster and are transitional to WETMEC 17. WETMEC 17 often has even shallower peat than WETMEC 16, and is usually more strongly sloping.

6.19.5 Origins and development

Examples of WETMEC 16 mostly have very little peat, and little is generally known about their ontogenesis and natural character. In some cases, as in the bottoms of some small valleyhead sites fed by weak seepages, the mineral (alluvial or colluvial) basal deposit covered by a thin layer of amorphous organic material (such as Drayton Parslow Fen) probably represent their long-term natural state. In others, it is almost certain that very large amounts of former peat have been removed, and the character of the site much changed (Box 6.39), though there is often little confirmatory evidence for this.

Box 6.30: Developmental history of Rhôs Gôch Common (Radnor)

Rhôs Gôch Common is a raised bog (WETMEC 1) site located within an elongate, trough-like, late-glacial lake basin. The main area of raised bog has an asymmetric location at the north-east end of the basin, whilst the south-west end supports a large area of fen, referable to WETMEC 16. Bartley (1960a, b) provides a gross stratigraphical description of Rhôs Gôch Common, with a primary focus on the ombrogenous deposit (which developed serally from the lake clays *via* a phase of fen). However, he also provides some information about the south-west (WETMEC 16) part of the basin. Here, the late-Devensian lake clays and their overlying silty muds are covered only by a thin (around 50 cm) layer of a rather loose peat rich in remains of *Juncus.* Thus these areas appear to have accumulated next-to-no peat since the early post-glacial period, though at the transition with the ombrogenous area they are overlain with a shallow accumulation of more recent *Sphagnum* peat which, using pollen data, Bartley (1960b) dated to the late Atlantic period. Although not recognised by Bartley, the absence of more substantial peat deposits in this part of the basin is almost certainly because they have been removed.

Rhôs Gôch Common presents a number of curious features: there is a large area of shallow peat at the south-west end of the basin, where there appears to have been next-to-no accumulation of peat throughout the post-glacial period; the location of the current ombrogenous surface is curiously asymmetric and tends to be summer-dry; and much of the bog seems to have "dried out and ceased to grow" towards the end of the Sub-Boreal period (zone VIIb) (Bartley, 1960b), despite the increased precipitation thought to be associated with the Sub-Atlantic period (zone VIII). Bartley appreciated that "*apparently no peat has been formed since the end of zone VII, but the possibility of the destruction of Sub-Atlantic peat by peat cutting cannot be entirely ruled out*." However, in this he seems to have been thinking just of the ombrogenous surface, not of the large area of fresh, shallow fen peat in the south-west (WETMEC 17) part of the basin: he suggested that the failure of significant post-glacial peat formation in this part of the site might be because it was situated "*in collecting areas in which the water from a number of streams converged and prevented any continuous peat formation*." However, an alternative possibility is that peat has been comprehensively stripped from much of this end of the site (the part nearest Rhôs Gôch and the main entrance to the Common). Bartley may not have considered this possibility because of the magnitude of peat removal it implies, but it would explain several of the anomalies associated with this site and is consistent with a report in the early nineteenth century that Rhôs Gôch was one of the three most important turbaries in Wales (Davies, 1814; Wisniewski, Paull and Slater, 1982).

Rose (1953) described a shallow peat core from the "bog centre" of Ockley Bog (Thursley Common), which shows a development from a black peaty mud (over sand[1]) at 55 cm bgl covered by a layer of swamp peat dominated by *Eriophorum angustifolium* and changing upwards into a little-humified *Sphagnum papillosum*-dominated peat. He interprets this as a hydroseral sequence in a shallow lake, and it is possible that this part of the complex may be situated in a shallow topographical basin. However, in view of the freshness of the peat reported by Rose ("*a foot or more of dead Sphagnum remains, scarcely humified at all, and little compressed*"), and evidence for turbary at this site (see 6.19.12) it is likely that the profile recorded may represent *de novo* terrestrialisation of a skinned, reflooded surface rather than residual, unworked peat.

[1] Rose's core apparently refers to a location with groundwater upflow that is referable to WETMEC 14, but it is similar to cores taken for this project over parts of the WETMEC 16 parts of the site.

6.19.6 Situation and surface relief

Samples of this variable WETMEC were recorded from a variety of contexts. The majority (66 per cent) were from valleyheads, but 15 per cent were from (former) floodplains, coastal flats and so on. The remainder were from shallow basins and troughs (valley bottoms). Most samples were taken from more or less flat areas, but a few had a visible, gentle slope (Table 6.57).

Table 6.57 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 16

	Mean	1	2	3	4	5	6	7
Surface layer permeability	4.4	2	2	31	17	22	22	3
Lower layer permeability	3.4	13	24	28	2	17	7	9
Basal substratum permeability	1.8	29	59	12				
Slope	1.3	82	9	9			X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.19.7 Substratum

Peat depth in this WETMEC is consistently fairly thin (mean of 1.0 m), and in a few instances there is virtually no peat upon basal silts and clays. In some (mostly wetter) sites the upper peat infill is fresh and unconsolidated, and is thought likely to be rather permeable, whereas in some drier examples it is more consolidated and perhaps less permeable (Table 6.57). Lower layers of peat can be somewhat more consolidated, but in many cases they are either similar to the surface layer, or in shallow-peat sites, largely absent. The basal substratum is typically of low permeability, composed of laterally extensive clays and silts, sometimes somewhat sandy. It is variously formed of alluvium, colluvium, lake clays and estuarine clays. At Dersingham Fen, estuarine clays are capped locally by rather solid ferrugineous concretions.

6.19.8 Water supply

Few detailed hydrological data are available from examples of WETMEC 17, which makes any assessment of their water supply speculative. It is, however, fairly clear that groundwater is the predominant telluric water source. Many sites have little evidence of significant land drainage inflows, and any rain-generated run-off may make only a little contribution to the summer water table in the mires (to the extent that some examples flanked by weak seepages tend to become summer-dry, such as parts of Retire Common). However, some examples undoubtedly receive some land drainage and, if this is enriched by agricultural nutrients, it may have a hydrochemical impact upon the mire disproportionate to its volumetric importance.

Some of the mires occupy headwater locations and tend to source drainage streams rather than be fed by them, and may contain endotelmic streams and water tracks. However, others flank watercourses, and in some instances alluvium provides the aquitard base of the WETMEC. In many cases, watercourses have been deepened and do not appear to provide a source of water in normal conditions. However, in some sites (such as parts of Cridmore Bog), frequent winter river flooding can occur. This may make rather little contribution to the summer water table of the WETMEC, but can have considerable nuisance value as a source of nutrient enrichment by silt deposition and ingress of enriched water.

Many examples of WETMEC 16 are flanked, at least in part, by springs and seepage slopes. In those cases where seepages are less obvious (such as Hyde Bog, parts of Morden Bog), the troughs are generally incised into permeable deposits, or multilayered aquifers, and lateral flow of groundwater into the trough is presumed – but not known – to occur. In other sites, especially examples of WETMEC 16c, groundwater outflow is to some extent uncoupled from the surface onto which it discharges. This is particularly obvious at Rhôs Gôch Common, where parts of the mire are (consistently) fed by overflow from a small stream along one edge of the basin. Whilst technically this represents a surface water source, the stream – which is endotelmic – is largely fed by groundwater discharge into the mire basin.

In some valleyhead sites (such as Drayton Parslow Fen), the valley bottom has been partially disconnected from the groundwater source by a small ditch dug along the base of the seepage slope, though lack of maintenance sometimes means that the drain may no longer have a significant function of intercepting groundwater outflow.

In partly drained sites such as Drayton Parslow Fen, the surface peat is thin, amorphous and consolidated, but in many instances the top-layer peat is rather loose and unconsolidated. It may or may not be underlain by a significant layer of more consolidated peat, and seems likely to offer only limited constraint upon lateral water flow. It is likely that water movement from the margins may occur through these spongy surface layers, as through the acrotelm of an ombrogenous bog, though sometimes water movement is channelled into preferential flow tracks provided by soakways and water tracks (WETMEC 15), and the actual extent of flow through the upper peat layers is not known. In some large sites, wet conditions are maintained for more than 100 m from the apparent groundwater source, though this may be partly due to natural or artificial topographical constraints upon drainage (such as Thursley Common). In other cases (such as parts of Dersingham Fen, Morden Bog), there is a tendency for the surface to become increasingly summer-dry with distance from the margin. At Dersingham Fen, and some others such as Syresham Fen, where groundwater flows across a silt-rich surface, an organic surface layer is often thin and, in some locations, largely absent.

6.19.9 WETMEC sub-types

The WETMEC sub-types that have been identified correspond to different clusters of the multivariate analyses. These seem mainly to reflect differences in topographical circumstances rather than significant difference in water supply mechanisms, though the sites included in WETMEC 16c are generally very different from the others, and a case could be made for elevating 16c to the status of an independent WETMEC.

WETMEC 16a Groundwater-Flushed Bottom

CLUSTER: 27

> *Examples at:* Dersingham Bog, Hyde Bog, Thursley Common, Winfrith Heath (Whitcombe Vale).

Some of the most distinctive and characteristic examples of WETMEC 16 belong to sub-type 16a. They are exemplified by the extensive topogenous mire surfaces at Dersingham Bog and Thursley and Ockley Common and these sites can be used to illustrate the character of this sub-type. The two sites have various similarities, including a large flattish mire surface developed over a thick aquitard apparently fed by lateral seepage from an adjoining Lower Greensand scarp. In both sites, but particularly at Thursley, the margins of the flat area support seepage mires which feed onto the flat surface. At Thursley, water supply patterns on the flat are complicated by soakways which cross parts of the area and by an old causeway which probably helps to retain water on parts of the site. Both Dersingham and Thursley have also been partly drained and, in all probability, substantial amounts of peat have been removed in the past. At Thursley much of the peat is shallow (less than one metre deep) and loose; at Dersingham there is even less peat, with thin deposits near the seepage scarp wedging out to next-to-nothing over the alluvial flat.

Other examples of WETMEC 16a are broadly similar to the Dersingham and Thursley sites, and comparably extensive (such as Whitcombe Vale, Box 6.31), but some samples clustered into this sub-type represent mostly small valley-bottom locations, sometimes sandwiched between marginal seepages and the main valley-bottom WETMECs.

Box 6.31: WETMEC 16 at Whitcombe Vale, Winfrith (Dorset) and Retire Common (Cornwall)

The Whitcombe Vale mire at Winfrith Heath occupies a valleyhead location and visibly slopes down the valley trough. The substratum consists mostly of a very thin (< 30 cm) depth of peat over a stiff dark clay, which appears to represent Head. This is likely to act as an aquitard unit and is expected to semi-confine the underlying Poole Formation so that groundwater seepage from this occurs mainly around the margins of the Head, to percolate along the valley bottom or follow soakways. At this site, the hydrological properties of the overlying peat are not certain. Although thin, much of it is firm and may be of fairly low permeability. However, considerable portions of the surface are covered by extensive loose *Sphagnum* mats, which may have acrotelm-like hydroregulatory properties, and soakways probably form channels of preferential water flow. Interestingly, in the lower part of the valley the Head is replaced by river terrace gravels. These are expected to permit groundwater flow and probably explain the absence of mire lower down the valley: water draining from the mire in the upper part of the valley is likely to percolate into the river terrace gravels.

Retire Common has some broad topographical similarities with Whitcombe Vale, but is drier over much of its surface. It occupies a gently sloping, broad, shallow, valleyhead trough located upon Devonian Meadfoot Beds, which are likely to support significant fissure flow and function as a minor aquifer. However, much of the bottom of the trough is covered by a stiff, clay-rich alluvium, which appears to act as a confining layer. Some locally-strong springs and seepages occur at the head of mire, apparently at the junction between the two deposits. Some of these feed directly into the main mire (and support examples of WETMECs 17a, 17b and 17d), but their water appears to have only limited influence over much of the site, doubtless partly because some of it becomes focused into soakways and, particularly, small drains. In consequence, much of the central area away from the margins has a tendency to become summer-dry, and may well be fed primarily by precipitation; although peat-based, its habitat is as much wet heath as mire. On the other hand, a diagonal drain across the mire appears to have the potential to recharge, at least locally, parts of the adjoining mire distant from the springs by lateral flow and episodic overflow. A sample of mire downslope of this has been clustered into WETMEC 17c, though as its surface is rather dry, any recharge from the drain may be limited.

WETMEC 16b: Groundwater-Flushed Bottom + watercourse inputs

CLUSTER: 28

Examples at: Clack Fen, Cridmore Bog, Matley Bog, Morden Bog, Pont-y-Spig

This rather heterogeneous WETMEC sub-type is similar to the last, but includes a series of samples quite close to a watercourse which potentially provides (or once provided) a source of surface water to neighbouring patches of mire at an appropriate elevation. However, in most, if not all, of these sites the stream has been deepened or canalised and probably acts more as a drain than a water source. In some sites episodic river flooding is known still to occur, but this may contribute little if anything to the maintenance of summer water levels in the adjoining mire, and in some cases has nuisance value by the introduction of alluvial material and nutrients (such as Cridmore Bog, IoW, which is located in the deep valley of the River Medina but is apparently fed by partly drained seepages from the adjoining Greensand).

This sub-type includes a number of valley-bottom sites over aquitards that are downslope of seepages and springs and appear to receive marginal groundwater inflows at least seasonally, but which tend to be rather summer-dry because the seepage discharge is weak, because they are distant from it, or because it is (partly) intercepted by a ditch along the base of the seepage slope. Other than the normally rather dry summer conditions, there is little conceptual difference between this sub-type and types (a) and (c). Some examples are fairly small, developed over clay-rich alluvium in valley bottoms. In some cases, the aquifer appears to be confined below much of the mire by the alluvium (such as Cridmore Bog).

WETMEC 16c: Groundwater-Overflow Bottom

CLUSTER: 29

> *Examples at:* Benacre Broad, Leighton Moss, Rhôs Gôch Common and Westwood Marsh (Walberswick)
>
> *Outliers at:* Swangey Fen

This sub-type is derived from a small number of rather variable samples, united by the presence of only a shallow layer of peat, which is often very loose, over an aquitard; a topogenous (basin, floodplain or coastal plain) location; and at least seasonal water throughflow fed, in part but not necessarily directly, from marginal groundwater outflows. The overflow bottoms can be substantially disconnected from the seepage system, and WETMEC 16c shows a rather similar relationship to WETMECs 16a and 16b, as does WETMEC 13d to the other WETMEC 13 sub-types. The main samples clustered here are a rather disparate group and share the features of gross past disturbance (drainage and/or peat cutting) followed by reflooding. An outlier sample within this group (Swangey Fen) is from a sump area alongside the River Thet fed by some downslope flow of groundwater, but also by significant surface drainage from adjoining fields. This sample does not fit any of the identified WETMECs well, but is closest to WETMEC 16c.

The samples from Rhôs Gôch Common are from the areas of swamp and fen at the south-west end of the mire, downstream of the raised bog, where there is only a shallow accumulation of loose peat over lake clay (Box 6.39). In addition to rainfall, it is irrigated by overspill of water from adjoining (lagg) streams. These streams are fed by springs and land drainage and some overspill occurs from them onto the WETMEC 16c surfaces, even during summer, partly because they have not been cleaned for many decades (see Figure 6.44).

Much of Leighton Moss consists of very shallow peat over clay and its wetness is maintained by rainfall and near-surface flow, partly from a ditch system sourced by strong springs near the head of the site.

Good examples of WETMEC 16c are provided by some of the Suffolk coastal broads and marshes which have strong groundwater inputs, and where high water tables are maintained both by the low altitude of the formerly drained, now reflooded, marshes and by bunds and sluices designed to impound the freshwater inflow and exclude brackish water surges (Figure

6.44). This is well illustrated in Westwood Marsh (Walberswick). HSI/ECUS (1999) suggest that at this site, upward flow of groundwater from the Crag may be largely constrained because of the alluvial (clay) infill, but there is strong spring flow from the Crag slopes surrounding the marsh which discharges onto the surface of the alluvium.

6.19.10 Ecological characteristics

The mean summer water table associated with WETMEC 16 is high (Table 6.58), but this encompasses a wide range of variation. Lowest water tables are mostly associated with small, valley-bottom sites where weak marginal seepages feed onto low-permeability, and sometimes partly drained, valley-bottom surfaces, but they are by no means confined to these; for example, at the large Morden Bog particularly low summer water tables were recorded at a location more than 100 m from the valley edge. Highest water tables are associated with (natural or artificial) topographical constraints on drainage, and at some individual sites (such as Cridmore Bog) there is considerable variation in the position of the water table relative to the surface due to local topographic features. The mean summer water table of WETMEC 16 is almost three cm lower than that of WETMEC 14, even amongst sites in the same region. For example, the water table of WETMEC 16 samples from Morden Bog and Hyde Bog seems generally to be lower, and their *Sphagnum* surfaces more desiccation-bleached, in summer than their WETMEC 14 counterparts in comparable locations in the New Forest.

Table 6.58 WETMEC 16: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	1.0	0.1	4.0
Summer water table (cm)	–2.7	–45	22
Rainfall (mm a^{-1})	793	558	1,140
PE (mm a^{-1})	593	546	615
Water pH	5.4	2.9	7.5
Soil pH	5.5	1	7.6
Conductivity (µS cm^{-1})	309	58	1,122
K_{corr} (µS cm^{-1})	291	58	747
HCO_3 (mg l^{-1})	60	0	447
$Fertility_{Phal}$ (mg)	13	1	50
Eh^{10} (mV)	297	162	537

See list of abbreviations in Appendix 1

6.19.11 Ecological types

Although still with a preponderance of samples from base-poor/oligotrophic locations, WETMEC 16 is more equitably spread across the range of base status and fertility than is the case with WETMEC 14, and this is reflected in the ecological types recorded (Table 6.59).

Table 6.59 Percentage distribution of samples of WETMEC 16 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	5	15	18
Sub-neutral	10	15	
Base-poor	27	5	

Oligotrophic, acidic/base-poor

Oligotrophic, low pH examples occur mainly in association with the Tertiary sand aquifers of the Hampshire Basin and adjoining area. They most typically support a *Sphagnum*-based vegetation (*Narthecium ossifragum–Sphagnum papillosum* mire (M21) and *Molinia caerulea–Potentilla erecta* mire (M25)). The latter is particularly associated with drier conditions.

Oligotrophic, sub-neutral

Examples of this condition occur in some samples irrigated from the Greensand at Thursley Bog (especially in the western arm), and Dersingham Fen, and from some locations distant from the margins of the mires on other formations. For example, at Morden Bog samples distant from the eastern margin (and closer to the central drainage channel) fell into this category, whereas those nearer the seepage margin were oligotrophic and base-poor. Samples from Whitcombe Vale at Winfrith Heath also fell into this category (the source of mild base-enrichment at this site has long been a source of some puzzlement and debate (Bellamy, 1967)). Most samples were representative of M25, but at Thursley some had similarities to *Molinia caerulea–Cirsium dissectum* fen meadow (M24) and at Winfrith one sample was unambiguously M24.

Oligotrophic, base-rich

This includes some topogenous samples from near the margins of Cors Erddreiniog and Cors Goch, in locations apparently fed by seepage from the Carboniferous limestone. In all cases the vegetation was referable to the *Cladio-Molinietum*, in some cases with a mix of Caricion davallianae species.

Mesotrophic, sub-neutral

Only a few samples are in this category, from the fen area of Rhôs Gôch Common, which is fed by spring-source stream water (from a Raglan Mudstone/Undifferentiated Silurian minor aquifer). A base-rich example of M25, from near the western water track at Thursley Common, can also be allocated to this category.

Eutrophic/hypertrophic, sub-neutral/base-rich

These are mostly valley-bottom sites where relatively base-rich groundwater flushes over stiff clay, as found at Clack Fen, Cridmore Bog, Swangey Fen, Southrepps Common and Whitwell Common. The reedbeds on parts of Leighton Moss and Westwood Marshes (Walberswick) also belong to this category. The samples from Cridmore, fed from Upper Greensand, are less base-rich than the examples in the South Midlands fed from calcareous Drift (sands and gravels) and those from East Anglia which are fed, in part, from the Chalk. Although the groundwater is derived from Carboniferous Limestone, the pH in the reedbeds at Leighton Moss is relatively low (6.0 to 6.5), possibly because these areas are quite distant from the marginal groundwater outflows, and reflecting the former status of some of this site as raised bog. The nutrient-rich conditions are probably largely a product of the clay or silt-rich substrata. Cridmore Bog is episodically flooded by the nutrient-rich Medina, and episodic inundation may occur in some other sites associated with watercourses.

6.19.12 Natural status

Little is known about the development and natural status of WETMEC 16 sites. Peat stratigraphical data tend to be thin on the ground as, very often, is the peat. In some cases the thin peaty layers, over an aquitard, may represent the natural state of the mire, but in others it is likely to be a product of past peat removal. There is generally little information about the magnitude of past turbary, nor the natural condition of the mire surface that was dug away, but there is reason to suspect extensive workings at some sites (Box 6.31, Box 6.32) and this may well have been widespread elsewhere.

Box 6.32: Past peat extraction at Thursley Common

The mires at Thursley and Ockley Common appear once to have supported a substantial peat industry, apparently partly to fuel the iron foundries at the nearby Hammer Pond. There is documentary evidence for extraction in the seventeenth century (in the Pudmore area) and this apparently continued during the nineteenth century, with eye-witness reports that peat was being dug and stacked until the 1920s. Extensive peat extraction at this site would account for the shallow depth of peat (mostly < 50 cm) currently found on much of the WETMEC 17 parts of this site. One source (Manning and Bray, 1809) suggests that the peat deposits at Thursley were then 12–14 feet (3.6–4.2 m) thick. Unfortunately the location referred to is not known, but assuming that it refers to the present-day Thursley site, and that the peat-depth value is correct, not only does it suggest that a large depth of peat has been removed, but it also raises questions about how such a depth of peat could have accumulated in this location given its flat topography. Possible explanations are: (a) that the recorded peat depth does not refer to the current Thursley site; or (b) that the site once supported a shallow dome of ombrogenous peat (a small raised bog) in which impeded drainage within the peat deposit itself provided the hydrological basis for the accumulation of some four metres of peat on the flat parts of the Common. There is no known evidence for the past occurrence of raised bog at this site, though Rose (1953) points to the ombrogenous affinities of the current (weakly minerotrophic) surface of Ockley Bog, and the extensive flat, low-permeability Sandgate Beds would seem suitable for the development of a shallow dome of ombrogenous peat. It is not clear, however, whether the climate of this area would have been appropriate to sustain the formation of a deposit of ombrogenous peat.

The natural condition of the WETMEC 16 surfaces is not well known, and is likely to have varied in response to the hydrochemical environment. However, some present WETMEC 16 sites are in locations which were undoubtedly (Leighton Moss), almost certainly (Rhôs Gôch Common) and possibly (Thursley Common: Box 6.32) once ombrogenous bog (WETMEC 1), and some residual WETMEC 1 remains at Rhôs Gôch Common.

Many of the other acidic sites are probably too small and uneven to support ombrogenous surfaces, though the precise status and developmental history of some large and flat examples, such as Morden Bog, is very poorly known and would benefit from further investigation.

6.19.13 Conservation value

Species diversity is often fairly low, either because of the intrinsically small species richness of base-poor mires or because many base-rich examples are quite productive and rank. However, WETMEC 16 may support examples of SAC habitats (see Tables 3.3 and 6.4).

Over 120 wetland plant species have been recorded from samples of WETMEC 16, including 18 nationally uncommon species: *Calamagrostis canescens, Calamagrostis stricta, Carex appropinquata, Carex elata, Cladium mariscus, Cladopodiella fluitans, Dactylorhiza praetermissa, Drosera intermedia, Epipactis palustris, Oenanthe lachenalii, Peucedanum palustre, Plagiomnium ellipticum, Ranunculus lingua, Sphagnum pulchrum, Sphagnum* *subsecundum, Stellaria palustris, Thelypteris palustris, Utricularia minor.* Many of these are characteristic of relatively base-rich conditions. Base-poor surfaces are less species-rich than base-rich examples and in general, in Southern England base-poor examples of WETMEC 16 are not as good as those of WETMEC 14. Nonetheless, base-poor examples of this WETMEC often support a range of locally uncommon taxa such as *Eleocharis multicaulis, Hypericum elodes, Myrica gale, Rhynchospora alba* and *Schoenus nigricans.*

The percentage occurrence in NVC communities of samples of WETMEC 16 is: M21: (30%); S25: (10%); M22: (8%); M25: (8%); B10: (5%); B23: (5%); S24: (5%); S27: (5%); M06: (3%); M23: (3%); S10: (3%); M03: (1%); M04: (1%); M05: (1%); M9-1: (1%); M24: (1%); M27: (1%); S04: (1%); S26: (1%). Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 16 is given in Table 6.3.

Whilst some examples of the vegetation of this WETMEC are rather undistinguished, they can have much local importance. For example, the WETMEC 16 surfaces at Cridmore Bog appear to constitute the best area of fen remaining on the Isle of Wight, and an example of S27 present there is perceived as one of best examples remaining within Southern England.

6.19.14 Vulnerability

Drainage has been attempted at a number of WETMEC 16 sites in the past. Drains may effectively dewater the peat layer, especially when this is loose and unconsolidated, but may have little impact upon the underlying clays and silts. The topography of some of the mires may impede effective drainage. For example, at Thursley and Ockley Commons a ditch (Frenchman's Drain) extends north-eastwards across much of Ockley Bog into and across Ockley Common, but this is occluded and is thought to flow only when water levels are very high. It appears to have little impact on the site at present, but could have been more significant in the past, especially when water (and peat) levels were higher.

The suspected absence of groundwater upflow into the peat deposits means that examples of WETMEC 16 are critically dependent on marginal groundwater outflows from the adjoining mineral aquifer. These can be, and have been, intercepted fairly easily by means of a catchwater drain along the bottom of a seepage slope, which has provided an efficient way of reducing water supply to areas of WETMEC 16 downslope of this. For example, at Retire Common (Box 6.31), small ditches appear to reduce the extent to which groundwater penetrates into the central part of the trough, leading to a scenario that tends to be summer-dry, and probably primarily fed by rainfall (ombrotrophic legacy telluric). This effect can be particularly significant when the groundwater outflows are small relative to the size of the mire. For this same reason, although groundwater abstraction may not directly dewater the aquitard-floored WETMEC 16 surfaces, a reduction of groundwater flow may reduce the area of valley-bottom mire that can be kept wet by groundwater in normal summer conditions – though this, of course, depends on many variables, including topographical constraints upon drainage. It is particularly important that the hydrological significance of the latter be recognised, as enhanced retention of water on WETMEC 16 surfaces can have various ecohydrological repercussions, which are not necessarily beneficial to existing conservation interest (Box 6.33).

Box 6.33: Impedance of water flow at Thursley Common (Surrey)

At Thursley and Ockley Commons, the natural pattern of water flow across the lower part of the site has been disrupted by artificial causeways. These are of some antiquity, but were partly damaged and breached in post-war years by military vehicles. Concerns that parts of the bog were thought to be too dry in summer were expressed as long ago as 1965 and resulted in the blocking of some small ditches, and the repair and strengthening of the main causeway in 1966. This undoubtedly helps to retain water in the West Bog and there is now a significant pool above the weir. Likewise, in 1971 a new causeway was constructed across the narrow neck of mire below the South Bog, along the line of a former damaged causeway, and in 1972/3 this was strengthened and a small weir was constructed. This is reported to have led both to ponding of the lower end of the South Bog and increased channelling and flow of water through the southern part of the West Bog (in the narrow valley immediately north of the neck). As the water in the western arm of Thursley is more base-rich than in some other parts of the mire, this operation has almost certainly resulted in the spread of more base-rich, backed-up water from the water tracks onto the flanking *Narthecium ossifragum–Sphagnum papillosum* mire (M21) mire, and has induced some floristic change in this, possibly in the direction of *Molinia caerulea–Potentilla erecta* mire (M25). Greshon (1989) holds the view that the *Molinia*-dominated vegetation of the water tracks has expanded since the installation of the water control structures. The occurrence of patches of mobilised iron in parts of the West Bog, associated with low redox potentials and localised *Sphagnum* die-back in the vegetation, could also be a consequence of the development of increasingly wet and stagnant conditions, though this is not certain (Wheeler and Shaw, 2001).

Contamination of groundwaters is also sometimes suspected of affecting WETMEC 16 surfaces but, as with WETMEC 14, hydrochemical data are sparse and not always easily interpreted. Again with regard to Thursley Bog, an area of land on the Greensand ridge above the mire was used as a sewage effluent dump from the late 1950s to 1974 which, as the Greensand (Folkestone Beds) aquifer is the primary groundwater source to the mire, could provide a source of contamination. However, there is little clear evidence that this has been a significant problem.

Examples of WETMEC 16 that border nutrient-rich watercourses are potentially vulnerable to flooding by these. There is some evidence that this is the case at Cridmore Bog, which flanks the River Medina. Although the various ditches on the site, and the course of the River Medina, have been dug to a depth of around 1.5 m and designed to function as drains rather than supply water to the site, there is evidence for silt inwash and high fertilities in parts of the site, which appears to be sourced by episodic flooding of the River Medina. As reflected by its allocation to WETMEC 16, the primary source of telluric water to Cridmore Bog seems to be groundwater outflow from adjoining Greensand hills, and the river appears more to have nuisance value as a source of enrichment than providing a significant source of water in summer. It may therefore be appropriate to divert the river away from much of the site, reducing its drainage function and its enrichment potential. This approach has been proposed in recent water management initiatives for Cridmore (Environment Agency, 2003).

6.20 WETMEC 17: Groundwater-Flushed Slopes

6.20.1 Outline

A soligenous WETMEC of sloping ground, upon a low-permeability substratum where wet conditions are maintained by flushing, by downslope flow of water over the underlying aquitard. Examples are typically rather small and fed by seepages or springs at the top of the slope, along with any surface run-off. Schematic sections are provided in Figure 6.46.

6.20.2 Occurrence

Example sites: Acres Down, Ashculm Turbary, Banc y Mwldan, Bicton Common, Buckherd Bottom, Clack Fen, Cors Erddreiniog, Cors Goch, Cors Llyn Coethlyn, Cors Nantisaf, Cors y Farl, Cwm Cadlan Grasslands, Dowrog Common, Great Candlestick Moss, Great Close Mire, Landford Bog, Matley Bog, Nantisaf, Nares Gladley Marsh, Nash Fen, Retire Common, Rosenannon Bog and Downs, Smallburgh Fen, Stagmire Moss, Stoborough Heath, Tarn Moor (Sunbiggin), Thursley Common, Trefeiddan Moor, Ventongimps Moor, Widden Bottom

A widely distributed unit often occurring as small units within, or alongside, other WETMECs. Extensive examples, or examples that occupy a substantial proportion of the mire surface, are much less common and were recorded mostly from parts of the New Forest, SW England and Wales. The distribution of examples in sites sampled is shown in Figure 6.45.

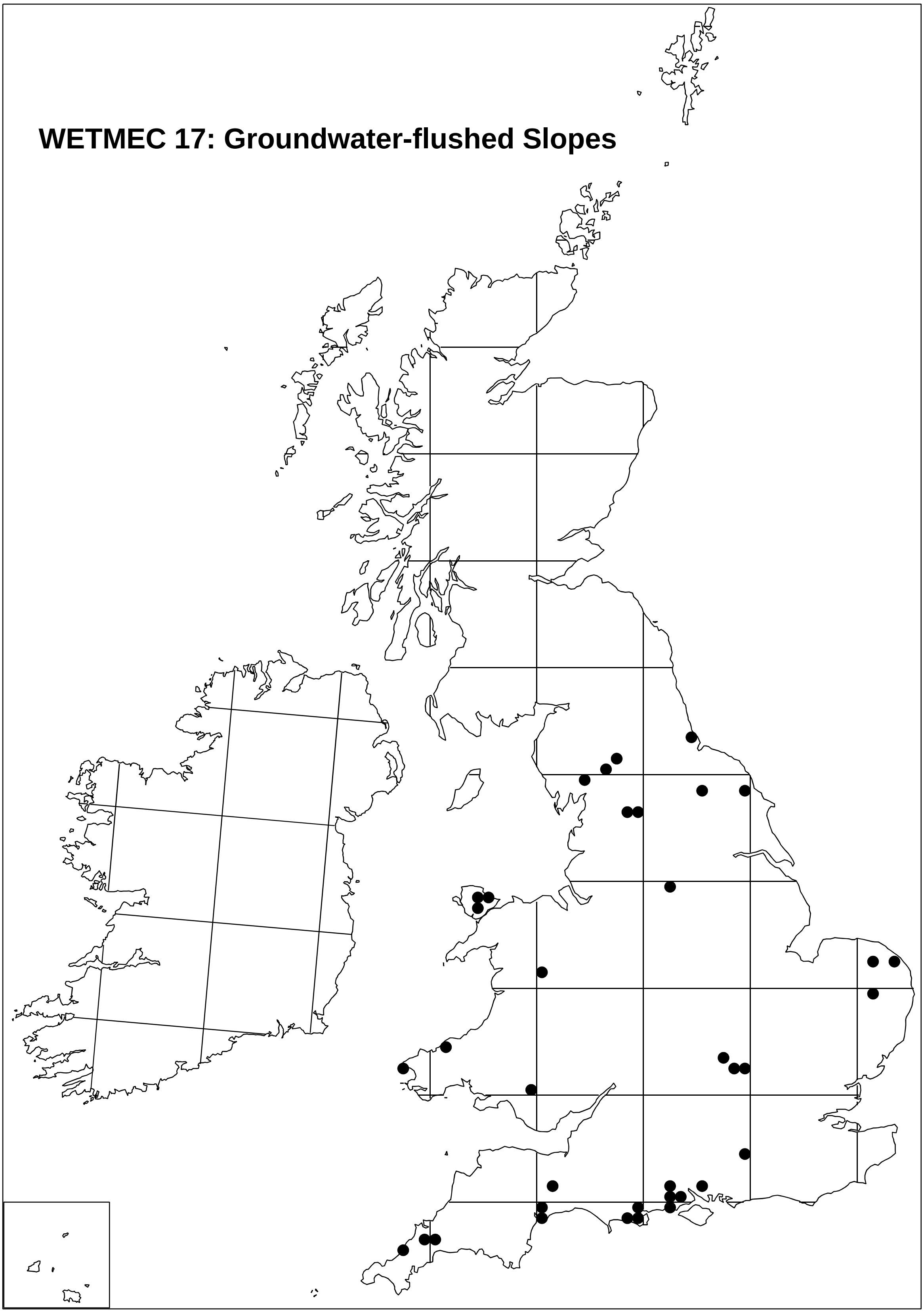


Figure 6.45 Distribution of examples of WETMEC 17 in sites sampled in England and Wales

6.20.3 Summary characteristics

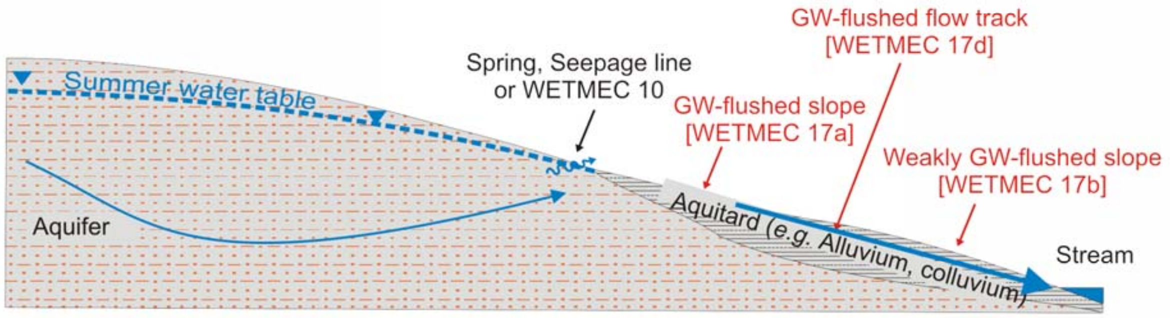
Situation	Mainly valleyheads, some hillslopes, and the margins of a few troughs and basins.
Location	Widely distributed, but often as small units with other WETMECs.
Size	Typically very small (< 1 ha, sometimes < 0.01 ha).
Surface relief	Usually sloping, sometimes quite steeply. May have channels and hollows formed by water flow.
Hydrotopography	Soligenous.
Water: ***supply***	Groundwater, sometimes with significant rain-generated run-off.
regime	Water table at surface when wet; can be seasonally dry.
distribution	Downslope-flow over aquitard from groundwater outflow at top of slope; surface flow in runnels or small water tracks.
superficial	Sometimes has small, shallow pools; active runnels are frequent.
Substratum	Shallow peat, mineral-enriched peat or strongly organic mineral soils, typically over stiff clays or silts.
peat depth	If present, usually < 50 cm, but up to 2 m at the base of some troughs and basins.
peat humification	Often strongly decomposed and humified except in some *Sphagnum*-dominated, base-poor examples.
peat composition	Often too decomposed to identify many macrofossils, but examples can have monocot peat and brushwood peat, with *Sphagnum* peat in some base-poor examples.
permeability	Surface layer can have very variable permeability characteristics; basal substratum mostly of low permeability.
Ecological types	Range from oligotrophic to eutrophic, base-poor to base-rich, depending mainly on groundwater source, but in some instances influenced by underlying substratum.
Associated WETMECs	May be found in association with permanent seepages (WETMEC 10) and, sometimes, Intermittent and Part-Drained Seepages (WETMEC 11). Can feed down into valley bottoms, especially with WETMEC 16.
Natural status	Some examples have been partly drained, but water supply mechanism is essentially natural. Some may have been subject to peat removal.
Use	Conservation. Examples usually have no other usage or are grazed as rough pasture.
Conservation value	Oligotrophic examples, base-rich to base poor are generally of high value and examples are included in a number of EU SAC sites.
Vulnerability	Main threats include: dereliction, reduction of groundwater supply through drainage or interception, agricultural enrichment.

WETMEC 17: GROUNDWATER-FLUSHED SLOPES

[See also WETMEC 15]

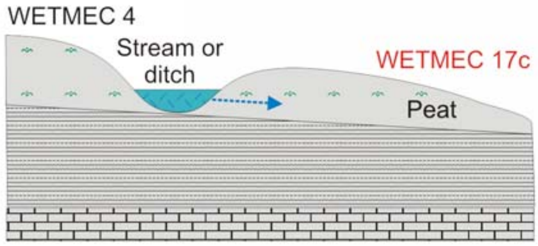
WETMEC 17: Groundwater-flushed Slopes
(*e.g.* Stoborough Heath, Ventogimps Moor)

- groundwater outflow at junction between aquifer and aquitard generates springs and seepages, sometimes with a significant (but usually small) area of WETMEC 10
- outflow water flows downslope over aquitard, usually with only a thin peat layer to form WETMEC 17a
- outflow water may become focussed into a soakway or water track (WETMEC 17d), which sometimes occupies a shallow, eroded gully within the slope
- as water becomes focussed into a soakway, or otherwise dissipated downslope, the lower parts of the mire may be drier than the upper parts (WETMEC 17b, or wet heath or wet grassland)
- water level of the stream does not necessarily influence the water table of the flushed slope



WETMEC 17c: Distributed Groundwater-flushed Slopes
(*e.g.* The Moors, Bishop's Waltham, Retire Common)

- groundwater outflow at junction between aquifer and underlying aquitard feeds into spring streams and / or ditches
- in suitable locations (*e.g.* Part-drained sites with a winding stream or a ditch across the slope), there may be potential for downslope recharge of the surface layers from the stream / ditch
- the importance of this mechanism is not known, and depends critically on hydraulic gradients and conductivities: in many cases the surface may be fed ± exclusively by precipitation, and one sample from Bishop's Waltham was clustered into WETMEC 4
- in principle, with sufficiently high permeabilities, this mechanism could support WETMEC 17a but all examples clustered into this unit had low water tables.



Conceptual diagram of part of Bishops Waltham Common (Hants)

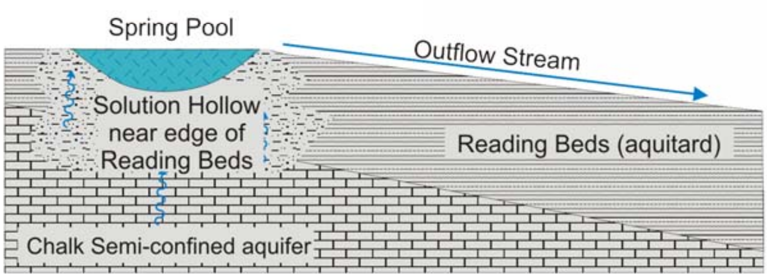


Figure 6.46 Schematic sections of types of Groundwater-Flushed Slopes (WETMEC 17)

6.20.4 Concept and description

CLUSTERS: 30, 31, 32

This WETMEC is most characteristic of valleyheads or hill and basin slopes in locations where contrasting lithological features result in groundwater outflows that feed surface or near-surface downslope flow over an aquitard. In some cases this WETMEC occurs below a quite well-developed seepage face but in others, whilst there is (sometimes quite strong) groundwater outflow, this is not directly associated with significant development of permanent seepages (WETMEC 10), and most of the mire occurs over clays (for example) downslope of the outflow. WETMEC 17 refers specifically to the flushed surface downslope of the outflow, but where the outflow is not associated with a significant seepage face, for practical purposes it can be treated as part of WETMEC 17.

The conformation of WETMEC 17 is very variable. Many examples are small, narrow strips of wet ground below a spring or seepage, but in some cases they occupy whole valleysides, though not usually as a uniformly wet surface. In these larger, wetter examples, WETMEC 17 may occur as strips of wet fen or soakways in shallow gullies separated by drier, more elevated, rounded ridges which may be – but are not necessarily – also referable to this WETMEC. The cause of this pattern along the slope may be due to the localisation of groundwater outflows, or it may be because water from a seepage line along the top of the slope has become funnelled into downslope gullies, in some cases by natural processes, in others assisted by attempted drainage. This pattern can be seen at Ventongimps Moor, where consistently wet conditions are restricted to the main flow tracks and depressions. Some sites consist primarily of a rather dry sloping surface, with strong localisation of wetter conditions (such as Ashculm Turbary). Others occupy flattish ground alongside (often groundwater-fed) streams and in some cases may receive recharge, or sometimes surface flow, from these. This is most usually a small-scale feature, which has been little-sampled in the present study, but in some sites (such as The Moor's, Bishop's Waltham) it occurs more extensively.

The downslope length of Groundwater-Flushed Slopes is also variable, and depends upon both the volume of groundwater outflow and the conformation of the surface. However, even in wet flushes there is a tendency for water to dissipate within the vegetation downslope, or to become focussed into runnels and small streams separated by more elevated peaty surfaces (such as Stoborough Heath). Some gullies are wet down the length of the slope and where there is limited resistance to water flow, some soakways and water tracks can be quite extensive. Overall, there is a tendency for Groundwater-Flushed Slopes to be wettest near the top (closest to the groundwater source). In some instances, where slow outflow is dissipated within a peaty slope, the bottom of the slope may be quite dry (though this may partly be a product of drainage by a stream or drain along the bottom of the slope rather than just due to limitations of supply).

Some flushes, mainly on the steeper slopes, show clear evidence of slumping and have an irregular surface of slumped material which can support a range of water conditions. Slumped examples occur in a number of locations in the New Forest (where there is an appropriate juxtaposition of contrasting substrata), and have been referred to as seepage steps (such as Acres Down, Buckherd Bottom) (see Box 6.22, WETMEC 10) and similar slippages are evident elsewhere (such as Ashculm Turbary). The resulting surfaces can have a complex topography and mix of low and high-permeability deposits, and can present a mosaic of seepages, flushes and recharge surfaces fed by groundwater-sourced streams and runnels.

Affinities and recognition

The term 'flush' is used here specifically to refer to groundwater flow over an aquitard slope. This corresponds to much common usage of the term, though sometimes 'flush' also refers to some (usually skeletal) permanent seepage faces or to surfaces fed primarily by surface run-off.

Flushes can often readily be separated from Permanent Seepage Slopes (WETMEC 10) by the presence of stiff clays or silts below the (often very thin) top layer of peat. However, permanent seepage faces can also occur above, or embedded within, aquitards and may form an intimate mosaic with them, particularly in locations where the underlying basal substratum is heterogeneous. In such situations, whilst it may be possible conceptually to split the mires into seepages and flushes, practically this is likely to be difficult and of limited value. In this project, the multivariate classification has generally clustered small flushed areas that are in close association with permanent seepages together with the seepages. The constituents of WETMEC 17 thus mostly represent reasonably extensive examples of flushes, often well below a seepage face, or where there is little significant development of an associated seepage wetland. Examples of WETMEC 17 often have only a thin peaty soil, can be somewhat drier in summer than many permanent seepages and, in some cases, are more obviously partly irrigated by surface run-off and drainage than is the case with permanent seepages.

Weakly Groundwater-Flushed Slopes (WETMEC 17b) are analogous to Intermittent and Part-Drained Seepages (WETMEC 11). Again, they can often be distinguished from this unit by the underlying clay aquitard, but this is less reliable than with WETMEC 10 as some intermittent seepages (WETMEC 11b: Slowly Permeable Partial Seepage) can also develop over an aquitard. In locations where the basal substratum is heterogeneous it is often not possible to know, without detailed measurements, whether a given surface is summer-dry because it receives only limited downslope flushing by groundwater or because of constraints upon groundwater upflow. In some cases this can be deduced by reference to the topography of the surface and the location of visible groundwater outflows, but in sites where the natural groundwater supply mechanisms have been disturbed (such as Cwm Cadlan) such simple assessments may not be possible.

Groundwater-Flushed Flow Tracks (WETMEC 17d) have obvious affinities with WETMEC 15, but can usually be easily distinguished because examples are often narrow, skeletal, consistently underlain by clay and silt and, often, quite strongly sloping. They can also have a relatively firm, often mineral, bottom with water flow over this, rather than the quaking or buoyant surfaces characteristic of many examples of WETMEC 15. Nonetheless the soft, sticky mineral deposits sometimes have a tenacious capacity for the unplanned separation of Wellington boots and feet, especially in some heavily poached locations.

6.20.5 Origins and development

Little is known about the origin and ontogenesis of most WETMEC 17 sites, reflecting the general absence of any significant accumulations of peat. Many of the comments made for WETMEC 10 (see 6.13.5) may apply equally to WETMEC 17, especially considerations of slumping and so on.

6.20.6 Situation and surface relief

Most samples (75 per cent) were from valleyhead contexts, with 15 per cent from hillslopes. Eight per cent were from the sloping margins of basins and two per cent from the slopes of troughs. The surface is usually sloping, sometimes quite steeply (Table 6.60), and may have channels and hollows formed by water flow.

6.20.7 Substratum

The majority of Groundwater-Flushed Slopes have a thin, sometimes skeletal, peaty surface (mean peat depth of 0.4 m). This often consists of an amorphous, structureless organic deposit, but examples cover the whole range of permeability characteristics from solid dense deposits to loose quaking surfaces (Table 6.60). Both extremes of this range can be associated with very wet, flowing conditions. At one extreme, water tracks can have dense peat deposits, probably of quite low permeability, which may floor the unit or form small embedded peaty mounds around which the water flows. At the other, flushes and flow tracks are covered by a loose quaking mat of vegetation (often *Sphagnum*-dominated), with water flow through or below this material. Most flushes do not have a middle/lower layer of peaty material, but a few examples are located over deep peat (maximum recorded depth of two metres). Examples with more than one metre depth of peat were all recorded from basin sites (Cors Goch, Cors Llyn Coethlyn, Cors y Farl and Great Candlestick Mire) and occupy the bottom of the slope, near the transition with the topogenous peats of the basin bottom. Most members of WETMEC 17 are quite strongly sloping, but a small number are more or less flat (Table 6.60).

The basal substratum is usually sticky clays and silts and of low permeability (Table 6.60), but some samples over deposits of a more loamy material were also clustered into WETMEC 17. The aquitard is often formed from Drift, alluvial or colluvial material, in which case it may be underlain by the main aquifer or it may be formed from an underlying low-permeability rock.

Table 6.60: Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 17

	Mean	1	2	3	4	5	6	7
Surface layer permeability	3.9	2	13	31	21	21	10	2
Lower layer permeability	3.2	8	21	38	19	2	2	
Basal substratum permeability	1.9	33	46	19	2			
Slope	3.1	4	15	46	33	2	X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.20.8 Water supply

WETMEC 17 typically occurs below the junction of an aquifer and aquitard where groundwater issues from the base of the aquifer. In some cases the site of groundwater outflow is marked by a distinct seepage face, and this can result in examples of WETMECS 10 and 11 forming a zone upslope of WETMEC 17 in some sites. However, in many cases there is no, or only limited, development of a seepage-mire above WETMEC 17, whilst in others the two units are so intimately intermixed (such as parts of Stoborough Heath) that it may be neither possible nor of much benefit to enforce the conceptual distinction between the two types.

In some sites, the location of groundwater outflow is clearly related to the junction of aquifer and aquitard bedrock units, but perhaps the most widespread circumstance in which WETMEC 17 occurs is created by groundwater outflow along the upper margin of a superficial deposit (alluvium, colluvium, lake muds and clays or Till) which lines the bottom of some valleys and basins and locally confines the aquifer (Box 6.34). The hydrodynamics of such systems can be particularly difficult to assess, because the superficial deposits can show considerable spatial variation in thickness and composition and because, in many locations, their character has been little investigated or documented. The distribution and character of Head deposits is probably critical to the ecohydrology of many valley mire systems, especially in Southern England, yet it has generally been poorly served by geological surveys. For example, in parts of the New Forest some valley-bottom deposits that are currently mapped as peat are almost certainly either Head or peat underlain by Head (see site account for Wilverley Bog).

Box 6.34: Groundwater outflow and WETMEC 17

Bicton Common (Devon)

A good example of the relationships between groundwater outflow and WETMEC type is evident at Bicton Common. Within this site, Budleigh Salterton pebble bed deposits outcrop on the upper valley slopes and on the surrounding higher ground. Streams have cut down through this deposit to expose an inlier of the underlying Littleham Mudstone, which forms a fairly narrow band along the valley bottoms and part of the adjoining slopes. Groundwater outflow mostly occurs at the base of the pebble beds, and is broadly related to the distribution of mires. Some seepages and springs occur just above the junction, on gravelly material, and have been clustered into WETMECs 10 and 11, whereas most of the lower slopes are occupied by WETMEC 17 (or, in drier locations, wet heath). The bottoms of the valleys contain soakways and water tracks (WETMEC 15). The precise disposition of WETMECs is, however, somewhat more complicated than this account suggests, because in places gravels (downwash of pebble bed material) extend downslope of the junction between the two bedrocks and support a local, shallow, superficial aquifer over the Mudstone. This effectively represents a downslope continuation of the main pebble bed aquifer and supports WETMECs 10 and 11 rather than the 17 which otherwise usually occupies the slopes below the lithological junction.

New Forest (Hampshire)

Over much of the New Forest, Barton Clay forms an aquitard unit below more permeable units (the ‘Barton Sands’ of older surveys), or sometimes superficial deposits. Springlines in the Forest are sometimes stated to be associated with this junction, and in some locations this may be correct. However, whilst the Barton Clay forms a low-permeability base to the overlying deposits, in many of the mire sites springs and seepages occur well above its level. In general, the occurrence of groundwater outflow seems more often to be attributable to either (a) the occurrence of low-permeability Head (sometimes alluvium) over aquifer units; or (b) lithological variation within the Barton Sands. The former Barton Sands are now subdivided into the more permeable upper Becton Sand and the rather less permeable, more clay- and silt-rich deposits of the underlying Chama Sand. Both the Becton Sand and Chama Sand deposits can form aquifer units which, in different contexts, are thought to provide groundwater supply to mires in the New Forest. However, the Becton Sands are generally coarser and more permeable than the Chama Sands and it seems likely that many of the seepages that feed the New Forest mires occur at the boundary between these two units, though sometimes complicated and modified by the occurrence of superficial deposits of clay-rich Head.

Cwm Cadlan (Powys)

In some sites, local variation in the substratum can produce complex groundwater outflow patterns. For example, at Cwm Cadlan many of the remaining wet flushes appear to be referable to WETMEC 17, but there are also local areas on the valley sides with more permeable deposits that appear to be WETMEC 10, and some drier adjoining areas on a more clay-rich drift which appear to be WETMEC 11. A rather unusual feature of the Cwm Cadlan valley, which helps to substantiate the occurrence of the groundwater flushing mechanism described here, is that drains have been dug along the *top* of the valleyside slope, presumably to intercept groundwater outflow along the top of the flushed slopes. However, these have modified the natural flushing patterns and can obfuscate assessment of the water supply mechanisms at this site. Although detailed measurements have not been made, flushes in locations without a land-spring ditch appeared to be wetter and more actively flowing (in March 2004) than those in locations below the ditches. However, some of the flushes beneath the ditches still support a (rather dry) version of M10 vegetation, suggesting that the ditches are not fully effective or that there is some degree of groundwater upflow onto the slope, in addition to downslope flushing.

6.20.9 WETMEC sub-types

The samples allocated to WETMEC 17 were clustered into three closely related clusters (30, 31, 32) at the 36-cluster level. These provide the basis for the three main WETMEC sub-types, which are broadly the flushed equivalents of Permanent Seepage Slopes (WETMEC 10), Intermittent and Part-Drained Seepages (WETMEC 11) and Sloping Seepage Flow Tracks (WETMEC 15b). A case could be made for elevating each of these sub-types to full WETMEC status. This has not been done, partly because relatively few data are available to characterise the units but also because, within the available dataset, they have a tendency to occur together at the same sites. Cluster 31 (WETMECs 17b and c) is split at the 72-cluster level into two fairly distinct types, those fed by general downslope water flow and those where any groundwater input is likely to be derived from groundwater-sourced streams or ditches. Although rather few examples of the latter have been sampled, the difference seems to be sufficiently distinctive to merit the segregation of Cluster 31 into two WETMEC sub-types (17b and 17c).

WETMEC 17a: Groundwater-Flushed Slopes

CLUSTER: 30

> *Examples at*: Acres Down, Banc y Mwldan, Buckherd Bottom, Cors Erddreiniog, Cors Nantisaf, Cors y Farl, Cwm Cadlan Grasslands, Matley Bog, Nantisaf, Nares Gladley Marsh, Retire Common, Stagmire Moss, Stoborough Heath, Ventongimps Moor, Widden Bottom

This represents the wet mire version of WETMEC 17, and it includes samples that are quite strongly influenced by downslope water flow, with a mean summer water table of 0.9 cm bgl. These surfaces can be as wet as many Permanent Seepage Slopes, though they often have a tendency to become drier downslope. This WETMEC sometimes occurs below quite well-developed permanent seepages (such as Nantisaf).

WETMEC 17b: Weakly Groundwater-Flushed Slopes

CLUSTER: 31.1 (72-CLUSTER LEVEL)

> *Examples at:* Acres Down, Ashculm Turbary, Buckherd Bottom, Clack Fen, Cors Goch, Cors Llyn Coethlyn , Dowrog Common, Great Candlestick Moss, Hense Moor, Nash Fen, Retire Common, Rosenannon Bog and Downs, Thursley Common

This is a rather ill-defined group represented by a small number of samples, united by the common features of a shallow (< 25 cm) layer of usually very amorphous peat over a low-permeability deposit and dry summer conditions (typically with moist to wet soil but a low, sometimes undetectable, water table). Samples often occur in the same sites as the strongly flushed slopes, and may occur lateral to these or below them. Although labelled 'Weakly Flushed Slopes', in some cases it is not certain that the stands receive significant groundwater inflows – they may be fed primarily by rain-generated run-off and by rainfall. This is perhaps particularly the case where the stands are elevated well (30–40 cm) above adjoining flushed slopes, but most examples were too dry to include in the present study.

This habitat and WETMEC sub-type is almost certainly under-represented in the available dataset. It is thought to be widespread in parts of England and Wales, but many examples appear to support wet grassland rather than wet mire (and often have vegetation allocated to M24 or M25) and have not been sampled for this project. The examples included here represent the wetter end of the spectrum.

WETMEC 17c: Distributed Groundwater-Flushed Slopes

CLUSTER: 31.2 (72-CLUSTER LEVEL)

Examples at: Retire Common, The Moors (Bishop's Waltham)

This unit represents a 72-cluster segregate of CLUSTER 31, and includes samples from gently sloping sites over an aquitard, where small spring-sourced streams and drains flow partly across the slope and may have the potential to recharge the adjoining wetland by downslope flow. However, the water supply mechanisms in these cases is uncertain and requires verification.

Samples clustered into WETMEC 17c come from only two sites: Retire Common (see Box 6.31, WETMEC 16) and The Moors at Bishop's Waltham (Box 6.35). In principle, given appropriate hydraulic gradients and conductivities, lateral recharge from groundwater-fed streams could contribute significantly to the water supply of various wetland sites, but WETMEC 17c represents the only part of the dataset where this possible mechanism has emerged, and all examples of this are from rather dry locations. A similar mechanism could also apply to some surface water-sourced streams feeding into mires, but again no likely examples have been encountered. In general, streams and ditches flowing through the mire sites examined are likely to function more as drains than as water sources.

Box 6.35: The Moors, Bishop's Waltham

This gently sloping site is located at the feather-edge of the Reading Beds. Strong springs from the underlying Chalk emerge near the junction between the two deposits, mostly where the Reading Beds are thin. The Reading Beds are extensively overlain by a compact and relatively dry chalky Head which seems to act as an aquitard, preventing significant groundwater upflow over the site as a whole, and the strong spring flow feeds into several small streams rather than into the mire. Much of the surface of the mire is fairly remote from the streams and elevated above them and has a rather low water table. Hence the areas of mire (fen meadow) are most likely to be fed primarily by precipitation, perhaps also by some local recharge from the spring streams that wind through the site. The relative contribution of these two components is not known, but any lateral recharge may be fairly limited and, in any case, because of their elevation the *surfaces* of many areas of mire are likely to be fed primarily by precipitation. [Interestingly, one sample from this site was clustered as a thin-peat variant of WETMEC 4 (Drained Ombrotrophic Surfaces)]

Rather surprisingly in view of its low water table, much of the mire is quite strongly peat-based. This almost certainly accumulated when surface conditions across the site were wetter than they are now, though neither the events that led to drying, nor the likely former water supply mechanisms, are evident. Despite an ostensible supply from Chalk groundwater, some of the more elevated peat surfaces are locally rather acidic, probably as a consequence of their ombrotrophic status gained from a lowering of the groundwater table in the mire.

WETMEC 17d: Groundwater-Flushed Flow Tracks

CLUSTER: 32

Examples at: Ashculm Turbary, Bicton Common, Buckherd Bottom, Landford Bog, Great Close Mire, Matley Bog, Retire Common, Stoborough Heath, Tarn Moor, Sunbiggin, Ventongimps Moor

These samples include a series of small soakways and water tracks associated with WETMEC 17, sometimes forming a mosaic with WETMEC 17a or occurring lateral to this. This sub-type differs from WETMEC 15 in that samples are typically narrow, skeletal, underlain directly by clay and silt and often quite strongly sloping. Some (poached) examples may constitute a series of small runnels interspersed with small islands of elevated peat or tussocks of *Molinia, Schoenus nigricans* and so on. Although the average summer water table of this WETMEC sub-type is the highest of the four (–0.1 cm), individual examples vary considerably in their degree of wetness. Those below strong springs typically retain a high water table in summer, but examples below weak springs, especially when they are quite strongly sloping, may often become relatively dry with moist or wet mud between the tussocks rather than surface water.

6.20.10 Ecological characteristics

There is considerable variation in environmental conditions within this WETMEC (Table 6.61). These are summarised by reference to the ecological types (below).

Table 6.61 WETMEC 17: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	0.4	0.1	2.0
Summer water table (cm)	–1.6	–20	12
Rainfall (mm a^{-1})	1,032	613	1,640
PE (mm a^{-1})	590	514	646
Water pH	5.9	4.1	7.4
Soil pH	5.9	4.6	7.2
Conductivity (µS cm^{-1})	266	70	620
K_{corr} (µS cm^{-1})	264	57	620
HCO_3 (mg l^{-1})	118	3.5	488
$Fertility_{Phal}$ (mg)	8	4	25
Eh^{10} (mV)	277	53	502

See list of abbreviations in Appendix 1

6.20.11 Ecological types

The samples clustered within WETMEC 17 were split equitably across the three base-richness categories, but show a strong preponderance towards oligotrophic conditions (Table 6.62). Elevated fertilities were primarily a feature of some base-rich samples.

Table 6.62 Percentage distribution of samples of WETMEC 17 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	20	13	9
Sub-neutral	26	7	
Base-poor	22	2	

Oligotrophic, base-poor

This includes a number of base-poor sites from the New Forest (Buckherd Bottom, Widden Bottom), Dorset (Stoborough Heath), SW England (Ashculm Turbary, Retire Common), Cumbria (Great Candlestick Mire) and Wales (Cors Llyn Coethlyn). They are dominated by nutrient-poor, acidic outflows. Typical vegetation on wet surfaces is *Narthecium ossifragum–Sphagnum papillosum* mire (M21), but some examples have closest affinities with *Scirpus cespitosus–Eriophorum vaginatum* blanket mire (M17). *Scirpus cespitosus–Erica tetralix* wet heath (M15) and *Molinia caerulea–Potentilla erecta* mire (M25) occur on more elevated, drier surfaces (WETMEC 17b). Some at the higher pH range of the unit may support sparse *Phragmites.*

Oligotrophic, sub-neutral

All samples in this type were from Southern and South-West England, but only a few were from the New Forest (parts of Acres Down, Matley Bog and Landford Bog). This was the main category for examples from the South-West (Retire Common, Rosenannon Bog, Ventongimps Moor). Examples of WETMEC 17a were mainly represented by M21, with some *Carex echinata–Sphagnum recurvum/auriculatum* mire (M6), and drier, often elevated surfaces (WETMEC 17b) by M25 or, in some locations M25/M24. Flow Tracks (WETMEC 17d) at the lower pH range of the unit were normally a *Molinia–Myrica* rich version of M21, or sometimes M21 with *Phragmites*, but the higher pH soakways tended to support *Schoenus nigricans–Narthecium ossifragum* mire (M14), or a similar community, occasionally *Hypericum elodes–Potamogeton polygonifolius* soakway (M29).

Oligotrophic, base-rich

Some good examples of this were from Wales, in locations proximate to Carboniferous Limestone deposits. They include examples below seepage slopes, close to topogenous deposits in the trough or valley bottoms (Cors Goch, Cors y Farl) or on slopes beneath the seepages (Cors Nantisaf, Nantisaf Springs), and typically with *Schoenus nigricans–Juncus subnodulosus* mire (M13) (sometimes *Juncus subnodulosus–Cirsium palustre* fen meadow (M22)). Examples (mostly with *Pinguicula vulgaris–Carex dioica* mire (M10)) were recorded in Northern England, from Tarn Moor (Sunbiggin) and Stagmire Moss. Less base-rich versions of this WETMEC were recorded from Cwm Cadlan, parts of Banc-y-Mwldan and from a few sites in the New Forest, including Acres Down and Boundway Hall, all of which supported a form of M10.

Mesotrophic, sub-neutral

This category includes a small number of samples from otherwise mainly oligotrophic systems, where some degree of enrichment is suspected, perhaps from agricultural sources (Cors Llyn Coethlyn, Hense Moor, Retire Common, Ventongimps Moor). The vegetation is variable, and includes *Carex echinata–Sphagnum recurvum/auriculatum* mire (M6), *Juncus effusus/acutiflorus–Galium palustre* rush pasture (M23) and *Molinia caerulea–Potentilla erecta* mire (M25). In addition, some soakways with taller herb vegetation on Irish Sea Till sites group here. This category also includes some water tracks which were all referable to *Hypericum elodes–Potamogeton polygonifolius* soakway (M29).

Mesotrophic/eutrophic, base-rich

Samples in this unit were from fairly wet flushed slopes, with only a thin layer of peat. The unit includes samples from the slopes of Corsydd Erddreiniog and Nantisaf, and Banc-y-Mwldan (north end). Some samples from Nares Gladley Marsh, on the Woburn Sands Formation of the Lower Greensand Group, also group here. Such examples mostly support M22 or similar vegetation, but some samples from the South Midlands and East Anglia support rank tall herb vegetation.

6.20.12 Natural status

Little is known about the natural status of WETMEC 17. The water supply mechanism appears to be essentially natural, but some sites have been partly drained and some may have been subject to peat removal (such as Ashculm Turbary). Some examples, such as The Moors, Bishop's Waltham (Box 6.35) seem likely to have been considerably modified, but no information has been found on past events at this site.

Many examples of WETMEC 17 would probably have been wooded, except perhaps the more acidic examples. In these cases, it is not clear to what extent an absence of trees is the product of an unsuitable ecohydrological environment or of light grazing pressure. In more base-rich conditions, even where the surface was naturally too wet or too unstable to support trees, many examples of this WETMEC are likely to have been (partly) overtopped by woody plants growing on drier ground around their margins, because of their typically small area. However, it is quite possible that parts of the surface of some of the more base-rich, wet examples of WETMEC 17 were naturally mainly herbaceous in character.

6.20.13 Conservation value

One hundred and thirty wetland plant species have been recorded from samples allocated to WETMEC 17. This large number reflects the wide range of habitat conditions found within the WETMEC, particularly the range from base-poor to base-rich. Oligotrophic examples are generally of high value and some are represented in a number of EU SAC sites (see Tables 3.3 and 6.4).

WETMEC 17 supports a number of nationally uncommon plant species, including: *Cladopodiella fluitans, Dactylorhiza praetermissa, Drosera anglica, D. intermedia, Epipactis palustris, Erica ciliaris, Eriophorum latifolium, Euphrasia pseudokerneri, Hypericum undulatum, Juncus alpino-articulatus, Oenanthe lachenalii, Osmunda regalis, Philonotis calcarea, Pinguicula lusitanica, Preissia quadrata, Primula farinosa, Selaginella selaginoides, Sphagnum pulchrum, Thelypteris palustris.* In addition, a range of more locally uncommon species occur, including *Carex dioica, Eleocharis multicaulis, E. quinqueflora, Hypercum elodes, Pinguicula vulgaris.*

The percentage occurrence in NVC communities of samples of WETMEC 17 is: M21: (27%); M22: (16%); M10: (10%); M25: (9%); M13: (7%); M14: (7%); M24: (7%); M17: (4%); M27: (1%); M4: (1%); M9-1: (1%); M29: (1%); W5: (1%). The wide range of communities recorded, spanning permanently wet slopes to summer-dry conditions, reflects the variety of sub-types encompassed in WETMEC 17, and also its span from acidic to base-rich conditions. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 17 is given in Table 6.3.

6.20.14 Vulnerability

Examples of WETMEC 17 can be damaged by drainage, but the nature of their water supply means that the relationship to drainage may be rather different to that of some other soligenous surfaces. For example, the fact that the flushes are fed by groundwater outflow at the top of the slope means that an effective drainage strategy would be to dig longitudinal drains along the top of the slope to capture groundwater outflow, and this approach appears to have been adopted at some sites. At Ventongimps Moor, several distinct springs occur along the top edge of the mire, below agricultural land, and feed into flushes and runnels (and some ponds). However, a land-spring drain runs along the upper margin of this site and several other drains were dug downslope (apparently in 1950), orthogonally from this. Groundwater undoubtedly still irrigates some of the slopes below this drain, but the natural groundwater supply to the mire surface has clearly been modified, and probably reduced. Some of the clearest examples of drains dug along the top of the valleyside slopes are found at Cwm Cadlan (Box 6.34).

The water supply mechanism of WETMEC 17 means that examples may be less vulnerable to water drawdown caused by deepening of axial valley drains than is the case for many examples of WETMEC 10. This, however, depends upon the details of the site in question, particularly the nature of the substratum. Where the flushed slope is essentially composed of a thin layer of peat upon a dense clay, deepening of axial drains may have little impact on the water table of the mire slopes. However, where there is a significant peat aquifer over the clay base, drain deepening may lead to increased water drawdown within this, and thus result in some surface drying. In some sites, drains have been dug across examples of WETMEC 17 or at the base of the WETMEC 17 slope (such as Retire Common, Cornwall). Even if these have rather limited impact upon WETMEC 17 upstream of the ditch, they can reduce water flow further downslope.

Examples of WETMEC 17 are potentially vulnerable to enrichment of any groundwater and surface water sources that feed into the top of the mire, and this may particularly affect the upper part of the mire. This process may be particularly problematic in sites fed by minor aquifers which are below farmland slopes with low-permeability soils, and may perhaps explain the rather high fertilities recorded from this WETMEC on slopes beneath farmland or improved fields (such as Cors Llyn Coethlyn and Ventongimps Moor).

6.21 WETMEC 18: Percolation Troughs

6.21.1 Outline

A WETMEC of gently sloping valley bottoms and troughs, mostly on fairly shallow peat located over low-permeability bedrock. Groundwater supply is thought unlikely to occur, or its role is uncertain but likely to be proportionately small relative to rainfall and surface run-off components. Water flow from the margins often becomes focussed into preferential flow paths, that is, the soakways and water tracks that constitute the closely related WETMEC 19 (Flow Tracks). It is presumed that there is also some down-trough flow through samples of WETMEC 18, but visible water flow is not normally apparent. Schematic sections are provided in Figure 6.48.

6.21.2 Occurrence

***Example sites*:** Birk Bank Moss, Cliburn Moss, Cors Graianog, Cors Gyfelog (Gyfelog Farm and NW arm), Eycott Hill, Knott End Moss, Silver Tarn, Stable Harvey Moss

Possibly quite a widely distributed unit, but mainly in the wetter parts of England and Wales. Many of the samples included within this WETMEC come from an important, but rather little known, series of mires in South Cumbria, located in (mostly) small hollows and troughs in the intricately undulating, hilly district between Grizebeck and Coniston. Here there are some 30–40 named mires and a number of un-named sites, but only a small sample was examined in this project, mostly from the area of Subberthwaite Common. This type of WETMEC also appears to occur quite widely in some oceanic parts of Scotland. For example, a mire at Little Loch Roag, Isle of Lewis (Goode and Lindsay, 1979), shares many similarities with some of the Subberthwaite troughs, and may also belong to this WETMEC and WETMEC 19. The distribution of examples in sites sampled is shown in Figure 6.47.

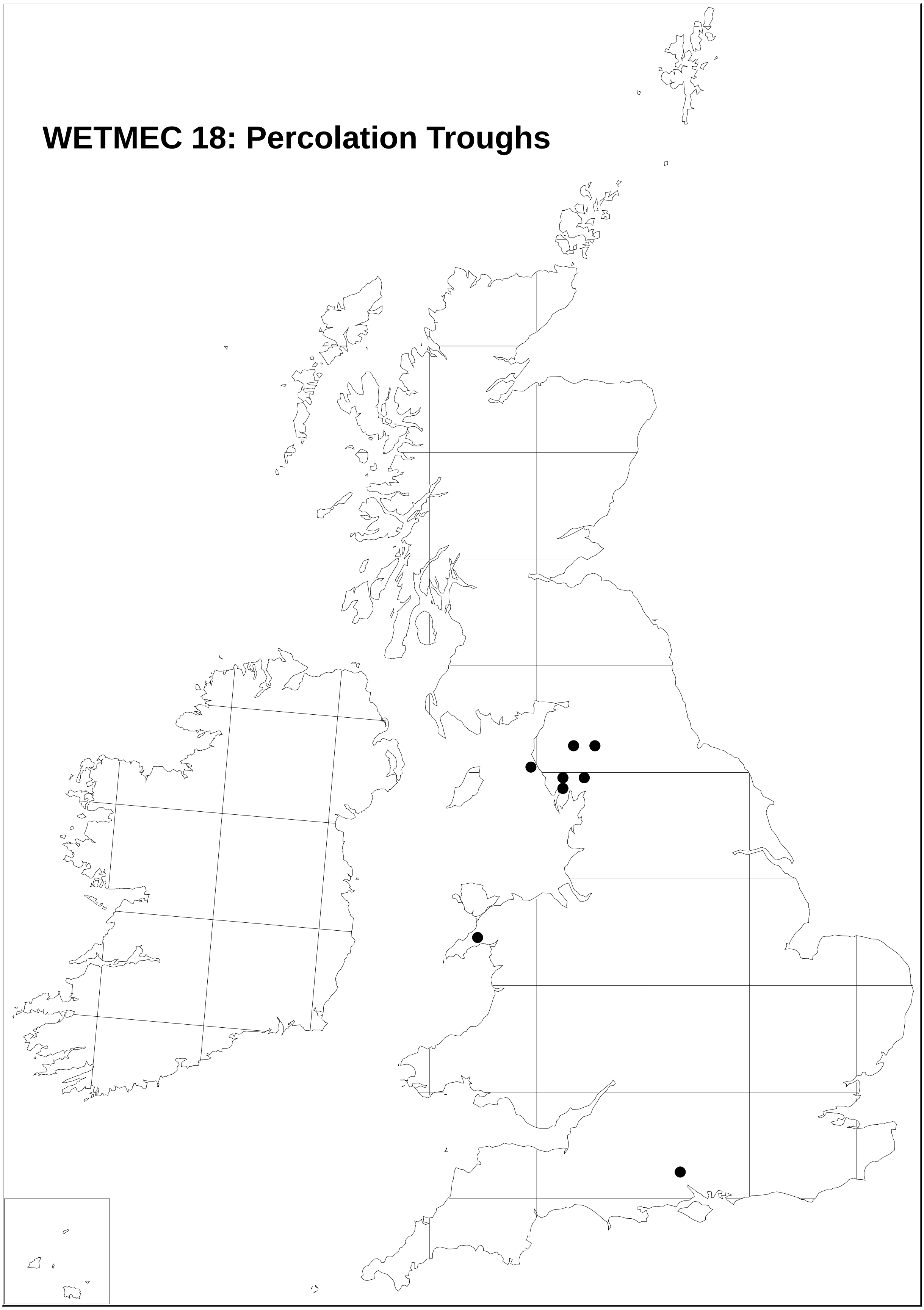


Figure 6.47 Distribution of examples of WETMEC 18 in sites sampled in England and Wales

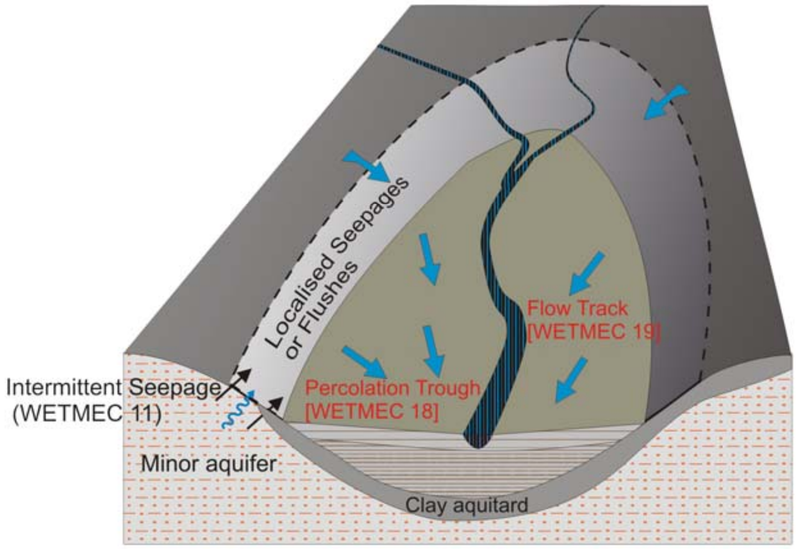
6.21.3 Summary Characteristics

Situation	Mostly valleyheads, some troughs and basins.
Location	Most samples are from Wales and Cumbria (in areas of fairly high rainfall).
Size	Small to quite large, flattish mire expanses, gently sloping along the length of broad valleyhead bottoms and troughs.
Surface relief	Narrow to broad flats and troughs, with a spongy, sometimes quaking surface. Mostly on more or less flat or gently sloping areas.
Hydrotopography	Rheo-topogenous, sometimes over overgrown topogenous basins.
Water: ***supply***	Probably mainly rainfall and surface run-off. Some groundwater inflow may occur, but generally not visually obvious and quantitative importance is not known and difficult to assess.
regime	Summer water table mostly at or near surface (sometimes slightly above).
distribution	Longitudinal flow along trough, with some lateral inflow from flanks, both upslope and, in some cases, probably from adjoining soakway. Visible flow not normally apparent.
superficial	Some small pools and, sometimes, small water channels.
Substratum	Soft or spongy upper layer, most often underlain by a more consolidated surface, and sometimes by gyttja. Basal material typically either solid material or silts and clays.
peat depth	Variable: typically > 1.5 m, but some shallow examples.
peat humification	Usually with a shallow (0.5 m) spongy surface; underlying peat, when present, usually more humified and often solid, especially lower down.
peat composition	Mostly monocot or *Sphagnum* peat near surface. Underlying peat is mostly either monocot or wood peat.
permeability	Upper peat variable, but mostly with quite high permeability characteristics. Lower deposits and basal substratum mostly with fairly low permeability characteristics.
Ecological types	Oligotrophic, base-poor to eutrophic, sub-neutral.
Associated WETMECs	Usually flanked by WETMEC 19 along drainage axes; sometimes drains into sumps with WETMEC 20.
Natural status	Some examples may form a natural persistent state, but the role of grazing in preventing tree colonisation is uncertain. More base-rich examples are susceptible both to acidification and tree colonisation.
Use	Conservation. Light grazing. Some occupy former turbaries.
Conservation value	Species diversity is generally rather low, partly because of the intrinsically low species richness of base-poor mires, but WETMEC has quite a large species total with some nationally uncommon species and may support examples of SAC habitats.
Vulnerability	Direct drainage. Surface water enrichment.

WETMEC 18: PERCOLATION TROUGHS and WETMEC 19: FLOW TRACKS

Peat filled Valleyhead Percolation Trough and Flow Track
(*e.g.* Birk Bank Moss)

- significant inputs from rain-generated run-off and precipitation
- importance of groundwater outflow uncertain, but probably small, either because of limited supply from a minor aquifer, or because of top-layer aquitards
- exotelmic stream inflow may produce some lateral recharge of flanking mire, especially during flooding episodes, but water course largely acts as a drain
- flow through trough may be focussed into a series of small subsidiary runnels, soakways and water tracks (not illustrated) or occurs by lateral percolation through loose surface peat and vegetation
- shallow gradient helps retain water
- some valleyhead percolation troughs are former lake basins which have developed into troughs by accumulation of peat up to and above the lip of the original basin



Peat-filled Valleyhead Percolation Trough and Water Track over lake basin (longitudinal section)
(*e.g.* Stable Harvey Moss)

- main details, as above
- part of system illustrated is a former lake basin which has undergone terrestrialisation to a peat-covered surface (probably initially WETMEC 19)
- under the influence of continued water inflows peat has accumulated above the natural lip of the basin to form a gently sloping surface which appears as a valleyhead trough

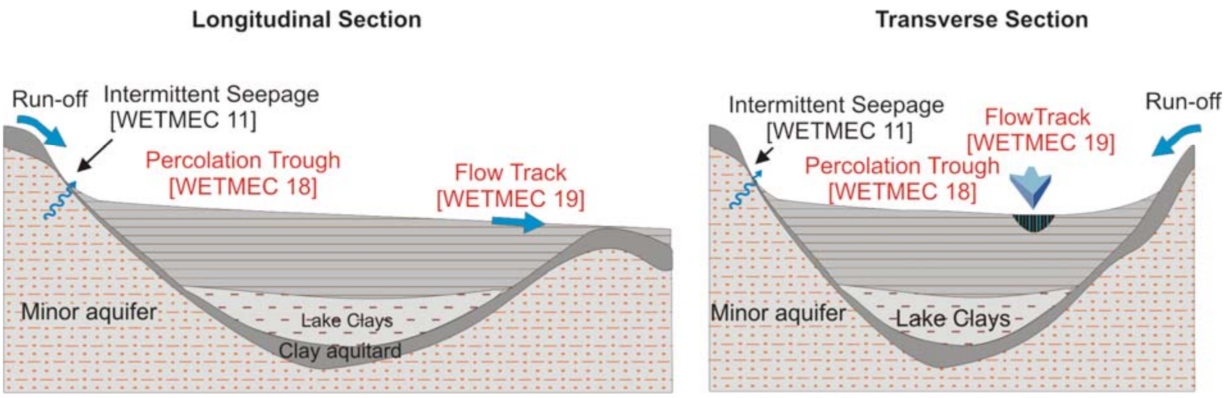


Figure 6.48 Schematic sections of types of Percolation Troughs (WETMEC 18) and Flow Tracks (WETMEC 19)

6.21.4 Concept and description

CLUSTER: 33

WETMEC 18 is an analogue of WETMEC 14 (Seepage Percolation Troughs), developed in locations with a wetter climate and where groundwater inputs are thought to be relatively small, or absent. Sites are mostly located over low-permeability rocks and in regions of relatively high rainfall (parts of Wales and Cumbria), and many examples have quite large surface water catchments. The hydrological processes within this WETMEC seem to be more or less the same as in WETMEC 14, and some samples allocated to WETMEC 18 are from sites, or parts of sites, where the likely occurrence of groundwater outflow is not known, and is difficult to assess (often because of lack of information on the character of the Drift in the local area), and to which there are at least some significant surface water inflows.

Most of the mires in this WETMEC occupy shallow headwater valleys within a rocky landscape in which the mires occupy troughs and basins intertwined with rocky knolls. Some examples (such as Stable Harvey Moss) occupy quite large, broad, gently sloping valleyhead troughs and basins, but many are in rather narrow troughs and small valleyheads in which WETMEC 18 forms a fairly flat, but often narrow surface. Some sites are essentially just rheo-topogenous troughs, with a sharp edge against fairly dry, rising valley slopes, but others grade outwards into (occasionally extensive) wet slopes, though these tend mostly to support wet heath rather than true mire. Many examples of WETMEC 18 flank an axial water Flow Track (WETMEC 19) and in some of the narrower troughs this can be the dominant WETMEC, with WETMEC 18 surfaces squeezed into a narrow, and sometimes discontinuous, band between this and the rising valley slopes. The down-valley slope is sometimes irregular and, in some locations, quite steep. Whereas this WETMEC can be considered to be an analogue of WETMEC 14, some sites are considerably smaller, more topographically irregular, and frequently steeper than their WETMEC 14 counterparts in the New Forest and Dorset.

Also included in this WETMEC are a few samples which differ from the general character of the WETMEC as described above. For example, some samples from the north margin of Cliburn Moss have been allocated here: this moss occupies a shallow basin within generally low-permeability deposits and samples referable to WETMEC 18 form a sort of lagg alongside an ombrogenous deposit. A few marginal samples from the north-west arm of Cors Gyfelog (Gwynedd) have also clustered here, though in a broader, more subdued topographical context than those from South Cumbria, as have some samples from Cors Graianog. At Cliburn Moss, Cors Graianog and, probably, Cors Gyfelog, this WETMEC appears largely to occupy old peat workings, though only at Cors Graianog is this visually obvious.

Affinities and recognition

WETMEC 18 (Cluster 33) is closely related to WETMEC 19 (Cluster 34). Both are fed primarily by flow along the troughs that they occupy, and differ mainly in the apparent rate of water throughflow and in the presence of surface water. WETMEC 18 does not normally have visible water flow, and water levels are not normally above the surface (except in small pools and so on), whereas WETMEC 19 usually has visible surface water.

The main difficulty in recognising WETMEC 18 is in distinguishing it from WETMEC 14 (Seepage Percolation Troughs). The latter WETMEC is sourced to a significant degree by groundwater, whereas groundwater outflow is thought not to be as important in examples of WETMEC 18. However, the actual role of groundwater in WETMEC 18 is difficult to assess; if examples receive any groundwater at all, this is likely to be by fracture flow from minor aquifers. There is often no visible evidence of any groundwater outflow features associated with the samples (though this also applies to some examples of WETMEC 14). Because of these difficulties, the status of WETMEC 18 is perhaps best assessed by reference to surface water-related features. Examples tend to be associated with low-permeability rocks and soils, where there is likely to be substantial run-off into the mire troughs, and this is frequently expressed by stream inflow into parts of the sites. Along with WETMEC 19, WETMEC 18 typically occurs in the higher rainfall areas of England and Wales, and the two units have by far the highest mean rainfall and lowest mean PE of all the WETMECs identified. Hence, rainfall and rain-generated run-off are likely to be important in maintaining summer water levels and any groundwater inflows that do occur are likely to be proportionately less significant than in WETMEC 14. However, some similar Cumbrian mire surfaces, which are clearly situated over permeable deposits and have associated seepages (as at Greendale Mires), have been clustered into WETMEC 14.

It is clear that WETMECs 14 and 18 intergrade conceptually, and can be difficult to separate in the field. A case could be made for considering them as a single WETMEC. However, examples that appear to belong to WETMEC 18 are known to occur quite widely outwith the area sampled in this study (for example, along the western coast of Scotland) and in view of this regional pattern, and the greater proportionate contribution of rainfall and run-off to WETMEC 18, the two units suggested by the multivariate classification have been retained. The actual importance of groundwater to these systems requires further hydrological examination.

6.21.5 Origins and development

Very little is known about the development of examples of this WETMEC, mainly because of lack of investigation rather than lack of peat and other wetland infill. Although occupying troughs and often with a visibly sloping surface, a number of examples appear to have originated hydroserally within small late-Devensian lake basins. For example, at Stable Harvey Moss, Hodgkinson *et al.* (2000) describe a stratigraphical sequence over late-Devensian clays (surface at 4.7 m bgl). This appears to have gone through a fairly classic post-glacial hydroseral sequence of lake muds (gyttja) > *Phragmites* swamp > monocot and sedge fen > alder woodland, all of which is overlain by about one metre of *Sphagnum*-rich peat. In some lowland contexts this sequence is not dissimilar to that which could lead to the formation of a small raised bog over a former lake, but Stable Harvey Moss, although rich in *Sphagnum*, is not a raised bog but rather a broad, irregular, gently sloping mire trough which provides little surface indication of the former lake basin. Other valleyhead troughs also appear to consist of separate basins that have become overgrown and linked by rheo-topogenous peat, with the original basin topography often obscured by peat development on the adjoining slopes, or across separating ridges. At Eycott Hill this is visually obvious – the basins are at markedly different levels and connected by fairly steep examples of WETMEC 18. The upper peats are mostly loose, often *Sphagnum*-dominated, over more consolidated monocot peats or wood peats. Where these occupy former lake basins, they often overlie deposits of gyttja. At Eycott Hill, the original basins are still evident as wet sumps (WETMEC 20) within a WETMEC 18/19 complex, and in some sites (such as Burney Tarn mire) small amounts of open water persist.

Although in a very different topographical context, the development of Cors Gyfelog shows similarities with some of the Cumbrian sites. This mire is developed over small late-Devensian lake basins which have become overgrown and linked by peat (Botterill, 1988), though the stratigraphy is complicated by the fact that substantial portions of the mire – including those with WETMEC 18 – appear to be turbaries, and the former natural character of this site is not well known. The character of Cliburn Moss also seems to have been modified by peat cutting. It is not known to what extent peat removal has occurred at other sites, but Hodgkinson *et al.* (2000) consider the upper peat profile at Stable Harvey Moss to have been truncated, presumably by peat extraction.

6.21.6 Situation and surface relief

Most samples (76 per cent) of WETMEC 18 were from valleyhead contexts. Eighteen per cent were from basins and six per cent from troughs. The samples typically occupy narrow to broad flats and troughs, sometimes with a spongy, sometimes quaking, surface. Most samples were taken from more or less flat or gently sloping areas, but a few were on moderate slopes.

6.21.7 Substratum

Peat depth is very variable beneath examples of this WETMEC, as is the nature of the underlying material. In a few cases (such as parts of Birkbank Moss) only shallow depths of peat (less than one metre) were recorded away from the margins of the mire, over what appeared to be solid bedrock, but in some sites depths of three to four metres have been recorded (such as Stable Harvey Moss, Cors Gyfelog). Typically the upper peats are mostly loose, often *Sphagnum*-dominated, and frequently quaking. They usually overlie more consolidated monocot peats or wood peats of lower permeability (Table 6.63). Where these occupy former lake basins, they often overlie deposits of gyttja. In many cases the basins, troughs and some of the slopes are lined with clay of varying thickness, and the basal substratum is mostly clays and silts, or presumed low-permeability bedrock.

Table 6.63 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 18

	Mean	1	2	3	4	5	6	7
Surface layer permeability	5.6			6		18	77	
Lower layer permeability	3.5		6	53	29	6	6	
Basal substratum permeability	2.9	12	29	18	41			
Slope	1.8	41	47	6	6		X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.21.8 Water supply

Most examples of WETMEC 18 are in high rainfall areas, and rainfall is likely to make an important contribution to their summer water table. The WETMEC often occupies troughs and hollows which are flanked by low-permeability rocks and soils, and there are generally few constraints on rain-generated run-off entering the mires. However, in most cases much of the surface water inflow from the catchment of the mire becomes funnelled into small axial streams and Flow Tracks (WETMEC 19) and may thereby largely bypass the WETMEC 18 surfaces. However, the water in the streams and flow tracks is almost certainly important in helping to maintain the water level in flanking examples of WETMEC 18, if only by maintaining a small drainage gradient. Moreover, in some more or less flat valley-bottom contexts, where a distinction between WETMECs 18 and 19 can sometimes be difficult to make, it is possible that water from WETMEC 19 may recharge adjoining flats of WETMEC 18, but the extent to which this occurs is not known.

The contribution made by groundwater to WETMEC 18 stands is poorly understood. Visible springs are generally absent, or scarce, around the site margins and in some case the rheo-topogenous trough infill abruptly abuts drier margins of the troughs, with no marginal seepages or flushes. In other cases, adjoining slopes and small feeder valleys may support wet pasture or wet heath, which may represent locations of intermittent groundwater outflow, but slopes that are clearly permanent seepages (WETMEC 10) or wet flushes (WETMEC 17a) are generally scarce, and notable by their distinctive species composition (such as Stable Harvey Moss).

Most of the bedrocks associated with WETMEC 18 generally have little primary porosity, but may nonetheless have fracture systems which support minor, superficial aquifers, especially in areas where much deformation has occurred, which is certainly the case for some WETMEC 18 locations such as South Lakeland. However, the contribution made by groundwater outflow to the water balance of the mire, or its hydrochemical characteristics, is generally not known (and merits further examination).

In other cases, such as the north-west arm of Cors Gyfelog, available hydrogeological data are so sparse that it is difficult to assess the likelihood of groundwater discharge into the mire. Little has been published about the nature of the Drift near this site, but as it is adjoined by sand and gravel works it may be postulated that the sand and gravels provide (or once provided) a minor aquifer which feeds locally into the site (though much of the mire is lined with clay).

Box 6.36: Groundwater conditions associated with WETMEC 18 in South Lakeland

In South Lakeland, the bedrock associated with a number of WETMEC 18 sites includes rocks of Silurian age from the Windermere Supergroup. The detailed hydrogeological character of these rocks is not well known. The rocks support a number of small springs, wells and borehole sources and may be thought of as a minor aquifer. Silurian rocks are mostly well cemented and consolidated. It is generally agreed that the primary porosity is very low (commonly two per cent), and makes no significant contribution to the total permeability and storage within the rocks. The lithological nature of the rock appears to have little influence on the aquifer characteristics, which are almost entirely controlled by the degree of induration and the extent of fracturing and jointing. Storage and flow of groundwater occurs predominantly within fracture systems developed by folding, faulting and jointing during the area's poly-deformational history.

In some sites (such as Birkbank and Knott Mosses) the fracture system is likely to be particularly well developed, due to the proximity of a fold hinge and a fault. Weathering enhances the fracture systems, and the network of open fractures can be several metres thick in valley areas but thin or absent in upland locations. Fractures at high elevations are commonly dry, but can act as recharge conduits to aquifer horizons at lower elevations. The occurrence of water-bearing fractures is greatest in the upper part of the aquifer, and permeability declines rapidly with depth as fractures become tighter and less common. Below 30–40 m depth, fractures and joints are expected to be closed, preventing groundwater flow. It has generally been observed that the combination of steep slopes and restriction of groundwater flow to fracture networks in this area results in small volumes of groundwater flow and small-scale flow systems. It thus seems likely that there is some groundwater flow into these mires. The exact contribution of this is not known, but it may have some hydrochemical effects, which could account for the mild base enrichment observed locally within these sites.

6.21.9 WETMEC sub-types

No WETMEC sub-types have been identified.

6.21.10 Ecological characteristics

The ecological characteristics of this WETMEC (Table 6.64) are broadly similar to those of WETMEC 14 (6.17.10). As with WETMEC 14, base-rich examples of WETMEC 18 are rather sparse, but the fertility of WETMEC 18 is generally slightly higher than that of 14. WETMEC 18 surfaces are slightly less base-rich and slightly more fertile than the WETMEC 19 soakways associated with them (Table 6.65).

Table 6.64 WETMEC 18: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	2.4	0.15	4.0
Summer water table (cm)	1.5	–16.8	23.0
Rainfall (mm a^{-1})	1,614	947	1,831
PE (mm a^{-1})	537	545	568
Water pH	5.1	4.1	6.6
Soil pH	5.2	3.9	6.3
Conductivity (µS cm^{-1})	192	66	1,051
K_{corr} (µS cm^{-1})	185	63	1,050
HCO_3 (mg l^{-1})	19	2	43
$Fertility_{Phal}$ (mg)	13	6	33
Eh^{10} (mV)	251	48	405

See list of abbreviations in Appendix 1

Table 6.65 Mean values of some hydrochemical and soil variables from samples of WETMEC 18 and proximate examples of WETMEC 19 in valleyhead mires in Cumbria

WETMEC	Water table (cm)	pH (water)	pH (soil)	EC µS cm^{-1}	HCO_3^- mg l^{-1}	Fertility (mg *Phalaris*)	Eh (mV)
18 (Percolation Troughs)	+0.4	5.1	5.2	191	19.4	9.8	244
19 (Flow Tracks)	+4.3	5.4	5.5	123	33.9	7.4	196

6.21.11 Ecological types

As with WETMEC 14, base-rich samples are poorly represented in WETMEC 18 (Table 6.66). However, WETMEC 18 has a greater representation of mesotrophic and eutrophic samples in the sub-neutral and base-poor classes.

Table 6.66 Percentage distribution of samples of WETMEC 18 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	5		
Sub-neutral	14	27	14
Base-poor	9	18	9

Oligotrophic, base-poor

These samples are typically strongly dominated by *Sphagnum* and are mostly referable to *Narthecium ossifragum–Sphagnum papillosum* mire (M21), grading into *Scirpus cespitosus–Erica tetralix* wet heath (M15) in some marginal locations. A *Sphagnum*-rich mat at the head of the NW arm of Cors Gyfelog has been allocated to *Carex echinata–Sphagnum recurvum/auriculatum* mire, *Carex echinata* sub-community (M6a).

Oligotrophic, sub-neutral

This category includes just two samples, both from Eycott Hill mires. Their highest MATCH coefficients are with *Carex lasiocarpa–Scorpidium* mire (M9-1).

Mesotrophic, base-poor

This includes some acidic samples from the NW arm of Cors Gyfelog, which may represent acidifying nuclei within the generally sub-neutral mesotrophic fen in this location. Their vegetation is best referred to *Carex rostrata–Sphagnum squarrosum* mire (M5). This category also includes some M21 and *Sphagnum cuspidatum/recurvum* bog pool community (M2) samples from Knott End Moss and Stable Harvey Moss. It is not clear why these samples are more fertile than is typical for M21, but they are all at the lower end of the mesotrophic band.

Mesotrophic, sub-neutral

Samples in this category are mostly from the NW arm of Cors Gyfelog or parts of the northern margin of Cliburn Moss. Samples from Cliburn are mostly referable to *Carex diandra–Calliergon* mire (M9-2); those from Cors Gyfelog are more problematic syntaxonomically: highest MATCH coefficients are variously with ‘M9’, M9-1, M9-2 and *Carex rostrata–Potentilla palustris* fen, *Carex rostrata–Equisetum fluviatile* sub-community (S27a), though they all occupy broadly similar conditions. A sample from the west basin of Silver Tarn, also allocated here, is referable to S27a.

Eutrophic, sub-neutral

This includes a small number of samples from along the northern margin of the NW arm of Cors Gyfelog. The substratum beneath these samples contains a visible silt component, which may be responsible for the higher fertility of this generally mesotrophic location. Vegetation with an appearance suggestive of enrichment extends into this part of Gyfelog from a small valley to the north-west, but no samples are available for this.

6.21.12 Natural status

Similar comments apply to WETMEC 18 as for WETMEC 14 (6.17.12). Some of the more acidic examples of this WETMEC appear to be self-sustaining systems, though it is not clear to what extent the light grazing to which they are subject contributes to the general absence of trees. Some sites have been cut over and the character of their natural surfaces is not known; in other cases, for example, the north-western arm of Cors Gyfelog, peat cutting is suspected but is not certain. In this site, if peat cutting has occurred it was on a large scale and has led to the creation of a relatively uniform, reflooded surface in which clear stratigraphical evidence for cutting edges or baulks has yet to be found (see discussion in the site account for Cors Gyfelog, Appendix 3). The area appears to be subject to seral acidification (buoyant mats of *Sphagnum*) and scrub colonisation.

At Cliburn Moss, WETMEC 18 occurs in a partly wooded lagg location between the upland margin and an ombrogenous deposit. The peat beneath WETMEC 18 is very thin, probably because of past peat cutting, and it is possible that some of the WETMEC 18 surface may once have been ombrogenous.

6.21.13 Conservation value

Species diversity is generally rather low, partly because of the intrinsically low species richness of base-poor mires but WETMEC 18 has quite a large species total, with some nationally uncommon species, and may support examples of SAC habitats (see Tables 3.3 and 6.4).

A hundred wetland plant species have been recorded from this WETMEC. These include some 13 nationally uncommon species: *Calliergon giganteum, Carex diandra, Carex lasiocarpa, Carex limosa, Drosera intermedia, Osmunda regalis, Rhizomnium pseudopunctatum, Selaginella selaginoides, Sparganium natans, Sphagnum contortum, Sphagnum subsecundum, Utricularia intermedia, Utricularia minor.* In addition, some samples support a variety of locally uncommon species, such as *Carex dioica, Drepanocladus exannulatus, Eleocharis multicaulis, Hypericum elodes* and *Rhynchospora alba.*

The percentage occurrence in NVC communities of samples of WETMEC 18 is: M9-2: (36%); S27: (18%); M21: (13%); M9-1: (9%); M5: (4%); M6: (4%); M15: (4%); M23: (4%). Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 18 is given in Table 6.3.

6.21.14 Vulnerability

Many examples of WETMEC 18 are in troughs embedded within areas of rough pasture and are probably subject to few, if any threats. However, all sites are potentially vulnerable to drainage, and in some cases (mostly occluded) past drainage lines are evident.

Enrichment is a potential or actual threat in some locations. Parts of the NW arm of Cors Gyfelog show evidence of enrichment, associated with silt deposition. The source of this is not known, but could be related to former gravel extraction operations nearby. There is also evidence of considerable nutrient enrichment at Cliburn Moss, apparently from farm drainage, but whilst this can be clearly demonstrated for examples of WETMEC 19 (6.22.14), it is not clear what threat is posed to flanking WETMEC 18 surfaces.

6.22 WETMEC 19: Flow Tracks

6.22.1 Outline

A WETMEC of the bottoms of valleyheads and troughs, often on fairly deep peat, irrigated by water supply from adjoining slopes and WETMECS and, in some cases, inflow streams. The role of groundwater supply is subject to the same considerations as for WETMEC 18 (Percolation Troughs). Water flows along the trough in preferential flow tracks. Examples with much open water, representing the transition between mire and true streams are designated as water tracks, whereas soakways essentially represent more consolidated water tracks, with less open water, and occur either alongside streams or watertracks or, in some valleyheads, replace water tracks as the main axial flow path (see also 6.18.1). Laterally, soakways and water tracks often grade into the Percolation Troughs of WETMEC 18. Some sites have winding axial streams which merge into water tracks. Schematic sections of WETMEC 18 and 19 are provided in Figure 6.48.

6.22.2 Occurrence

Example sites: Birk Bank Moss, Bowscale Moss, Cliburn Moss, Cors Gyfelog , Cors y Llyn, Eycott Hill, Great Candlestick Moss, Knott End Moss, Stable Harvey Moss, Wybunbury Moss

WETMEC 19 occurs in the same range of sites as WETMEC 18, but is also present at a small number of sites from which WETMEC 18 is either absent or not recorded. The examples at Cliburn Moss and Wybunbury Moss represent water tracks in the lagg of an ombrogenous deposit (at Wybunbury, only the southern lagg has been allocated to this WETMEC – the northern lagg is clearly groundwater-fed and clusters with WETMEC 15). The distribution of examples in sites sampled is shown in Figure 6.49.

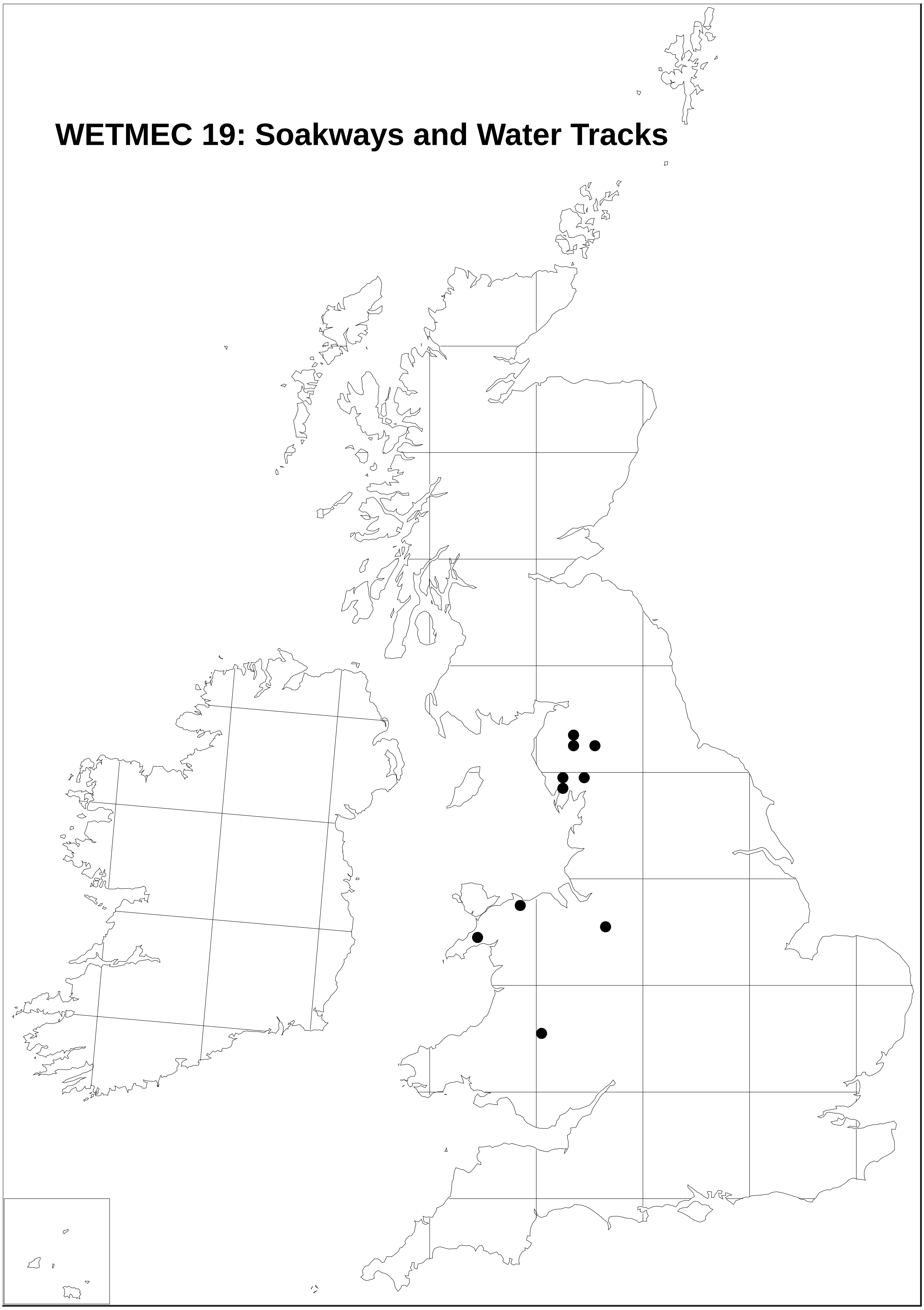


Figure 6.49 Distribution of examples of WETMEC 19 in sites sampled in England and Wales

6.22.3 Summary characteristics

Situation		Mostly valleyheads, some troughs and basins.
Location		Most examples are from Wales and Cumbria.
Size		Usually fairly narrow linear features (around < 30 m to > 0.5 km length).
Surface relief		Narrow flats and troughs, soakways with an (often buoyant) more or less continuous vegetation mat, water tracks with much open water. Often with a perceptible slope.
Hydrotopography		Rheophilous, but sometimes over overgrown topogenous basins.
Water:	***supply***	Probably mainly rainfall and surface run-off. Some groundwater inflow may occur, but generally not visually obvious and quantitative importance is difficult to assess.
	regime	Summer water table typically at or above surface.
	distribution	Longitudinal flow along trough in preferential flow paths, with some lateral flow from flanks.
	superficial	Water channels, sometimes braided or otherwise mosaiciform in water tracks. Surface water usually visible.
Substratum		Most often water and liquid muds over more solid peat, but sometimes with a more consolidated surface. Sometimes underlain by gyttja. Basal material typically low permeability, either solid material or silts and clays.
	peat depth	Typically > 2.5 m, but some shallower examples.
	peat humification	Usually with a shallow (0.5 m) spongy or semi-floating surface (soakways) or open water (water tracks); underlying 'peat' may be semi-liquid, but can be more humified and often quite solid, especially lower down.
	peat composition	Mostly monocot or *Sphagnum* peat. Wood peat in some examples.
	permeability	Upper layers mostly with high-permeability characteristics, over less permeable middle–lower layers. Basal substratum with low-permeability characteristics.
Ecological types		Oligotrophic, base-poor to eutrophic, sub-neutral.
Associated WETMECs		Mostly flanked by other WETMECs, especially WETMEC 18. Sometimes drains into sumps with WETMEC 20.
Natural status		Many examples appear to form a natural persistent state, but some are in occluded drains or flooded peat workings.
Use		Conservation. Generally too wet for easy access. Some occupy former turbaries.
Conservation value		Species diversity is generally rather low but has a large species total with a number of nationally uncommon species, and may support examples of SAC habitats. May provide a relatively base-rich element within otherwise base-poor mires.
Vulnerability		Direct drainage. Damming can pond back water and affect this and flanking WETMECs. Surface water enrichment.

6.22.4 Concept and description

CLUSTER: 34

WETMEC 19 is very similar to WETMEC 15 (Seepage Flow Tracks), differing primarily in the apparent importance of groundwater supply. Most examples also occur on deeper peat than WETMEC 15, reflecting their frequent occurrence in peat-filled troughs and basins. The unit is often flanked laterally by examples of WETMEC 18 (Percolation Troughs). At some, mostly rather flat, locations there is a clear lateral zonation of stream > water track > soakway > WETMEC 18, but at others one or more elements of this is missing. In some sites water tracks do not flank the streams, but form part of them along lengths of the mire, with small braided channels separated by flats and tumps of peat.

Most examples of WETMEC 19 are very narrow (less than five metres wide). The main exception to this is the NW arm of Cors Gyfelog where there is a broad soakway–water track complex which appears to occupy a reflooded peat working. At this site, it is particularly difficult to make a clear distinction between WETMECs 19 and 18.

Affinities and recognition

The differences between WETMECs 19 and 18, and their distinction from groundwater-fed analogues (WETMECs 14, 15 and 16) have been considered under WETMEC 18 (6.21.4).

6.22.5 Origins and development

No specific information is available about the development of most examples of WETMEC 19, which are assumed to have a similar developmental history to the WETMEC 18 surfaces and troughs within which they are embedded. As a clearly flowing feature, this WETMEC exemplifies the way in which some former small lake basins have not only been obliterated by peat formation, but, with regard to the mire surface, have changed from a topogenous hollow into a sloping valleyhead trough.

6.22.6 Situation and surface relief

Most samples (74 per cent) were from valleyhead contexts. Twenty per cent were from basins and six per cent from troughs. Three of the basin locations (Cliburn Moss, Cors y Llyn and Wybunbury Moss) were in the lagg between the basin margin and a deposit of ombrogenous peat.

These occur in narrow flats and troughs, in soakways with a (often buoyant) more or less continuous vegetation mat, and water tracks with much open water. Most samples were taken from more or less flat or gently sloping areas (Table 6.67).

6.22.7 Substratum

Substratum characteristics are broadly similar to those of WETMEC 15, except that the basal substratum mostly consists of low-permeability material (Table 6.67). The surface layer, and sometimes the middle peat layer, are typically loose and unconsolidated, or consist of a buoyant mat over a liquid deposit. There are, however, some exceptions to this, where the water track is much more obviously a shallow surface flow feature, with flow along a shallow channel over consolidated peat. Examples of this were found at Great Candlestick Moss, the outflow of Stable Harvey Moss and parts of Cliburn Moss. In the latter case, the water track may be draining over a cut-over surface and is only on shallow peat.

Table 6.67 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 19

	Mean	1	2	3	4	5	6	7
Surface layer permeability	5.6			18		5	59	18
Lower layer permeability	3.2		5	77	14		5	
Basal substratum permeability	3.1	5	36	59				
Slope	1.9	32	50	18			X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.22.8 Water supply

Water supply considerations are similar to those of WETMEC 18. WETMEC 19 soakways and water tracks are natural drainage features of mires, but telluric water is not only derived from WETMEC units, but also by direct run-off from adjoining slopes and WETMEC 19 is frequently stream-fed. In some cases, the water tracks flank a stream which may drain a quite large surface water catchment, and which may feed into the WETMEC 19; in others, surface water inflows disperse into a WETMEC 19 surface on their passage through the mire. In yet other instances, examples of WETMEC 19 are completely endotelmic, and represent a flow track into which water draining from adjoining mire surfaces becomes focussed.

The role of groundwater in WETMEC 19 samples is generally as uncertain as that in WETMEC 18. At Cliburn Moss, the soakway system seems to be fed primarily by surface run-off, though the Till which confines the underlying Penrith Sandstone aquifer contains some thin layers of sand and gravel and these may provide a minor groundwater contribution to parts of the mire.

In some sites that are generally base-poor (such as Birk Bank Moss, Table 6.68), there are evident zonations in which both the vegetation and hydrochemical conditions show some evidence of base enrichment downslope along the length of a single endotelmic soakway. This may suggest changes in water source along the soakway, with surface drainage and precipitation dominating at the top with a possible groundwater input lower down. However, the differences are not great and an alternative explanation is that the changes could relate to increased flow rates lower down the soakway.

Table 6.68 Mean water pH and conductivity values measured in four consecutive vegetation zones downstream along a sloping endotelmic soakway in the south-west arm of Birk Bank Moss (Cumbria).

Vegetation*	Water pH	Water EC (µS cm^{-1})
Sphagnum cuspidatum/recurvum lawn	4.3	100
Sphagnum auriculatum lawn	4.6	91
S. auriculatum–Eleocharis multicaulis soakway	4.9	145

Eleocharis multicaulis–Scorpidium soakway	5.5	178

**The four vegetation zones occur within a length of about 40 m, and show progressive base enrichment down the soakway, which is associated with visibly increased flow. Values are means of five samples.*

6.22.9 WETMEC sub-types

No WETMEC sub-types have been identified.

6.22.10 Ecological characteristics

The ecological characteristics of WETMEC 19 are very similar to those of WETMEC 18. However, examples generally have a higher water table and often occur on slightly deeper peat, reflecting its axial location in many of the troughs and basins. As with the relationship between paired samples of WETMEC 14 and 15, the water in stands of WETMEC 19 tends to be somewhat more base-rich than adjoining examples of WETMEC 18, and slightly less fertile (Table 6.65). Overall, mean redox potentials are lower in the water track than the adjoining mire, though this relationship is reversed for some individual sample pairs.

Table 6.69 WETMEC 19: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	2.8	0.7	5.0
Summer water table (cm)	3.0	–17.3	36.0
Rainfall (mm a^{-1})	1,627	702	1,831
PE (mm a^{-1})	531	454	614
Water pH	5.3	4.1	6.6
Soil pH	5.3	3.9	6.3
Conductivity (µS cm^{-1})	127	67	212
K_{corr} (µS cm^{-1})	122	66	211
HCO_3 (mg l^{-1})	29	2	87
$Fertility_{Phal}$ (mg)	8	4	19
Eh^{10} (mV)	236	54	405

See list of abbreviations in Appendix 1

Data from an axial flowpath of a feeder arm of Birk Bank Moss (Cumbria) (Table 6.68) show a slight but progressive increase in base richness downstream, associated with visibly increased flow and a pronounced change in species composition. However, it is not clear if the somewhat more base-rich conditions downstream are a consequence of increased water flow or if they reflect enrichment of the flow by other sources, perhaps by local groundwater outflow.

6.22.11 Ecological types

Overall, the distribution of WETMEC 19 samples across the pH and fertility classes (Table 6.70) is rather similar to that of WETMEC 18, but there are more sub-neutral examples than in WETMEC 18 and a corresponding reduction in oligotrophic examples. However, the biggest difference is in the smaller number of eutrophic samples than in WETMEC 18. A possible reason for this is that the sites which support eutrophic examples of WETMEC 18 have been modified in various ways, and either do not have flow tracks associated with

WETMEC 18, or support a vegetation type (such as wooded vegetation) which would have excluded them from this project.

Table 6.70 Percentage distribution of samples of WETMEC 19 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	4		
Sub-neutral	39	26	4
Base-poor	17	9	

Oligotrophic, base-poor

These samples are strongly dominated by *Sphagnum* and are mostly referable to *Sphagnum auriculatum* bog pool community (M1) or *Sphagnum cuspidatum/recurvum* bog pool community (M2), though a few have closest affinities with *Narthecium ossifragum–Sphagnum papillosum* mire (M21).

Oligotrophic, sub-neutral

This, the dominant category, includes a number of relatively base-rich samples. One quite base-rich example was referable to M1, but the majority were either *Carex lasiocarpa–Scorpidium* mire (M9-1) or *Hypericum elodes–Potamogeton polygonifolius* soakway (M29), though some were close to *Schoenus nigricans–Narthecium ossifragum* mire (M14).

Mesotrophic, base-poor

This includes some acidic samples of M2 and wet M21 from Knott End Moss where, as was the case for WETMEC 18, samples were more fertile than is often the case for these communities. The reason for this is not known, but all samples were at the lower end of the mesotrophic band.

Mesotrophic, sub-neutral

Samples in this category are mostly from the NW arm of Cors Gyfelog, parts of the northern margin of Cliburn Moss and the north-western lagg at Cors y Llyn. Samples from Cliburn are at the transition between the soakway and the main open patch of fen and appear to represent an enriched form of *Carex diandra–Calliergon* mire (M9-2), influenced by the adjoining water track. Parts of the lagg at Cors y Llyn also appear to be slightly enriched (Wheeler and Shaw, 2004b), apparently from field drainage. At Cors Gyfelog, samples in this category show evidence of, or are close to samples with, some silt enrichment. These samples are a problem syntaxonomically: highest MATCH coefficients are variously with M9 and M29, but the values are low.

Eutrophic, sub-neutral

This includes a sample from the northern margin of the NW arm of Cors Gyfelog. The others are from the soakway at Cliburn Moss, which appears to be enriched by agricultural drainage.

6.22.12 Natural status

Soakways and water tracks are natural drainage features of mires. They are particularly associated with sites with high rates of water inflow and with valleyhead sites where the conformation of the landscape helps to create flow tracks, though they also occur within some relatively flat peatlands. Examples of WETMEC 19 may represent some of the least disturbed surface features of mires, but in general many of the WETMEC 19 examples are not quite as treacherous as their WETMEC 15 counterparts, and may be more readily accessed periodically by grazing animals. Some examples of WETMEC 19 are developed in old peat workings, and these may produce broader examples of the WETMEC than would naturally be found. One example of WETMEC 19 occupies an occluded drain at Bowscale Moss.

6.22.13 Conservation value

Species diversity is generally rather low, but the WETMEC has a large species total with a number of nationally uncommon species and may support examples of SAC habitats (see Tables 3.3 and 6.4). May provide a relatively base-rich element within otherwise base-poor mires.

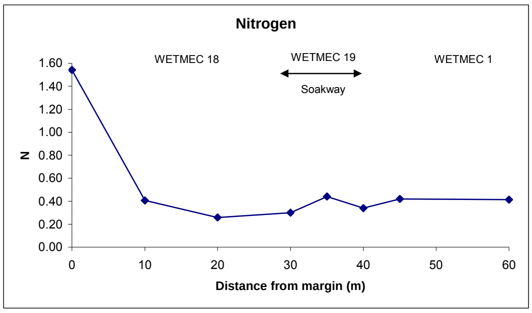
Ninety-two wetland plant species have been recorded from WETMEC 19. They include 13 nationally uncommon species: *Andromeda polifolia, Calliergon giganteum, Carex lasiocarpa, Carex limosa, Carex magellanica, Carex pauciflora, Drosera anglica, Drosera intermedia, Hammarbya paludosa, Osmunda regalis, Sphagnum contortum, Sphagnum subsecundum, Utricularia intermedia, Utricularia minor.* Three of these (*A. polifolia*, *C. magellanica* and *C. pauciflora*) were recorded from a single artificial soakway (an occluded drain) on Bowscale Moss. In addition, some samples support a variety of locally uncommon species, such as *Carex dioica, Eleocharis multicaulis, Hypericum elodes, Rhynchospora alba* and *Scorpidium scorpioides.*

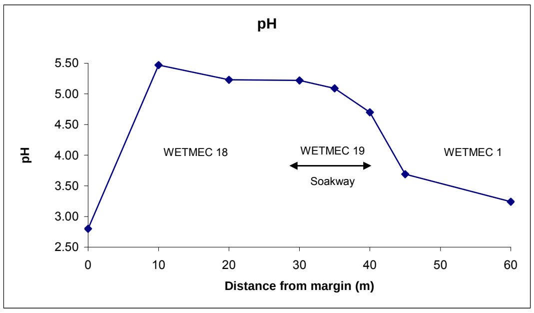
The percentage occurrence in NVC communities of samples of WETMEC 19 is: M9-1: (39%); M29: (17%); M1: (13%); M2: (8%); M10: (4%); M14: (4%); M15: (4%); M21: (4%); S10: (4%). The version of M9 that occurs is a soakway form of M9a. Unlike comparable flow tracks in Southern England, there are only a few records for M14. M14 and M9-1 occupy very similar habitats and appear to be geographical vicariants of the same basic community. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 19 is given in Table 6.3.

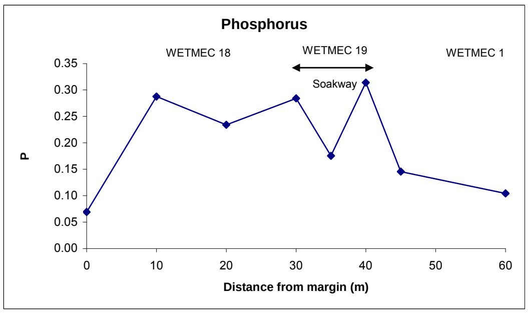
6.22.14 Vulnerability

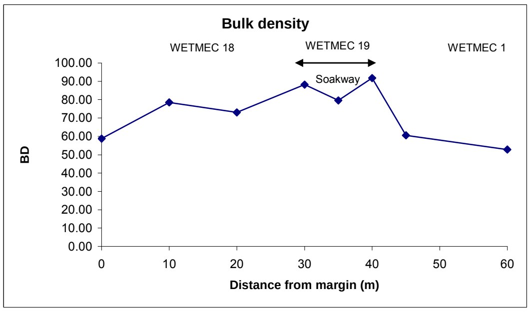
Many examples of WETMEC 19 are embedded within areas of rough pasture and are probably subject to few, if any, actual threats. However, all are potentially vulnerable to drainage, and in some sites (such as Cliburn Moss) indirect drainage may have lowered water tables. Nutrient enrichment is also a potential problem at some sites. There is evidence of localised enrichment of the NW lagg of Cors y Llyn and the NW arm of Cors Gyfelog, where it is associated with some silt deposition, but particular concern has been expressed over possible enrichment of Cliburn Moss (Box 6.37).

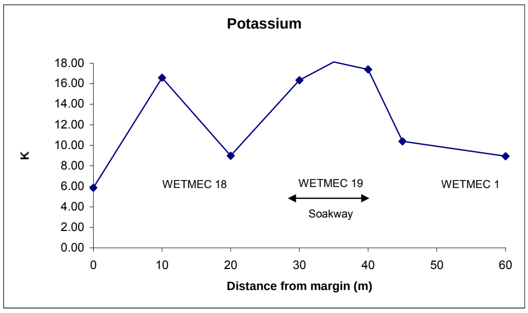
Box 6.37: Nutrient enrichment at Cliburn Moss, Cumbria

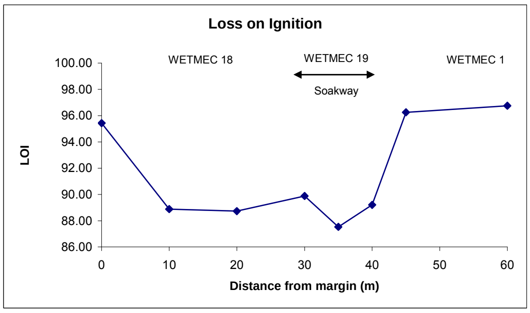


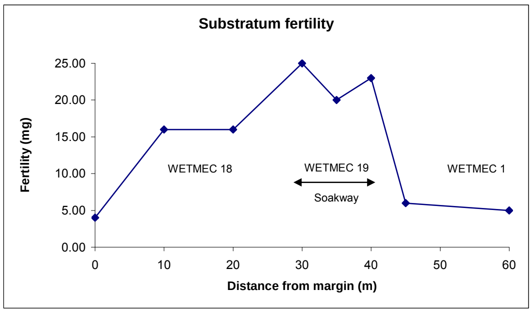












These figures show variation in some chemical characteristics of the peat along a transect across a flow track at Cliburn Moss. Values of elements are concentrations (mg/l peat) extracted from fresh samples of peat. Samples were collected in September 2004.

Cliburn Moss occupies a shallow basin, and includes an area of (mostly wooded) ombrogenous bog and fen. Surface water inflows into parts of this site, particularly around the eastern end and along the northern sides, where there are some tile drain inputs. Artificial pools dug along the north-eastern margin apparently intercept tile drains, but these overflow into the mire in wet conditions in winter and summer. In normal summers little, if any, overflow seems to occur (C. Auld, personal communication 2004), and the surface water inputs may have only limited function in maintaining high water tables. Nonetheless, they appear to be nutrient rich, and as this land drainage water is mostly funnelled into soakways which flow through the mire, they have considerable nuisance value as a source of nutrient enrichment, especially as enriched conditions spread beyond the limits of the flow tracks into adjoining WETMECs.

6.23 WETMEC 20: Percolation Basins

6.23.1 Outline

A topogenous WETMEC of basins and hollows with a significant supply of water from surface drainage. Some of this may originate from springs and seepages peripheral to the basin, but many examples receive stream inflow. The depressions containing WETMEC 20 are located over low-permeability substrata and may also contain low-permeability paludogenic deposits (especially gyttja). Schematic sections are provided in Figure 6.51.

6.23.2 Occurrence

Example sites: Cors Gyfelog , Cors Llyn Coethlyn , Dowrog Common, Emer Bog (Baddesley Common), Eycott Hill, Llyn y Fawnog, St. David's Airfield Heaths, Trefeiddan Moor

Outlier sites: Betley Mere, Cranberry Rough, Moorthwaite Moss

Only a small number of samples and sites were allocated to this cluster. It is almost certainly more widespread than is suggested by this, but its distributional bias towards high rainfall areas (Wales and Cumbria: see Figure 6.50) may well be typical and further investigation of basin mires in both of these areas would be desirable. Nonetheless, some examples do occur in low-rainfall regions (such as Emer Bog). Some of the most characteristic examples of this WETMEC occur in the vicinity of St David's. Loynton Moss may also naturally belong here, but did not cluster into WETMEC 20. This basin once had significant surface water inflows, and would have fitted WETMEC 20 well, but the severing of its main surface inflow and current large dependency on precipitation has resulted in this site being classified elsewhere (WETMEC 3).

The hydroseral fringe of one of the West Midlands meres (Betley Mere) was clustered into this unit as an outlier. It is possible that other examples of the West Midland's mere fringes also belong here, but they were not sampled as part of this project.

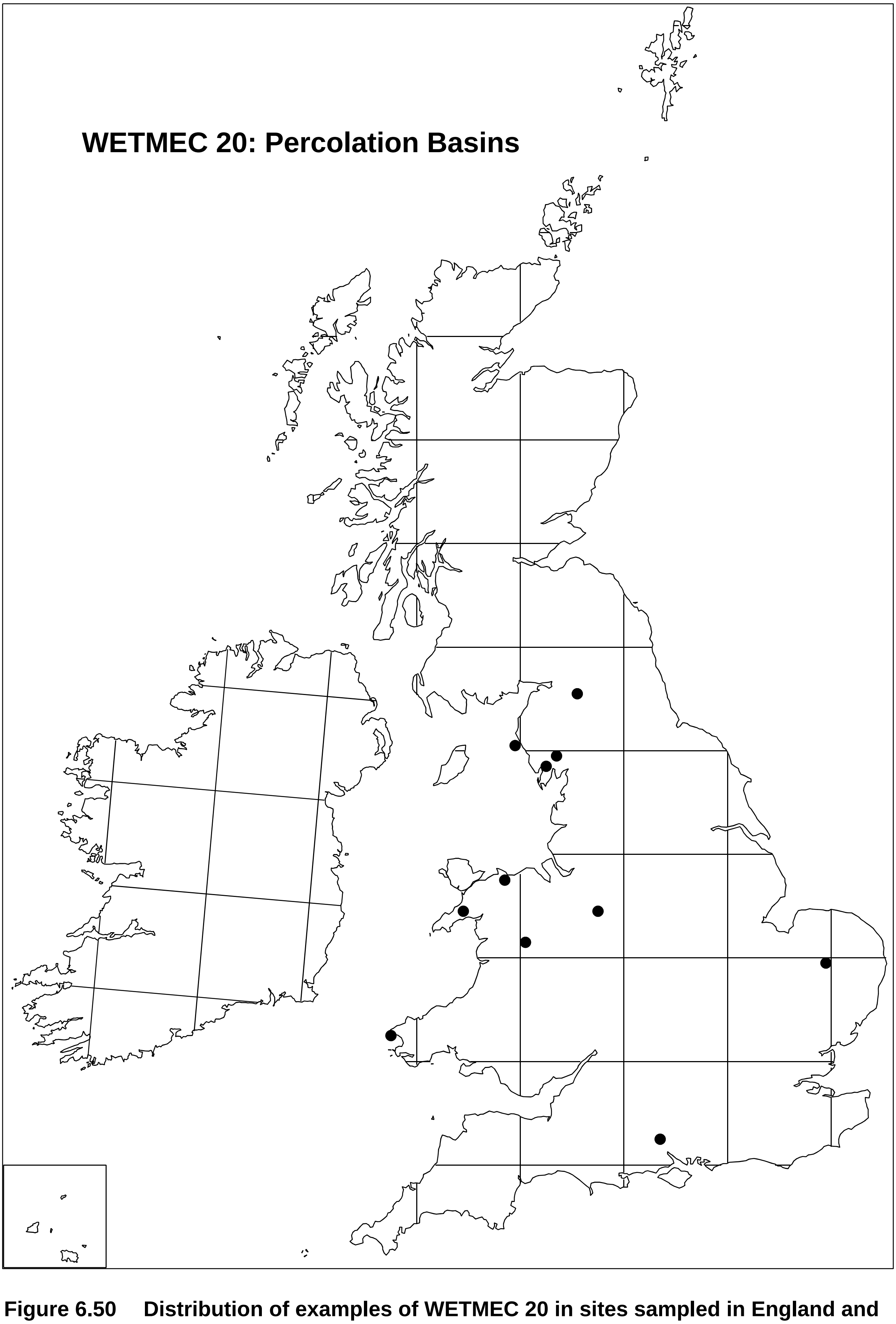


Figure 6.50 Distribution of examples of WETMEC 20 in sites sampled in England and Wales

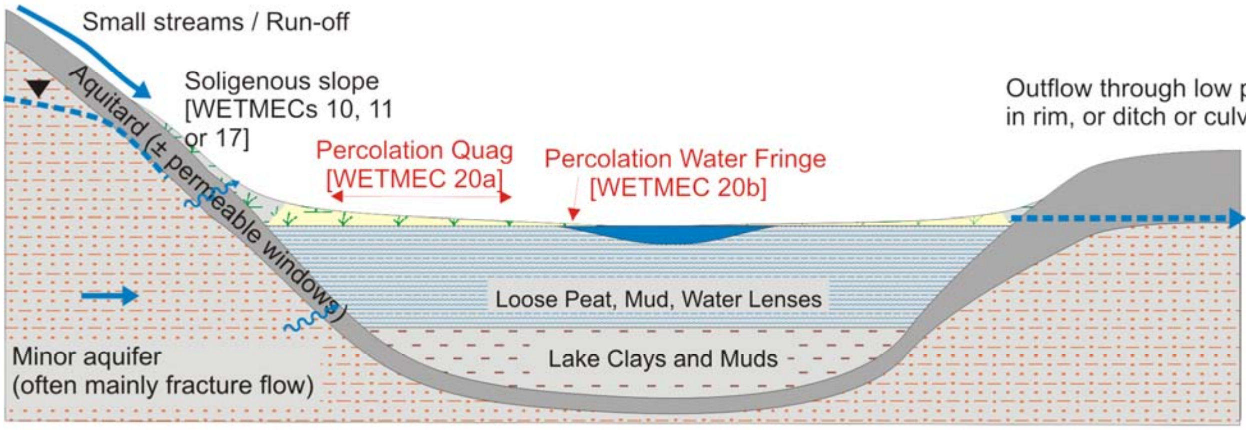
Summary Characteristics

Situation	Basins, valleyhead basins and troughs.
Size	Tiny examples in small basins, through narrow hydroseral fringes to modest areas of fen (10 ha).
Location	Mostly sampled from NW England and Wales, but may be more widespread.
Surface relief	Even (appears more or less flat, but gently slopes to river or outfall).
Hydrotopography	Rheo-topogenous.
Water: ***supply***	Surface water, possibly some groundwater.
regime	Summer water table usually at or near the surface.
distribution	Mainly surface/near-surface flow.
superficial	May contain shallow pools or adjoin a small lake or watercourse.
Substratum	Unconsolidated muds or peat (sometimes over gyttja). Basal material usually a stiff clay or silt.
peat depth	Mostly fairly shallow (< 2 m) but sometimes quite deep (2–5 m).
peat humification	Upper layer is buoyant or loose and fresh, often a hydroseral infill. Underlying peat, if present, varies in humification. Sometimes little material between the surface layer and basal clays.
peat composition	Variable. Loose upper layers typically herbaceous–moss peat (hypnoid mosses or *Sphagnum*), but may also be monocot or brushwood peat.
permeability	Upper layers mostly have high-permeability characteristics, over less permeable middle/lower layers. Basal substratum of low permeability.
Ecological types	Range from oligotrophic, sub-neutral/base-poor to eutrophic/hypertrophic, sub-neutral depending mainly on substratum characteristics and enrichment of surface water. Most examples are base-rich/sub-neutral and eutrophic/mesotrophic.
Associated WETMECs	May adjoin Groundwater-Flushed Slopes (WETMEC 17). Some examples are embedded within Percolation Troughs (WETMEC 18) and may be fed, or crossed, by a soakway (WETMEC 19).
Natural status	Some are more or less natural hydroseral units, but many seem to be associated with turbaries or former clay diggings.
Use	Conservation. Light grazing. Some are unmanaged. Some occupy former turbaries or clay workings.
Conservation value	Important mainly for oligotrophic/mesotrophic semi-floating vegetation (SAC habitat “transition mire …”).
Vulnerability	Main threat to some examples has been direct drainage. Some are much enriched by surface water inflows (dissolved nutrients and silt deposition). Some are subject to dereliction and hydroseral succession. The latter can be associated with consolidation or acidification of buoyant surfaces.

WETMEC 20: PERCOLATION BASINS

WETMEC 20: Percolation Basin
(*e.g.* Cors Llyn y Coethlyn)

- basin surface fed by significant surface drainage (streams and run-off)
- basin separated from underlying (usually minor) aquifer by (Till *etc.*) aquitard
- may be some groundwater outflow through windows in aquitard, giving rise to 'wet' conditions on the basin slopes (mire, wet heath, wet grassland *etc.*)
- wetland infill probably also acts as a local aquitard, constraining significant upflow directly into the basin



WETMEC 20: Percolation Basin
(*e.g.* Dowrog Common, Trefeiddan Moor)

- basin surface fed by some surface drainage (streams and run-off)
- basin separated from underlying (usually minor) aquifer by (Till *etc.*) aquitard
- some groundwater outflow originates around the lip of the aquitard and gives rise to 'wet' conditions on the basin slopes (mire, wet heath, wet grassland *etc.*)

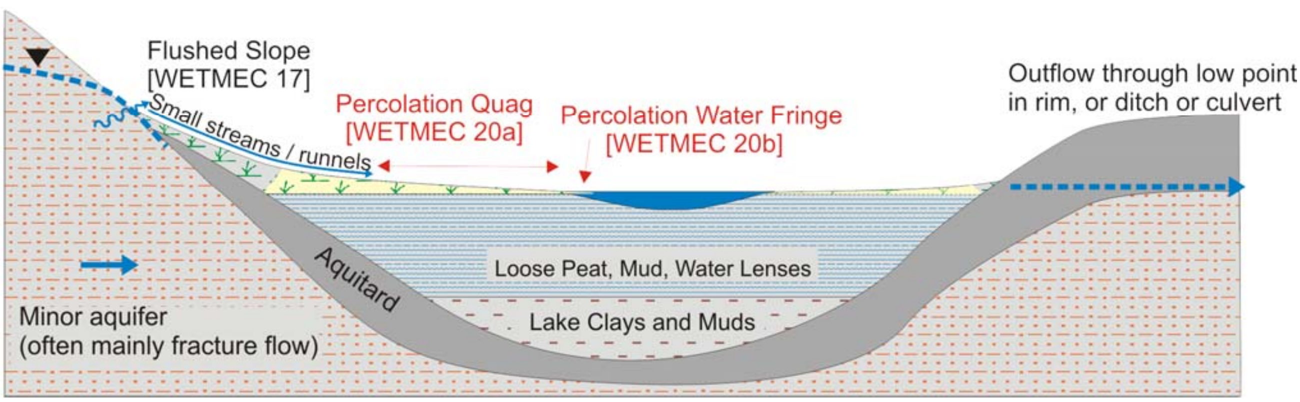


Figure 6.51 Schematic sections of Percolation Basins (WETMEC 20)

6.23.3 Concept and description

CLUSTERS: 35, 36

WETMEC 20 includes a small number of samples from basins and hollows that are lined with low-permeability deposits and which receive a significant land drainage input (streams and run-off). Most recorded examples were located in quite high rainfall regions (Cumbria and Wales) but some samples clustered here were from the South and East of England (such as Emer Bog, Hampshire). In some examples, there appears to be little water outflow in dry conditions.

Most samples allocated to this WETMEC 20 show strong similarities with the Seepage Percolation Basins of WETMEC 13, and differ from these mainly by having few, if any, features associated with groundwater inflows or by significant surface water (stream) inflows. This does not imply that there is no contribution from groundwater, but where this occurs it seems to be mainly as surface or near-surface flow over a peripheral aquitard, mostly as streams or associated with examples of WETMEC 17 (Groundwater-Flushed Slopes).

The topogenous infill of the basins clustered into WETMEC 20 are often similar to those of WETMEC 13, with a loose, quaking or buoyant peat surface over unconsolidated material, but the depth of the unconsolidated deposit is often less than in many examples of WETMEC 13. Examples appear to function in much the same way as Seepage Percolation Basins, but with a different water source. The buoyant surfaces seem likely to have fairly high permeability and facilitate the dispersion of surface water inflows across the WETMEC. Streams flowing into WETMEC 20 basins sometimes disperse into soakways within mires on the peripheral slopes, rather than entering the basin bottom directly. In a few cases, water flow into WETMEC 20 remains partly focussed within a soakway (WETMEC 19) across some or all of the basin, so that it effectively splits the WETMEC 20 surface. In some locations the buoyant surfaces are prone to acidification and *Sphagnum* colonisation.

In many sites WETMEC 20 forms the main topogenous component of the basin in which it occurs, but some samples clustered here are minor constituents associated with other WETMECs. For example, at the mainly ombrogenous Moorthwaite Moss, a eutrophic depression (an old peat working) fed by a ditch from an adjoining field has been clustered into WETMEC 20. Likewise, the sample from Cranberry Rough represents a minor part of the site (a small sump alongside an artificial pool in the north-east corner of the fen).

Most basins associated with WETMEC 20 are fairly small and, if they contain a body of open water at all, this is often quite small proportionate to the mire basin as a whole. An exception to this generalisation is provided by the hydroseral fringe of Betley Mere, which has been clustered into WETMEC 20. Betley Mere is a relatively small, fairly shallow lake, but it is large in proportion to its hydroseral fringe and forms an outlier to cluster 36, probably because it is atypical in the context of this survey. It is, however, similar to many other West Midland meres and it seems likely that the marginal fens found around some of these, where similar circumstances prevail, may also be referable to WETMEC 20[1].

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[1] Most of the fen fringes of the West Midland mere have not been included within this project, mainly because their hydroseral margins are very narrow and fragmented, or composed of swamp and fen woodland rather than herbaceous fen.

Affinities and recognition

WETMEC 20 is sometimes embedded within WETMEC 18 and fed by WETMEC 19. It can be separated from these by occupying a topogenous sump rather than being sloping and with clearly directional water flow. However, some locations (such as the NW arm of Cors Gyfelog) are transitional between the two types.

Perhaps the main difficulty in recognising WETMEC 20 is in distinguishing it from WETMEC 13. The latter WETMEC is sourced to a significant degree by groundwater, whereas groundwater supply is thought not to be as important to examples of WETMEC 20. However, the actual role of groundwater in WETMEC 20 is difficult to assess, as it is not always certain that examples are underlain by a continuous aquitard. Moreover, many examples are likely to be fed by fracture flow from a minor aquifer, if they receive groundwater at all. WETMEC 20 is perhaps best assessed with reference to the presence of surface water-related features, especially inflow streams, but these are not present in all cases. Examples of the WETMEC tend be associated with low-permeability rocks (bedrock or drift) and soils, and there is often likely to be significant run-off and land drainage into these systems, especially in high rainfall regions. However, some examples of WETMEC 20 appear to be fed primarily by rainfall with only a small contribution from local telluric sources; in these cases, the relatively high base richness found in some examples may be a product of the proximity of relatively base-rich mineral material underlying the mire (the overlying vegetation mats are sometimes thin). As in some instances this could be because the sites are old clay workings, it is quite possible that the current hydrochemical environment is not in a long-term stable relationship with the dominant water supply mechanisms.

Because of the uncertainties surrounding groundwater supply, resolving the precise status of individual sites may require detailed hydrogeological studies. This is reflected to some extent in the cluster analysis, where some samples are transitional between the clusters composing WETMECs 13 and 20. For example, Silver Tarn (allocated to WETMEC 13) has some features which are typical of WETMEC 20, such as a quite well-developed inflow stream, whereas Llyn y Fawnog (WETMEC 20) has some features suggestive of WETMEC 13 (see Box 6.38). The clustering solution seems appropriate given the available data, but the latter are frequently sparse.

In terms of water exchange processes, WETMEC 20 also has some clear affinities with WETMEC 6 (Surface Water Percolation Floodplains). The essential difference between the samples clustered into these two units is that those in WETMEC 20 are located in basins, normally at or near the head of drainage systems, whereas those in WETMEC 6 are in floodplains and are clearly fed by watercourses. Thus, samples fringing Betley Mere, which is located in a basin near the head of a small valley, have been clustered into WETMEC 20, whereas those from North Fen, Esthwaite, near where the Black Beck debouches into the lake, have been clustered into WETMEC 6. Examples of WETMEC 20 are also more often fed directly by surface inflows from adjoining upland than those in floodplain contexts. Nonetheless, it is clear that the two types intergrade, and the specification of their differences, particularly between different types of open-water transition samples, is not helped by the small number of samples available in this study.

6.23.4 Origins and development

Very little is known about the stratigraphy and development of most WETMEC 20 sites, but there is evidence for considerable past disturbance in many examples. Many basins have apparently been modified. The Pembrokeshire basins are particularly interesting in this respect, as some of them appear to have been dug for clay (Box 6.38). The basin at Emer Bog appears to have been open water in the sixteenth century, possibly as a consequence of peat removal. A number of examples are known to occupy abandoned turbaries, as at Llyn y

Fawnog (Box 6.38). At Moorthwaite Moss, the small (atypical) example of WETMEC 20 occupies an old peat working.

It is not known to what extent peat digging has occurred at more remote examples of WETMEC 20, such as Cors Llyn Coethlyn and the Eycott Hill mires. At the last site, examples of WETMEC 20 occur in wet sumps which appear to represent former lake basins, embedded within other WETMECs. In other Cumbrian valleyhead troughs and basins, where there is little evidence for present-day WETMEC 20, stratigraphical data (such as Stable Harvey Moss: Hodgkinson, 2000) point to the occurrence of terrestrialised lake surfaces, which may well once have supported WETMEC 20 as a seral phase in the development of the present-day mires. In these instances, peat accumulation has continued beyond the original limits of the lake basin, and above the former lake water level, so that the former open water and associated examples of WETMEC 20 in the topogenous basins have been replaced by gently sloping valleyhead troughs of (mostly) WETMEC 18. It seems likely that the present-day WETMEC 20 sumps in sites such as Eycott Hill Mires may also eventually develop into WETMEC 18 surfaces. Indeed, the development of soakway-like structures cutting across some WETMEC 20 surfaces, which can be observed at certain sites, may well represent an early phase in such an ontogenic process.

Box 6.38: Development of WETMEC 20 in artificial contexts in Wales

Basins around St David's (Pembrokeshire)

A number of small, shallow basins occur in the vicinity of St David's and support some good examples of WETMEC 29. They tend to contain a fairly shallow infill of loose fresh peat, in some cases more a proto-peat of loose rhizomes and so on, over a stiff base of blue clay (Irish Sea Till). Some of these basins are known to have been dug for the underlying clay, a process which has continued until fairly recently in some locations. For example, at Pwll Trefeiddan (Trefeiddan Moor) small, deep clay pits were dug until at least 1939 (D. Rees *fide* M. Sutton, 2004), whilst at Dowrog Common clay digging was underway at the beginning of the nineteenth century, apparently on a large scale. Fenton (1811) refers to "*the famous moor called Ddyfrog … most of which is under water and appears like a considerable lake for seven or eight months of the year, and is seldom entirely dry",* and which provides *"an abundant supply of … clay, which when mixed with culm, the chief firing of the country, cements and prepares it for use*". S. Evans (*in lit*., 1994) refers to "regular ridges in straight lines on its floor" and Salmon (1993) indicates that clay was dug from the southern end of the Dowrog Pool area, perhaps, until the 1930s. This not only indicates that clay was dug from these wetland sites, but also raises the possibility that some of the basins now supporting WETMEC 20 were largely created by clay extraction.

The natural importance of stream inflow to these sites can be uncertain, and in some cases may have become modified. At Dowrog Common, it appears that there were once structures in place to enable the circulation of water between a leat, which once formed a mill stream from the river Alun to an old mill at Rhodiad-y-Brenin, and Dowrog Pool. However, now the Pool appears to have neither surface water inflow nor outflow, and may be fed mainly by rainfall and dispersed drainage from rainfall-generated run-off from the adjoining slopes. Water is presumably lost from the Pool by lateral groundwater flow into the surrounding peat, towards the River Alun, as well as by evapotranspiration.

Llyn y Fawnog (Conwy)

Llyn y Fawnog is a smallish (around eight ha) mire which occupies an oval basin in the hills south of Colwyn Bay. It appears to have been much modified, though little is known about this. The name *Fawnog* is suggestive of past turbary and the first edition Ordnance Survey (1879) maps the entire site as open water; the gradual hydroseral replacement of this by swamp to the present-day mire is evident on subsequent map editions. A complication at this site is that at some stage a narrow, artificial ridge some 1.5 m high was built around the outfall end of the site. This is now breached by the outflow stream, but its ends are continuous with the basin slopes, and it appears to have been constructed to form a dam, presumably to maintain higher water levels in the basin. Damming could perhaps explain the open water of the nineteenth century maps, rather than peat excavation. However, peat cores taken at the site show, in most locations, a buoyant vegetation mat over loose muds and thin lake sediments that are underlain by a solid red-brown peat at about 80 cm depth, a stratigraphy which is compatible with past peat extraction. It is possible that peat was once dug extensively at this site and that the site was subsequently flooded above the original water level by the dam.

The water supply to Llyn y Fawnog is surrounded by uncertainties. This site is located over the Elwy Formation, which is considered to act as a minor fractured aquifer. On many of the slopes surrounding the mire, and within much of the mire itself, the aquifer is thought to be separated from the mire system by low-permeability Till. However, near the southern margin of the basin at least, hand cores suggest that the peat is less than 1.5 m thick, and rests directly on the Elwy Formation, perhaps allowing some interaction between the mire and the aquifer. This site has no obvious strong surface water inflows and is in many respects transitional between WETMEC 20 and 13.

Box 6.39: Betley Mere (Cheshire)

Betley Mere differs from other WETMEC 20 sites in retaining a large area of open water. WETMEC 20 accommodates the marginal, hydroseral fringe of this. The mere, which occupies an apparent subsidence hollow in salt-bearing beds, is located within a large peat-filled trough, but most of the peatland surrounding the mere has been drained to a greater or lesser extent. Deep peat occurs both north-west and south of the mere. At the north-western end, there are deep (six metre) peat deposits overlying lake muds and shell marl (Greatrex, 1972; Leah *et al.*, 1998)**,** indicating that the present mere is the remnant of a once more extensive lake. Greatrex (1972) also found bands of *Sphagnum* peat at various levels in the profiles, suggesting short-term development of more acidic conditions; in one core there was a surface cap of *Eriophorum* and *Sphagnum* peat, pointing to a possible former ombrogenous surface. No stratigraphical data have been located for the peat deposit immediately south of the mere, but its name (Cracow Moss) is suggestive of a former *Sphagnum* surface. It seems likely that before drainage (and possibly removal of surface peats by shallow turbary), Betley Mere was a calcareous lake embedded in a complex of undrained, base-rich fen flanked by more acidic mires, perhaps small raised bogs.

Betley Mere differs from others clustered into WETMEC 20 (of which it is an outlier site) in that it is surrounded by, and possibly embedded within, glacial sands and gravel, and is less obviously located over an aquitard. However, the lake muds and shell marls within the lake deposit may constrain groundwater exchange, and other paludogenic constraints on connectivity with mineral aquifers, as discussed for WETMECs 2 and 3, may apply equally here. Labadz and Butcher (2005) consider that there is "*no direct evidence of relationship between Betley Mere and its underlying solid geology, but the weight of evidence is that the glacial sands are probably in hydraulic connectivity with the mere to some degree*." However, even if this is correct, the mere fringes merit their clustering within WETMEC 20 (rather than 13) by the importance of surface water inflows to the lake. Moss *et al.* (1992) gauged flows in and out of Betley Mere and found that the inflows were some 57 times greater than measured outflows; they concluded that much of the water must be lost to groundwater seepage (or via undetected outflows). Thus, water levels in the mere appear to be maintained by a combination of direct precipitation (around 700 mm a^{-1}), surface drainage from the surrounding land and probable groundwater inputs, but surface drainage seems likely to be by far the largest of these (there is a significant catchment area for the inflowing stream at the north east of the mere).

Betley Mere, and its associated hydroseral fringes of WETMEC 20, appears to be largely a natural lake, but its surroundings have been considerably modified (Box 6.39). Wetland complexes including a calcareous lake surrounded by fen and acid bogs no longer really occur in the West Midlands meres, though Hatchmere (Cheshire) comes close. Here a calcareous lake is flanked by quite base-rich hydroseral fen, but away from the open water, and particularly on the western and north-western sides, acidic surface conditions prevail (Lind, 1949), though it is not clear to what extent these are (or once were) ombrogenous.

Sweat Mere was not sampled in this project, but merits honorary mention because it was considered to provide a "most complete hydrosere" by Tansley (1939), ranging from open water to marginal oakwood. In fact, the more marginal zones appear to be rooted on solid peat rather than forming an end-phase of the current autogenic hydrosere around the residual pool (Sinker, 1962), and the precise ontogenic status of this basin is not really known.

6.23.5 Situation and surface relief

Seventy-eight per cent of sites were recorded from basins, with the remainder from valleyhead troughs. Surfaces are generally even (appear more or less flat, but gently slope to river or outfall) (Table 6.71).

6.23.6 Substratum

The Pembrokeshire basins are generally shallow, but others are much deeper with quite thick accumulations of paludogenic deposits. The surface layer of the substratum is consistently loose and unconsolidated, with the highest mean surface layer permeability of all WETMECs (Table 6.71). The middle layers are also fairly loose and the mean middle layer permeability was second only to that of WETMEC 15 (though a number of examples, such as some samples from the St David's Head area, did not really have a middle layer and the surface layer was effectively superimposed upon the basal substratum). The basal deposits were consistently composed of clays and silts, sometimes with a covering of lake muds (gyttja). These samples thus represent the combination of a loose, often buoyant, surface over a low-permeability base.

Table 6.71 Mean value and percentage distribution of ranked categories of substratum permeability and slope in WETMEC 20

	Mean	1	2	3	4	5	6	7
Surface layer permeability	6.3				9	13	22	57
Lower layer permeability	4.6			23	23	32	18	5
Basal substratum permeability	1.3	70	30					
Slope	1	96	4				X	X

Surface layer, lower layer and basal substratum categories represent ranked estimates of permeability based upon gross composition [1: low – 7: high]. Slope categories are estimates of steepness of slope [1: flat – 5: steep]

6.23.7 Water supply

Basins in WETMEC 20 usually have some clear surface water inflows and outflows, though these are not always obvious and in some cases (such as Dowrog Common) former surface water flows may have become occluded (Box 6.38). At Eycott Hill Mires, the surface inflow into WETMEC 20 is largely endotelmic, but other sites are fed by stream inflows originating outwith the mire (such as Cors Llyn Coethlyn and Waun Llandruidion). In some cases (such as Cors Llyn Coethlyn), drains on the valley bottom (some now occluded) interrupt the natural drainage pattern.

The role of groundwater in WETMEC 20 samples is generally poorly understood. Most samples are located over low-permeability substrata which may prevent much groundwater upflow, but in a number of cases surface and near-surface flow into the basins occurs, sourced in part by peripheral seepages and springs (such as Cors Llyn Coethlyn). At Dowrog Common, some springs occur well above the Pool at the edge of the confining Till, but they seem to be rather weak and unlikely to make much contribution to the basin itself. A similar comment could be made for a soakway feeding into Trefeiddan Moor: the soakway may be fed either by surface run-off or by seepage from a Pebidian Volcanic Complex minor aquifer, emerging around the margin of the Till.

The likelihood of groundwater upflow through the basal clays lining WETMEC 20 basins is not really known, partly because there is little information about the variability, thickness and lateral persistence of potentially confining deposits. At Trefeiddan Moor, the pre-Cambrian aquifer appears to be confined by a thick clay layer beneath the mire and seems to have a piezometric head well above the water level in the wetland; however, the possibility of windows of higher permeability cannot be discounted, especially if past clay digging has left parts of the Till rather thin. This could also be the case at Dowrog Common. Likewise at Emer Bog, the basin receives some seasonal stream inflow, but may also be fed by weak groundwater seepage from the Wittering Formation (although this is often considered an aquitard, sandy facies occur in the vicinity of Emer Bog). Llyn y Fawnog provides a similar set of uncertainties (Box 6.38).

The outlier site of Betley Mere differs from most of the others clustered into WETMEC 20 in that it is surrounded by, and possibly embedded within, glacial sands and gravel, and may receive some groundwater from these. However, the water balance of the lake appears to be dominated by precipitation and surface inflows (Moss et al., 1992) (Box 6.39). The importance of surface run-off and drainage to the WETMEC 20 basins means that they may experience a wider amplitude of seasonal water level change than their seepage fed counterparts in WETMEC 13. However, few data are available relating to this, and in any case the buoyant surfaces found in many examples may help to buffer the ecological impact of water level variation.

More detailed hydrogeological investigations may be needed to clarify the status of many WETMEC 20 sites with regard to telluric water supply. In some sites telluric inflows from any source may be modest, and the presence of wet conditions may be due primarily to precipitation and the retention of water within the topogenous basins.

6.23.8 WETMEC sub-types

Two WETMEC sub-types have been identified, corresponding to the multivariate clusters 35 and 36. No other clear subdivisions are evident at the 72-cluster stage, but in view of the apparent variability of water sources (presence or absence of stream inflows, peripheral groundwater inflows and possible upflows), it seems likely that further sub-sets of this variable WETMEC may exist. However, available data are too few and uncertain for these to be identified at present.

WETMEC 20a: Percolation Quag

CLUSTER: 35

Examples at: Cors Gyfelog, Cors Llyn Coethlyn, Dowrog Common, Emer Bog (Baddesley Common), Eycott Hill, Hollas Moss, Llyn y Fawnog, St. David's Airfield Heaths, Trefeiddan Moor

This represents the most widespread type of Percolation Basin sampled. In almost all cases the surface is loose and buoyant. It may contain small pools, but it is not specifically associated with the margins of larger open water bodies. However, some of these surfaces (such as Llyn y Fawnog) have almost certainly developed fairly recently by terrestrialisation of open water, and in some instances (such as Maendewi Pool, Dowrog Common) WETMEC 20a is separated from a residual pool by an (often narrow) band of WETMEC 20b. It is usually not possible to specify a clear dividing line between WETMECs 20a and 20b in sites where they occur together, but the surface of WETMEC 20a is generally more consolidated and less swampy than that of 20b. Examples of WETMEC 20a are also more likely to be fed directly by run-off from adjoining slopes, whereas those of WETMEC 20b are kept wet primarily by the water body around or in which they occur. This may be fed from various sources in addition to run-off from nearby slopes.

WETMEC 20b: Percolation Water Fringe

CLUSTER: 36

Examples at: Dowrog Common, Cors Llyn Coethlyn
Outlier at: Betley Mere

WETMEC 20b is rather similar to 20a: in essence, samples clustered into this unit effectively represent stands like 20a but which are bordered on one or more sides by a body of open water (which is often being colonised by WETMEC 20b vegetation). The small number of samples allocated to this unit is probably a reflection of the small number of appropriate stands that were sampled. This may have been because: (a) stands were too narrow and heterogeneous to form appropriate sampling units; (b) they were too swampy and outwith the wetland scope of this study; or (c) sites with this type of surface were not selected for inclusion in this project. It is likely that the narrow bands of hydroseral vegetation which flank several of the West Midlands meres may be referable to this unit, but with the exception of the margin of Betley Mere (Staffs), the meres were not included in this project.

Another problem with WETMEC 20b is that, particularly in small and shallow basins, it may just form a transient precursor to WETMEC 20a. Thus, it may have once occurred at sites such as Llyn y Fawnog, to be replaced largely by WETMEC 20a concomitant with the diminution of open water.

6.23.9 Ecological characteristics

The ecological characteristics of WETMEC 20 are broadly similar to those of WETMEC 13, but on average the surface was slightly wetter. Also, the mean and maximum pH values were lower than WETMEC 13, reflecting the general absence of WETMEC 20 from locations with Chalk or Limestone substrata (the sample from Cranberry Rough is separated from the Chalk aquifer by clay-rich Drift). Nonetheless, some WETMEC 20 samples were quite base-rich, especially those from the basins in the vicinity of St David's; in these cases, this is probably due to the influence of the 'Irish Sea Drift' close to the surface of the mires (the maximum bicarbonate concentration was recorded from Dowrog Pool).

Table 6.72 WETMEC 20: values of selected ecohydrological variables

Variable	Mean	Minimum	Maximum
PAL depth (m)	2.1	0.2	5
Summer water table (cm)	1.9	–22	31
Rainfall (mm a^{-1})	983	622	1,679
PE (mm a^{-1})	583	515	625
Water pH	5.6	3.9	6.8
Soil pH	5.6	3.9	7.1
Conductivity (µS cm^{-1})	352	94	916
K_{corr} (µS cm^{-1})	348	82	916
HCO_3 (mg l^{-1})	89	0	366
$Fertility_{Phal}$ (mg)	15	4	39
Eh^{10} (mV)	239	64	446

See list of abbreviations in Appendix 1

6.23.10 Ecological types

The occurrence of WETMEC 20 samples in relation to base-richness and fertility categories is summarised in Table 6.73.

Table 6.73 Percentage distribution of samples of WETMEC 20 in pH and fertility classes

	Oligotrophic	Mesotrophic	Eutrophic
Base-rich	4	22	9
Sub-neutral	13	22	9
Base-poor		18	

Oligotrophic, sub-neutral/base rich

These include low productivity samples from the mires around St David's, but relate to small subsidiary basins which are not part of the main systems (such as a small, isolated depression with M9b at Waun Llandruidion). Samples of *Carex rostrata* swamp (S9) and *Hypericum elodes–Potamogeton polygonifolius* soakway (M29) from Llyn y Fawnog are also included here.

Mesotrophic, base-poor

These include acidic samples at sites without inflow streams, or in locations remote from these, at Cors Llyn Coethlyn (*Carex rostrata–Sphagnum recurvum* mire (M4), *Carex rostrata–Sphagnum squarrosum* mire (M5)), Llyn y Fawnog (*Sphagnum cuspidatum/recurvum* bog pool community (M2) and M5), and Cors Gyfelog (M5 in an isolated peat trench in the Gyfelog Farm section).

Mesotrophic, sub-neutral/base-rich

These samples are all from mire basins near St David's. Much of their vegetation hovers tantalisingly between M9-2 and *Carex rostrata–Potentilla palustris* tall herb fen (S27).

Eutrophic, base-poor

Only one sample is included here, the field run-off enriched peat trench at Moorthwaite Moss. This supports a degraded form of M21b and, although in many ways anomalous, provides an interesting illustration of the effect of nutrient enrichment upon an ombrogenous peat pit (see site account for Moorthwaite Moss in Appendix 3).

Eutrophic/hypertrophic, sub-neutral/base-rich

Within this category are grouped some surprisingly enriched examples of WETMEC 20, from disparate locations. One is from Waun Llechell (St David's), from an '*Equisetum fluviatile* swamp with *Carex diandra*'. This is being colonised by *Typha latifolia* but still (just) retains its identity as a degraded form of M9-2. The cause of the enrichment is not certain: the site adjoins an abandoned rubbish tip (Mynydd Diwyn) situated along the northern side of Waun Llechell and receives land drainage inflow by a small stream (which passes close to the tip before dissipating into the mire). Little is known about the tip but, although it may largely contain fairly inert materials (it is thought to have been a former bomb disposal site), it may enrich the stream feeding into Llechell.

Two samples from Emer Bog are also eutrophic/hypertrophic, one from the main area of S27, the other, perhaps more surprisingly, from a patch of M5. In the latter case, the *Sphagnum* peat is thin and the collected peat and water samples may as much reflect conditions in the underlying monocot deposit as in the superficial *Sphagnum* mat itself. The final example in this category comes from a patch of S27 adjoining an artificial pond at Cranberry Rough, possibly enriched by the spoil raised in the excavation of this. Despite being eutrophic, the nationally rare grass *Calamagrostis stricta* has been recorded from this location.

The reedbeds (S4) sampled around the fringes of Betley Mere were eutrophic. Labadz and Butcher (2005) report that "*moderately high ammonium and soluble and total phosphorus concentrations have been recorded in the inflow streams suggesting pollution from some source, probably from farms*". The sewage treatment works on the eastern side of the mere (Betley WWTW) is thought not to discharge into the mere.

6.23.11 Natural status

The natural condition of many WETMEC 20 surfaces is difficult to assess, as they appear to be a relatively recent product of peat or clay extraction. Others, such as Cors Llyn Coethlyn, may not have been thus disturbed, but have at least been partly drained. This site retains its eponymous (small) lake, and the WETMEC 20 surfaces around it essentially represent stages in the terrestrialisation of this, and include both fen woodland and open fen (the latter probably mostly maintained by grazing). The ultimate natural state that may be expected in this context could perhaps be a small raised bog. Alternatively, progressive peat accumulation within the mire as a whole could lead to the expansion and coalescence of material from the arms of the mire across the lake, to form a complex of *Sphagnum*-rich surfaces and soakways (WETMECs 18 and 19) sloping down the valley, thereby replacing the former lake basin with a valleyhead mire. This process appears already to have occurred at sites such as Stable Harvey Moss (Cumbria), where WETMECs 18 and 19 are suspected to have replaced former examples of WETMEC 20, and may well be ongoing in WETMEC 20 sumps at sites such as Eycott Hill.

Assessment of the natural status of the Pembrokeshire basins near St David's is speculative, as the magnitude of clay extraction associated with them is not really known, nor is the character of the vegetation before extraction. It is not even certain that sites such as Dowrog Pool supported proper mire vegetation before clay excavation, or it may have been a shallow system of wet heath and valley mire rather than a topogenous hollow (Box 6.38).

6.23.12 Conservation value

WETMEC 20 is important mainly for oligotrophic/mesotrophic semi floating vegetation (SAC habitat "transition mire and quaking bog", see Tables 3.3 and 6.4). A total of 95 wetland plant species have been recorded, reflecting the quite wide pH range over which this WETMEC occurs. Thirteen nationally uncommon taxa are included in this total: *Calamagrostis canescens, Calamagrostis stricta, Calliergon giganteum, Carex appropinquata, Carex diandra, Carex lasiocarpa, Carex viridula ssp viridula, Cicuta virosa, Dactylorhiza praetermissa, Hypericum undulatum, Peucedanum palustre, Stellaria palustris, Utricularia minor.* However, several of these species were found only at the outlier site of Cranberry Rough (Norfolk) and are essentially atypical of the unit. Other species that are locally uncommon include *Eleocharis multicaulis, Eleogiton fluitans* and *Hypericum elodes.*

The percentage occurrence in NVC communities of samples of WETMEC 20 is: S27: (39%); M5: (17%); M9-2: (17%); M4: (8%); M2: (4%); M21: (4%); M22: (4%); M29: (4%); S4: (40%); S24: (4%). This list has some similarities to that of WETMEC 13 (Seepage Percolation Basins) but differs in supporting a greater proportion of acidic mire communities and a smaller proportion of M9-2. This is likely to be because: (a) the basins receive less groundwater than WETMEC 13; (b) the associated bedrocks are generally less calcareous than those around many examples of WETMEC 13; and (c) examples of WETMEC 20 generally occur in higher rainfall regions than many examples of WETMEC 13. Percentage occurrence of the main herbaceous wetland NVC community types in WETMEC 20 is given in Table 6.3.

6.23.13 Vulnerability

As with WETMEC 13, examples of WETMEC 20 are potentially vulnerable to direct drainage. However, their apparent isolation from major groundwater sources may mean that they are less vulnerable to groundwater abstraction. Many basins have been drained to some degree, but still support wet (sometimes swampy) conditions.

The topogenous character of WETMEC 20 basins, in conjunction with a low-permeability basal substratum, means that the water table within them can often be readily modified by drainage structures. For example, it has been suggested that at Betley Mere there was, historically, an outflow control structure which was used to maintain higher water levels in the mere, probably in the context of drainage of the surrounding peatland. At Llyn y Fawnog, an earth dam of some 1.5 m high may once have maintained a much higher water level in the basin, but has since been breached. On the other hand, the natural outfalls to some WETMEC 20 sites (such as Eycott Hill Mires, Sweat Mere) have been deepened, and water tables within the basins presumably lowered. The relative ease with which such changes can be made is a component of this WETMEC's vulnerability. However, water level change does not necessarily have a detrimental effect upon WETMEC 20. In some contexts, the vegetation has sufficient buoyancy and vertical mobility to buffer against water level change; in others, it may just shift the position of the hydroseral zones. For example, at Hatchmere, where there appears to have been a considerable drop in water level and reduction in mere area since 1873 consequent upon deepening of the outflow channel, Lind (1949) points out: "*The drainage operations have had the effect of exposing around the lake margin new areas of highly organic, water-logged mud upon which vegetation has gradually established*."

Examples of WETMEC 20 can be particularly vulnerable to nutrient enrichment, especially those that are fed by extensive surface drainage networks, which have the capacity to capture agricultural (and other) nutrients from a quite wide catchment and, in some cases, produce considerable silt inwash into the mire. Emer Bog (Hampshire) provides a good example of an enrichment problem (Box 6.40).

Box 6.40: Nutrient enrichment at Emer Bog (Hampshire)

Emer Bog consists of a complex of topogenous and soligenous mire located at the eastern end of Baddesley Common. It occupies a small embayment in a low, but sharply rising hillslope and the main area of herbaceous, topogenous mire occupies a shallow basin. This is referable to WETMEC 20 and supports *inter alia* much S27 and patches of M5 vegetation. Phytometric determinations of soil fertility gave a value for a sample of S27 that was almost three times the national average for this community, whilst that for a sample of M5 was more than twice the national average for the community. Moreover, the values for S27 put this sample in the top two per cent of the fertility scale for all the samples that have been assayed from UK fens. Allen (2003) provided some evidence for hydrochemical change in the basin. There appears to have been a slight increase in the pH of surface waters in the mire between 1996 and 2002, and he reported slight to moderately high concentrations of inorganic nitrogen-N (0.9–5.1 mg l^{-1}) in August 2002, and very high concentrations of orthophosphate-P (0.1–0.7 mg l^{-1})[1]. Though these are subject to the usual caveats on the interpretation of reported dissolved concentrations of N and P in mires, they do provide a *prima facie* case for suspecting substantial P enrichment. However, the cause of these high values remains far from clear: water in the inflowing southern stream sampled in August 2002 contained 0.06–0.09 mg l^{-1} orthophosphate-P (Allen, 2003). The peat samples assayed for both M5 and S27 contained a rather greasy, silt-like material of uncertain identity, but the relevance of this, if any, is uncertain.

[1]Allen (2003) considered that the concentrations of both N and P merited such terms such as eutrophic and hypertrophic to describe nutrient conditions at Emer Bog , However, whilst measured concentrations of orthophosphate may merit this categorisation, the values of N reported were not particularly high (for a wetland context).

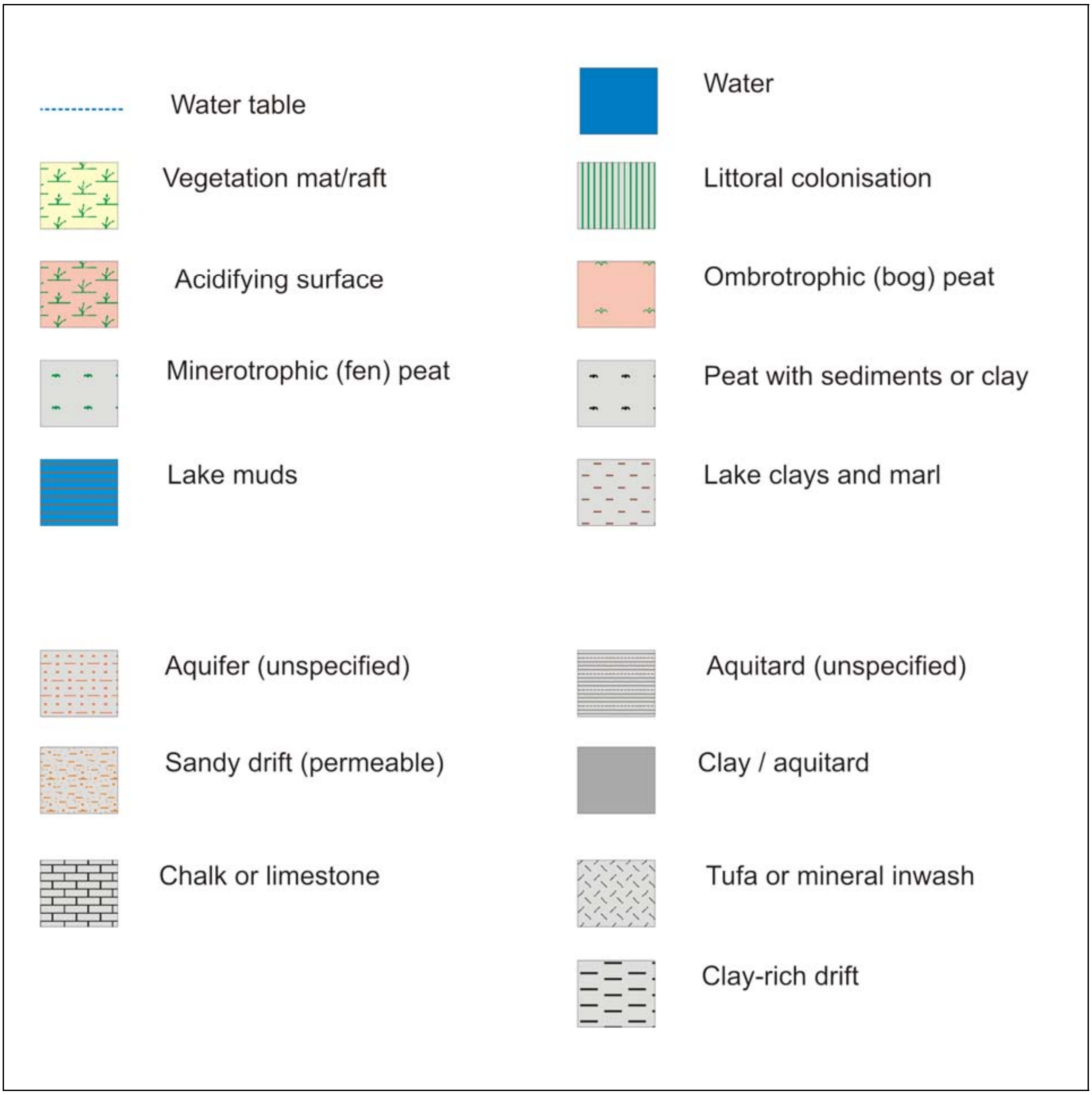


Figure 6.52 Key to schematic sections illustrating different WETMEC types

PART 3:

ECOHYDROLOGY OF WETLAND PLANT COMMUNITIES

7 Introduction to community accounts

7.1 Scope of accounts

The community accounts provided here relate to selected communities that are well represented across the sites included in the *Wetland Framework* project. Not all communities are included: particular attention is given to those that are used to define 'European features' (see Table 3.1 and Table 3.3) and to some others to which they are quite closely related. Communities for which only limited data are available, or which are poorly represented across the sites, are not included. Accounts presented in Wheeler and Shaw (2000a) have been updated.

The community accounts are intended to supplement the material provided by Rodwell (1991a, b; 1995), not to replace it (with the exception of Rodwell's M9 community, which has been reformulated here as M9-1, M9-2 and M9-3 (see 10.3)). More information is available now than when the original accounts were written, and some of this (such as distribution data, summary environmental characteristics) is presented here, along with information sourced for this project. This is used to amplify, and sometimes modify, information and insights provided by Rodwell. The material presented here thus highlights some deficiencies in Rodwell's accounts and approach, without providing balancing or mitigating comment about their proficiencies. Thus, though some of the text below appears critical, there is a great deal of material presented by Rodwell which we endorse.

Because of its multivariate, intergrading character, vegetation is not an easy subject to classify. Moreover, any proposed classification requires decisions on matters such as the desirable scope of its end units. For example, which is best: a small number of broad, heterogeneous units, or a larger number of segregates with narrower compass and which admit more precise floristic and environmental definition? The answer to this partly depends upon the potential users and intended use of the classification, and any general classification is likely to be a compromise between the number of units and the crispness of their definition; different users are likely to have different views on what constitutes the most appropriate compromise.

Another difficulty, which is often not appreciated, relates to the national scope of the NVC classification allied to the regionally shifting environmental and community inter-relationships between species. Vegetation analyses on individual sites sometimes generate end-units that do not fit any NVC categories. In some instances, this may be because the vegetation in question was not really sampled by NVC and new units are needed to accommodate it. However, in other cases units which appear to be discrete and well-defined at a local scale can lose their coherence and identity in a national vegetational context. Ideally, it would be possible to bore down from a broad national classification to narrower units of local applicability, and sometimes this is the case. However, there is not always a continuous hierarchical pathway that can unambiguously connect national syntaxa to locally derived units.

7.2 Data sources

Several data sources of varying scope have been used in the analyses – details of these are given in Appendix 2.

7.3 Identification and analysis of communities

7.3.1 Allocation of samples to communities

Each quadrat sample used has been allocated to an NVC community. The community of best fit was identified using a combination of the descriptions, keys and floristic tables provided by Rodwell (1991a, b, 1995) in conjunction with the identification programme MATCH (version 2.16). The coefficients of MATCH cannot be regarded as infallible guides to community identity, but the programme was created by workers involved with the NVC project, is presumably based upon the data tables used in the original determination of NVC communities and is therefore likely to provide as reliable a guide to the communities as they were recognised when the *NVC* was produced as anything available. In some cases, the communities to which samples were allocated did not correspond with our perception of their true relationships. Some samples clearly did not match *any* defined communities very well, and these were excluded from subsequent analyses. Some stands are clearly transitional between community types, but transitional types can be difficult to recognise and handle, both in vegetation analyses and in database design.

7.3.2 Detrended correspondence analysis (DCA) of community data

The inter-relationships between selected community types have been examined using detrended correspondence analysis (DCA) ordination. The ordinations essentially represent parsimonious summarisations of the multi-dimensional variation within the floristic dataset into two or three dimensions (axes), which have been calculated to optimise the geometric similarity amongst the samples. Thus, samples which are closest together are generally most similar to each other, and those which are furthest apart are generally least similar. Each sample has been allocated to the NVC community of best fit, as described above, and this is displayed on the diagrams. These show not only the inter-relationships amongst individual samples but also the variability of, and inter-relationships between, the NVC communities to which the samples have been allocated.

In interpreting the DCA ordinations, the following points should be considered:

- The NVC communities assigned to each sample are just labels; this information has not formed part of the DCA.
- The precise output of any ordination may vary to some degree depending on the procedure used and options selected (such as data transformation options).
- The precise output of any ordination depends on the number and character of samples included within it. Thus, the geometric distance between a sample pair on the ordination depends not only on their mutual similarities, but also upon their similarities with other samples on the ordination and the similarities between other samples. Thus, the distance (similarity) between any two samples is likely to vary depending on the character of the other samples included in the analysis.
- Ideally, individual communities would plot as discrete, coherent entities on the ordination. However, this is rarely the case and more often different communities form part of a continuous series, and may overlap in the ordination space.
- Samples assigned to a particular NVC community can often plot closer to (be more similar with) nearby samples assigned to a different community than to some samples of the community to which they have been allocated: this is an inevitable consequence of any attempt to recognise discrete units within a dataset showing a good deal of continuity with related units.

- If the samples allocated to a particular community all cluster close together, as a discrete group, then the community may have considerable coherence and be relatively easy to characterise. If samples allocated to a community are much spread out, or form localised outliers, it may be concluded either that the community is itself nebulous, variable and probably ill-defined, or that some of the samples allocated to it could be better classified in a different unit.
- Some overlap between samples allocated to different communities may occur. This could be because the communities do not provide very meaningful segregates of the dataset (in other words, they are not very good communities); because some samples allocated to one community could be better allocated to the other; or because a number of samples are transitional types between the two communities and therefore of intermediate character.
- Stands of vegetation which are transitional floristically between two (or more) communities occur frequently and sometimes extensively. The existence of some overlap between samples allocated to different communities on the DCA ordinations does not necessarily imply that the communities in question are ill-conceived entities – it may just mean that transitional types are quite frequent and are well represented with the sample set analysed. However, if there is much overlap between communities on the ordination, and especially if there is more overlap than non-overlap, the value of one or more of the communities concerned can be questioned. Because of the potential uncertainties in allocating new field samples to an existing floristic classification (which is a potential problem with all polythetic classifications), the occurrence of substantial overlap on the ordinations could be indicative either of a poorly defined, and perhaps poorly conceived, unit or of difficulties in determining the community to which individual samples belong (or both, as the two possibilities are often inter-related).

7.4 Overview of relationships

7.4.1 Communities in relation to main environmental variables

Base richness, fertility and summer water table

Wheeler and Shaw (1995b) and Wheeler and Proctor (2000) have identified the importance of three main environmental gradients in relation to variation in the species composition of British wetland vegetation: water base richness, soil fertility and summer water table. Figure 7.1, modified from Wheeler and Proctor (2000), shows the relationships amongst the main NVC communities, based on community means of water pH, soil fertility and summer water table (note that not all of the communities plotted are considered further here).

Various points emerge from Figure 7.1(a). One is that communities with very high mean soil fertility values invariably also have high pH means. At the other extreme, communities M2 and M18 (which are typical of ombrogenous bogs) plot close together in the acidic, low fertility sector of the diagram, along with M21, a community of weakly minerotrophic mires. Other poor-fen communities (M4, M5 and M6) also have low mean pH values associated with them, but higher mean fertilities than the foregoing. At low fertilities, there is a striking discontinuity between the mean pH values associated with the base-poor (M2, M15, M18, M21) and base-rich communities (M10, M13), reflecting the bimodality of pH distribution. This bimodality becomes progressively less clearly expressed as fertility increases.

Figure 7.1(d) shows the relationship between community means of summer water table and water pH. The communities included are categorised either as 'mire' or 'tall fen and swamp' syntaxa (Rodwell, 1991a, b; 1995), but they span a summer water table range of almost 40 cm. The summer water table means for the more acidic communities are consistently fairly high, but there is a much wider range of mean water tables across the more base-rich communities. The reason for this is not certain, and may partly reflect the range of samples available within the FENBASE dataset analysed. However, it also appears that in base-rich circumstances with low water tables, the vegetation tends to be more regarded as a form of wetland vegetation than is the case in base-poor conditions, where the vegetation found in summer-dry sites tends to be regarded as a form of heath or acid grassland rather than 'wetland'. This difference in perception may reflect a greater capacity of base-rich mire species to continue to grow at low water tables than species in base-poor mires, and may possibly relate to a deeper potential maximum rooting depth in some species of more base-rich wetlands.

Main water sources (summer conditions)

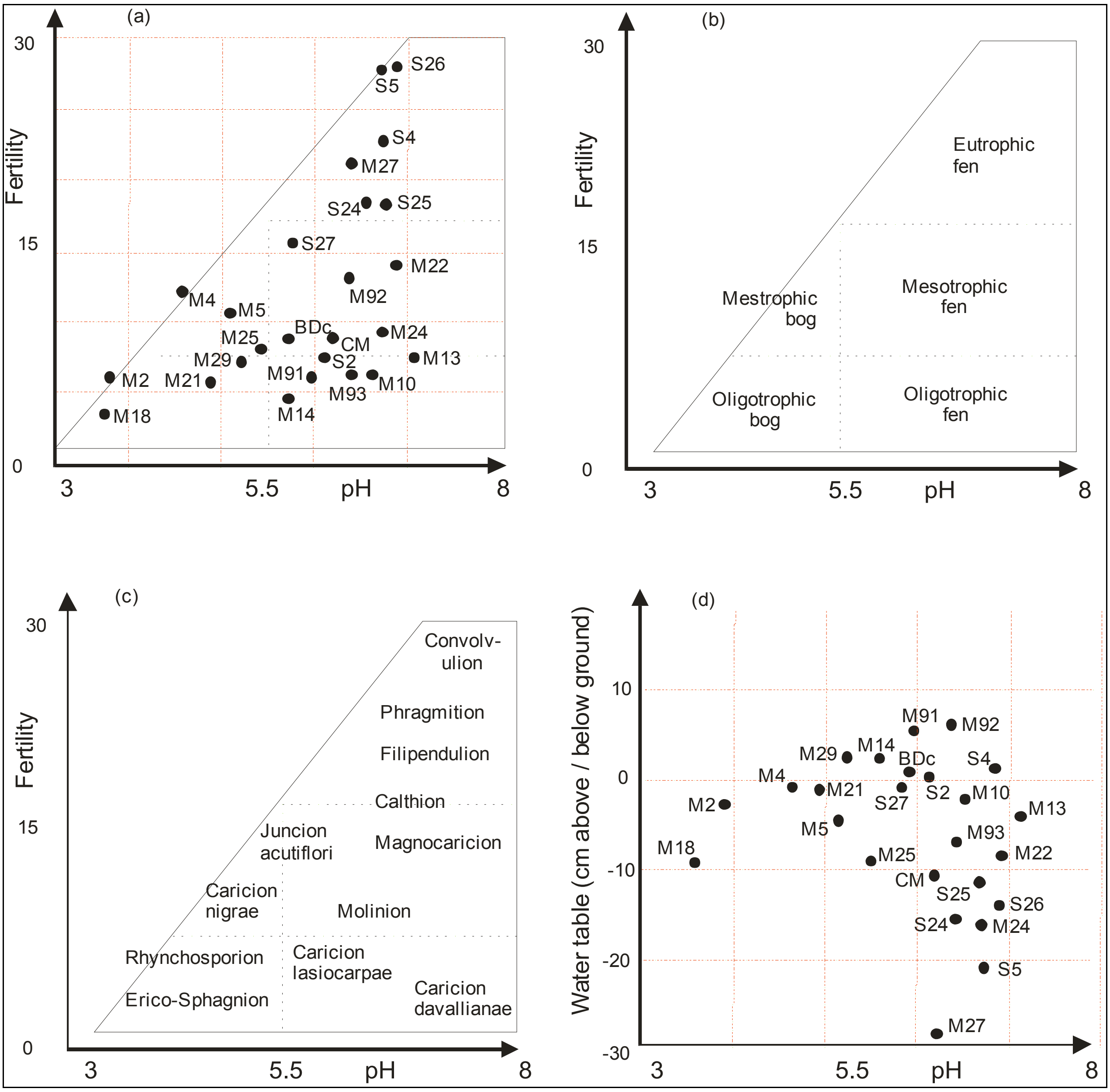
The importance of the main sources of water in maintaining the summer water table of individual stands has been estimated using information collected for the identification of WETMECs. This has been categorised into the contribution made by groundwater, surface water and rainfall and used to assess the relationship between these sources and the occurrence of different wetland vegetation types. These data are presented as mean values for each community along the three axes of a ternary plot (Figure 7.2). As the water source data are based on estimated rank values, caution should be applied when using these results, but nonetheless these appear to provide a fair summary of the broad inter-relationships between the communities.

Many of the communities occupy a roughly central position on the ternary plot, indicating potential supply by all three water sources. In some stands this is because both surface water and groundwater are important contributors to the summer water table, in addition to precipitation. However, it appears that in most cases the summer water supply to individual stands is derived primarily from either surface or groundwater sources. In consequence, the intermediate position of mean values for many of the communities is almost certainly a reflection of the balance between the number of sites fed by groundwater and the number fed by surface water. A corollary of this is that, for these communities, groundwater and surface water sources are apparently interchangeable, providing their quality (hydrochemical character) is similar.

Some groups of communities are strongly biased to one or other of the main water sources. For example, M10, M13, M14 and M21 (and to some extent M22) are strongly dominated by groundwater supply. Surface water inflows are unimportant in maintaining the summer water table of most examples, and precipitation is also of little direct importance. This limited significance of precipitation may be because examples of these communities occur in regions with rather low summer rainfall, or because groundwater outflow so strongly dominates water supply that rainfall events cause little *direct* modification of the position of the summer water table (the communities remain wet even in dry, though not necessarily in drought, periods).

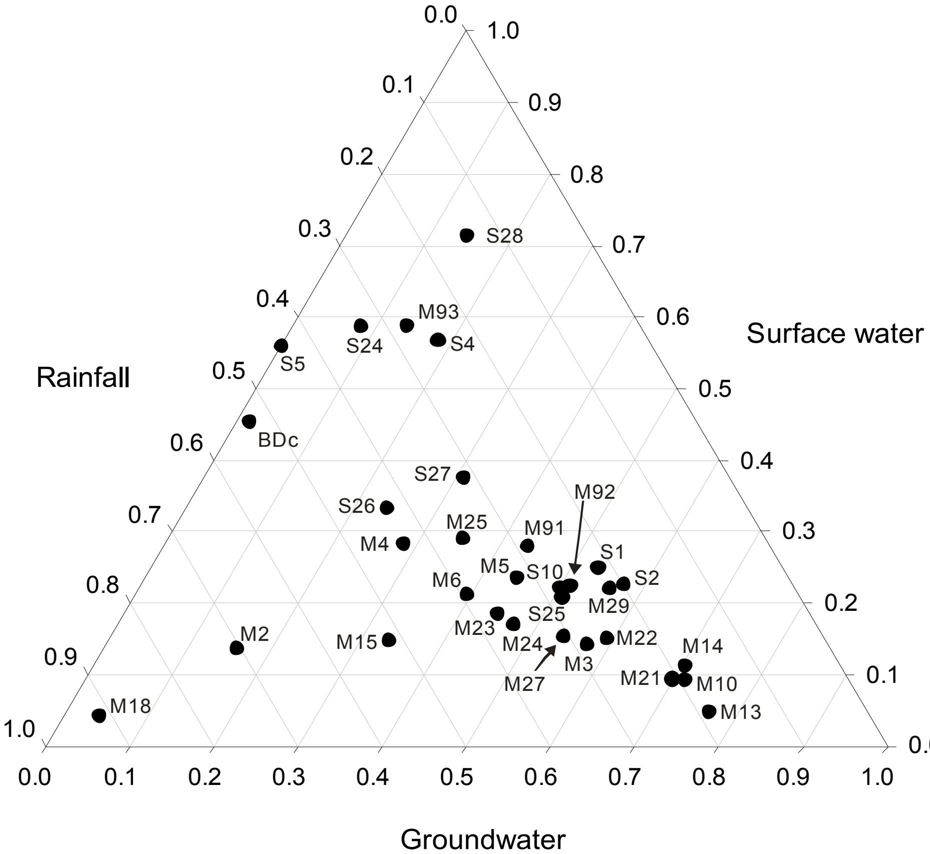
On the other hand, as might be expected a small number of communities are associated with surfaces that are fed primarily, and directly, by rainfall, most notably M2 and M18. M18 is the most strongly ombrotrophic of this pair, and many examples of this are exclusively associated with direct precipitation supply. However, some M18 stands are closely associated with minor groundwater or surface water sources, though the importance of these to the vegetation is often not clear (in many instances, weak telluric inputs probably help support a surface layer of meteoric water rather than contributing directly to surface conditions). A similar comment can be made for certain M2 stands, but other examples of these are almost certainly irrigated by weakly minerotrophic water, as well as by rainfall.

Some communities are primarily associated with surface water supply (S4, S5, S24 and M9-3). These are all communities of floodplains which appear to receive either episodic inundation from watercourses or summer sub-irrigation from rivers (or river-connected dykes) through a transmissive top layer of peat (or both). There is no evidence that any of the communities considered are *generically* dependent on land drainage or rain-generated run-off, though such run-off may provide an important supply to individual examples of certain communities (such as M1, M9-1), particularly in high-rainfall locations on a low-permeability bedrock or drift.



(a) Approximate position of selected plant community types on pH and fertility axes; (b) subdivision into broad pH and trophic status categories; (c) schematic arrangement of the main alliances of mires on pH and fertility axes; (all modified from Wheeler and Proctor, 2000); (d) approximate position of selected plant community types on summer water table and pH axes.

Figure 7.1 Variation of wetland vegetation in Britain in relation to pH, substratum fertility and summer water table



The contribution of each water source was assessed independently using a five-point scale (see text). The figures here represent the mean score for each community, normalised in order to produce a ternary plot.

Figure 7.2 Ternary plot of the estimated relative contribution of groundwater, surface water and rainfall to the maintenance of summer water tables associated with selected wetland vegetation types

8 M4 (*Carex rostrata–Sphagnum recurvum*) mire

8.1 Context

Examples of the M4 community have been included in the “transition mire and quaking bog” SAC interest feature. [See Tables 3.1 and 3.3]

8.1.1 Concept and status

The M4 unit was generated by Rodwell (1991b), who encompassed within it elements of more local units that had already been recognised by other workers. It is not a particularly distinctive unit, partly because it is rather species-poor and lacks good characterising species. Its defining characteristics are given as a prominence of *Carex rostrata* coupled with a moss layer dominated by Sphagnum *recurvum, S. cuspidatum* or *Polytrichum commune*. It does, however, show much intergradation with M2, M5 and M6, and some individual stands may be very difficult to identify.

DCA ordinations of samples allocated to either M4 or M5 (FenBASE database) (Figure 9.1, see under M5) show: (a) that the two communities do show some broad distributional differences on the ordination; but (b) there is much overlap between samples referred to the two units; and (c) that much of the range of M4 on the ordination is also occupied by M5. Thus, whilst some samples of M5 are clearly quite different to those of M4, it is harder to segregate many examples of M4 from the ordination space occupied by M5. These data suggest that whilst there is some reason to support the distinction of the two units M4 and M5, there is a great deal of overlap between these units, and they may perhaps be better seen as two sub-communities of a single unit.

8.1.2 Floristic composition

Although a total of 101 species were recorded in samples of this community (Table 8.1), the community is the most species-poor of the main poor-fen communities (mean of 13.7 species per sample), comprising a carpet of Sphagna, in which *Sphagnum recurvum* is particularly prominent, with a cover of sedges (most commonly *C. rostrata*), but with a variable and rather impoverished poor-fen herb flora (such as *Agrostis canina ssp. canina, Agrostis stolonifera, Potentilla erecta, Galium palustre*). It supports only a few rare species (Table 8.1).

No sub-communities have been distinguished.

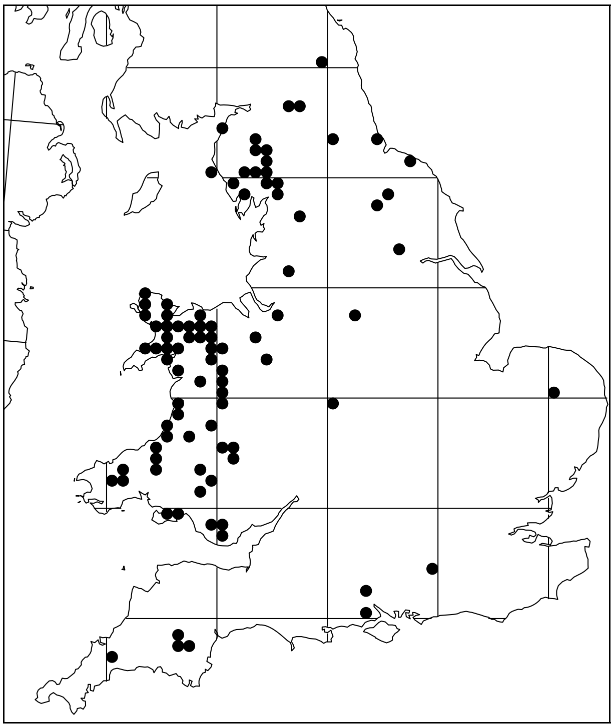
Table 8.1 Number of species recorded in samples of M4

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	101	13.7	0.22	6	31
Mire species (spp 4 m^{-2})	67	10.5	0.19	4	24
Rare mire species* (spp 4 m^{-2})	6	0.3	0.16	0	2

* These include: *Carex elata, Carex lasiocarpa, Carex limosa, Carex magellanica, Osmunda regalis, Sphagnum teres*

8.1.3 Distribution

The community has a mainly western and northern distribution in Britain, being found in South and North-West England, Wales and throughout Scotland (see map in Rodwell, 1991b). In England and Wales, it has been recorded from 123 wetland sites (FENBASE database) (Figure 8.1).



(data *from FenBASE datbase*)

Figure 8.1 Distribution of M4 in England and Wales

8.1.4 Landscape situation and topography

Essentially a community of topogenous situations, both stagno-topogenous and rheo-topogenous. It is particularly associated with small basins, but can occur in topogenous hollows in various contexts, including former peat cuttings and bog pools, sometimes in valleyhead and floodplain systems. Also occurs in the laggs of some raised bogs, and has been recorded from some soakways.

8.1.5 Substratum

Occurs on (often rather loose) solid peat or else on a quaking or buoyant hydroseral surface.

8.1.6 Zonation and succession

This community can occur in association with ombrotrophic mires, sometimes forming a community of the lagg, sometimes occupying peat workings which have become partly irrigated by ingress of telluric water from the margins of the basin. It also forms complexes with other weakly minerotrophic habitats and communities in basins, and is sometimes an apparent hydroseral derivative from a preceding phase of more base-rich conditions.

Rodwell's (1991b) observation that "the place of the community in terrestrialising successions is obscure" remains generally valid, partly because this community has no distinctive macrofossil signature that can be detected in stratigraphical cores. However, it seems probable that M4 may be a precursor to M18 in some sites (such as Tarn Moss). In some instances (such as Rhôs Gôch Common, Radnorshire) the community forms part of a zonation: M5 > M4 > ombrotrophic surface, but this may well be more of a zonation that has developed subsequent to turbary than an autogenic hydroseral pathway. A complication is that in some locations, this community may have developed in response to mild enrichment of former ombrogenous surfaces (see Tallis, 1973) and may represent a reversal in the more usual minerotrophic > ombrotrophic progression.

In some sites (such as Forest Camp, Delamere) the M4 community forms a buoyant mat more or less directly encroaching upon open water, apparently developing in association with buoyant rhizome mats of swamp species (such as *Carex rostrata, Equisetum fluviatile, Typha latifolia*), and perhaps in response to a drainage-induced lowering of the level of open water in the basins[1].

8.2 Water supply mechanisms and conceptual model

The community occurs primarily as buoyant, wet surfaces in weakly minerotrophic basins which may have little or no known direct groundwater supply but which are fed primarily by precipitation, supplemented by some surface water inflows of rain-generated run-off, field drainage or stream inflow. In some examples there may be a contribution from groundwater, but where this occurs it seems to be mainly as surface or near-surface flow over a peripheral aquitard, sometimes as streams but sometimes from flushed slopes. Rodwell (1991b) states that this community is characteristic of seepage areas, but whilst it always occupies locations that receive some (often weak) telluric inflow, these are often not obviously provided by groundwater outflow from a mineral aquifer, and overall this community has one of the *lower* associations with groundwater outflow of all those considered in this investigation.

Forty-five per cent of M4 samples were identified as occurring within WETMEC 3 (Buoyant Weakly Minerotrophic Surfaces (transition bogs) such as Tarn Moss, Cumbria), with 18 per cent within WETMEC 20 (Percolation Basins such as Cors Llyn Coethlyn,Montgomery). One example occurred within each of WETMECs 12, 14, 16 and 17.

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[1] Tallis (1973) reported that spread of the *Sphagnum* surface in the Forest Camp basins was related to a lowering of the water level of the pools, as a consequence of drainage operations some 40-years previously.

8.3 Regimes

8.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 8.2, together with mean recorded values for summer water table associated with stands of M14.

Table 8.2 Rainfall, potential evaporation and water table data for M4

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	1,091	596	1,465
Potential evaporation (mm a^{-1})	548	462	668
Mean summer water table (cm agl or bgl)	–0.4	–33.5	15.0

Specific time-series data for stands of M4 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Typically close to surface level year round.
- Summer water level typically at or just below surface. Most examples were within the narrow range of –10 to +10 cm.
- Association with semi-floating basin or turf pond infill provides vertical mobility and thus hydrological stability.
- There is some evidence that lateral expansion of this community over adjoining open water can be promoted by a lowering of the water level. This has been suggested for Forest Camp (Tallis, 1973), Black Lake and Hatchmere (Lind, 1949) in the Delamere Forest basins.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can be speculated that partial drainage would lead first to the loss of the more aquatic Sphagna, and perhaps a transition to *Carex echinata–Sphagnum recurvum/auriculatum* mire (M6), with subsequent loss of wetland species and increased representation by dryland species. Further peat drying and degradation would lead to development of rank fen, rapidly becoming wooded without management.
- Prolonged dry periods may make the stands more prone to damage by burning, as well as permitting greater access by grazing animals.
- This community may often be stable, but – and subject to the caveats (above) about uncertainties concerning hydroseral relationships – autogenic accumulation of peat may lead to the gradual development of an ombrogenous surface or some form of acidic woodland; draining may speed this succession, particularly in favour of a wooded community.
- Prolonged, deep inundation, particularly in the spring or summer months, is likely to kill some species and lead to development of bog-pool vegetation types. However, this effect may be limited in examples with a buoyant raft.

8.3.2 Nutrients/hydrochemistry

Typically found in base-poor conditions and where conditions are generally of low to moderate fertility. However, it can span a wide fertility range, suggesting that base poverty may be more limiting to plant growth than the availability of major plant nutrients (Shaw and Wheeler, 1991). Figures for pH, conductivity and substratum fertility measured in stands of M4 are presented in Table 8.3.

In some locations this community may have expanded at the expense of even more base-poor types (M2 and M18), in response to mild enrichment with nutrients and bases. Scarcity of earlier data makes it difficult to document this possibility, but it is notable that at Abbots Moss, chemical concentrations reported in 1960 (Bellamy, 1967) appear to be considerably smaller than those recorded in recent years.

The substratum of some examples of this community is surprisingly fertile, with eutrophic values recorded in some sites. The highest value (31 mg) is from Emer Bog, where there is a suspected enrichment problem (of uncertain cause), but high values have been recorded elsewhere. At Cors y Llyn, a peat fertility of 21 mg from one example of M4 may be a consequence of land-drainage inflows. The response of M4 to nutrient enrichment is not known, but it is unlikely to be stable, and an expansion of 'undesirable' species like *Juncus effusus*, *Typha latifolia* and, in drier locations, woody plants, seems likely to occur, at least in the medium to long term.

Table 8.3 pH, conductivity and substratum fertility measured in stands of M4

Variable	Mean	SE	Minimum	Maximum
Water pH	4.6	0.006	3.9	6.1
Soil pH	4.7	0.007	3.7	6.1
Water conductivity (K_{corr} µS cm^{-1})	96	1.1	16	336
Substratum fertility[1] (mg phytometer)	12.1	0.47	5	31

8.3.3 Management

The community appears to be relatively stable in the absence of management, possibly because of the generally high water tables. It occurs in grazed sites as well as sites where there is no positive management, although it can be difficult to judge the degree to which stands are actually grazed, even when there is open access to stock; the degree of penetration by any stock will depend largely on the wetness of the site and the stability of the substratum. Shaw and Wheeler (1991) found no evidence that managed stands were more species-rich than unmanaged ones. Stands could be damaged by heavy grazing.

Natural successional processes mean that where the community is established on a floating raft, conservation of this vegetation type may eventually require rejuvenation of the hydroseral conditions (by excavation of the substratum) in order to permit re-establishment of a floating raft (and prevent succession to woodland or ombrotrophic bog).

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

8.4 Implications for decision making

8.4.1 Vulnerability

Conservation management involves ensuring consistently wet, low fertility and relatively base-poor conditions, and (possibly) maintenance of hydroseral conditions (peat excavation). The main threats are from drainage (or interception of supply) and nutrient enrichment (from both telluric and meteoric sources). Figure 8.2 outlines some of the possible floristic impacts of changes to the stand environment.

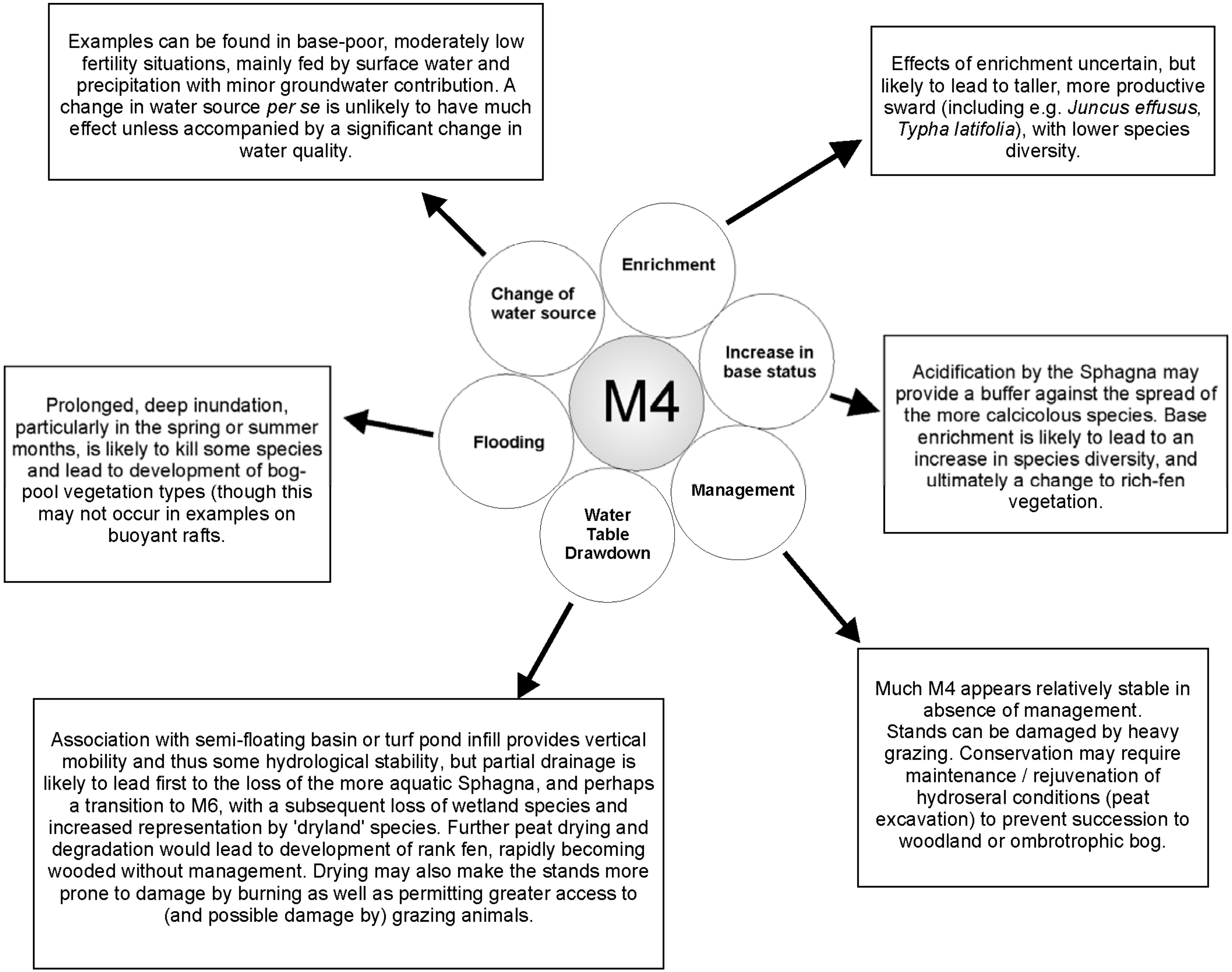


Figure 8.2 Possible effects of environmental change on stands of M4

8.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M4 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M4 in the short to medium term.
- Conservation of M4 may require rejuvenation of the hydroseral conditions (excavation of the substratum).

8.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently no data to better inform the temporal water table characteristics of M4 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M4 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites,
- Data on the spatial extent of M4 are lacking.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.
- A more throrough assessment is required of the distinctiveness and compass of M4 as a vegetation unit, especially in relation to M5.

9 M5 (*Carex rostrata–Sphagnum squarrosum*) mire

9.1 Context

Examples of the M5 community have been included in the "transition mire and quaking bog" SAC feature. [See Tables 3.1 and 3.3]

9.1.1 Concept and status

The M5 unit was generated by Rodwell (1991b), who encompassed within it elements of other units that had already been recognised by other workers. Some were rather local units, as described for example from Malham Tarn by Proctor (1974), but others were more regional units (such as those described from Scotland by Spence (1964)). M5 is undoubtedly a useful category, but it is not easily defined, partly because it is often variable, even within a single site. Its defining characteristics are a prominence of *Carex rostrata* coupled with a moss layer dominated by *Sphagnum squarrosum* and with a range of poor-fen herbs. The latter are particularly problematic for the definition of the unit, because they vary considerably and different combinations of herbs may occur in different stands. M5 shows much intergradation with M4, and the allocation of some individual stands can be very difficult.

DCA ordinations of the samples allocated to either M4 or M5 (Figure 9.1) show: (a) that the two communities show some broad distributional differences on the ordination; but (b) there is much overlap between samples referred to the two units; and (c) that much of the range of M4 on the ordination is occupied by M5. Thus, whilst some samples of M5 are clearly different to those of M4, it is harder to segregate many examples of M4 from the ordination space occupied by M5. Whilst there is reason to support distinction of the two units, there is a great deal of overlap between them, and they may be better seen as two sub-communities of a single unit.

Betulo-Dryopteridetum cristatae (B25)

Figure 9.1 also shows samples of the *Betulo-Dryopteridetum cristatae* which was recognised and described by Wheeler (1978, 1980c) from the Norfolk Broadland, and which is important in supporting populations of the nationally rare *Dryopteris cristata.* It has a *Sphagnum* carpet based mainly on *S. squarrosum* and *S. palustre*, but also with *S. recurvum* and, locally, *S. teres.* Wheeler (1975, 1980c) was primarily concerned with rich-fen vegetation and these stands of acidic fen were sampled only because they occurred as small stands embedded within rich-fen vegetation and, at that time, their affinities to other acidic fen types were not known.

For reasons that are not entirely clear, Rodwell (1991a) subsumed the *Betulo-Dryopteridetum* within his *Salix cinerea–Betula pubescens–Phragmites australis* woodland (W2). This was an unfortunate outcome, not least because the optimal development of the *Betulo-Dryopteridetum* is as an *herbaceous* vegetation type, and the autogenic development of wooded conditions represents a successional degeneration of the community that leads ultimately to the loss of most of the species characteristic of the vegetation (including *D. cristata*). The community which comes closest to the *Betulo-Dryopteridetum* in the NVC scheme, in terms of concept, floristics and ecology, is M5, not W2. It is, however, distinct from other examples of M5 (Figure 9.1) mainly by the occurrence of a number of Broadland species, and we suggest that it should either be considered to form a distinct sub-community of M5, or be regarded as an independent, if rather idiosyncratic, unit.

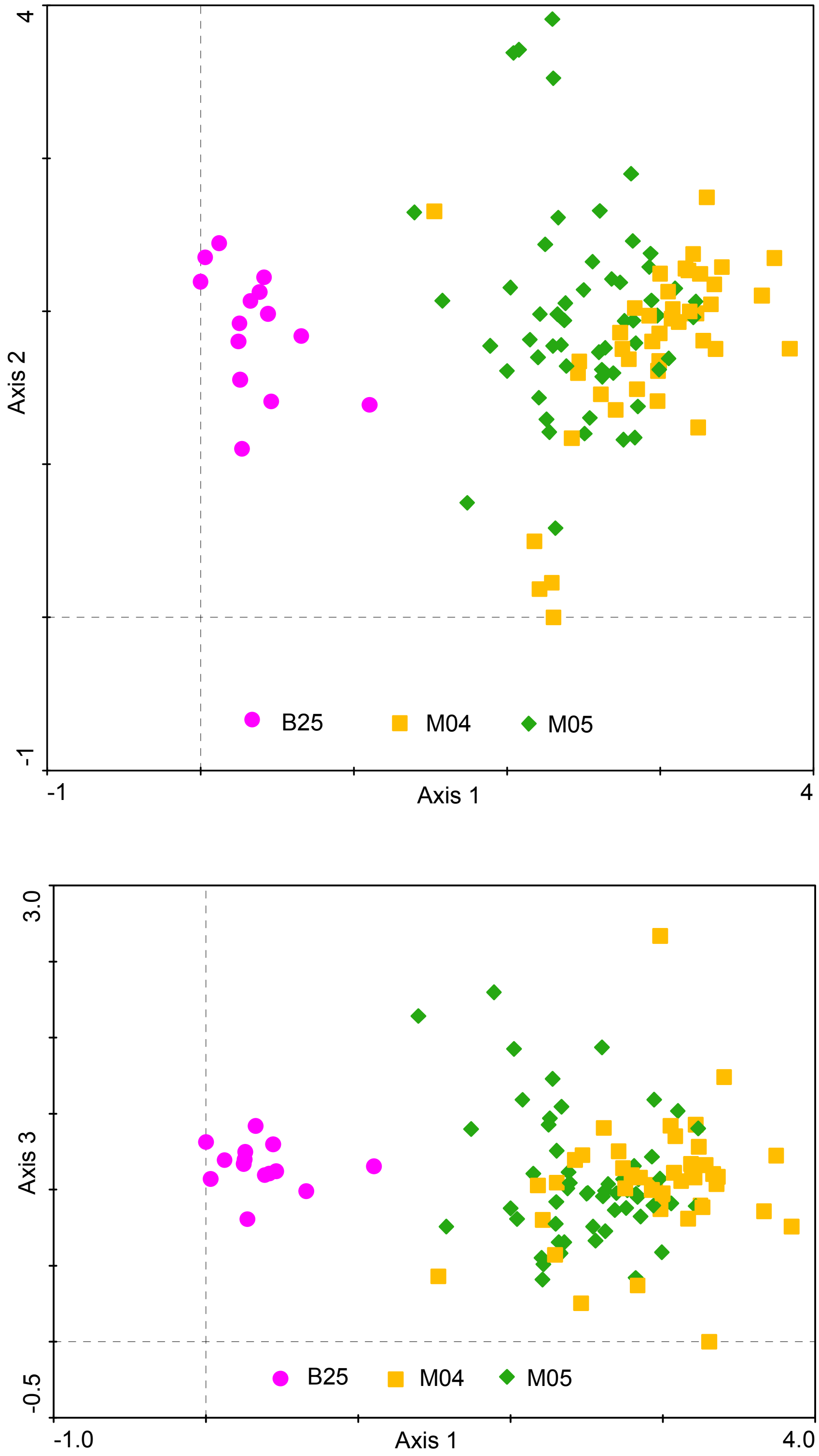


Figure 9.1 Plots of samples of *Betulo-Dryopteridetum* (B25), *Carex rostrata–Sphagnum recurvum* mire (M4) and *C. rostrata–S. squarrosum* mire (M5) on Axes 1~2 and 1~3 of a detrended correspondence analysis ordination

9.1.2 Floristic composition

This rather heterogeneous community can be moderately species-rich (up to 43 species per sample; Table 9.1), and is often richer than M4. It is characterised by the dominance of sedges (especially *Carex rostrata*) with scattered poor-fen herbs over a patchy carpet of moderately base-tolerant Sphagna (particularly *S. squarrosum* and *S. palustre*); it very often occurs as a raft of vegetation, sometimes forming small, buoyant patches within more base-rich swamp or (wet) fen.

Examples of *Betulo-Dryopteridetum cristatae* from the Norfolk Broadland have not been included in the following analyses, but most comments made for M5 apply equally to this unit (see 9.1.1).

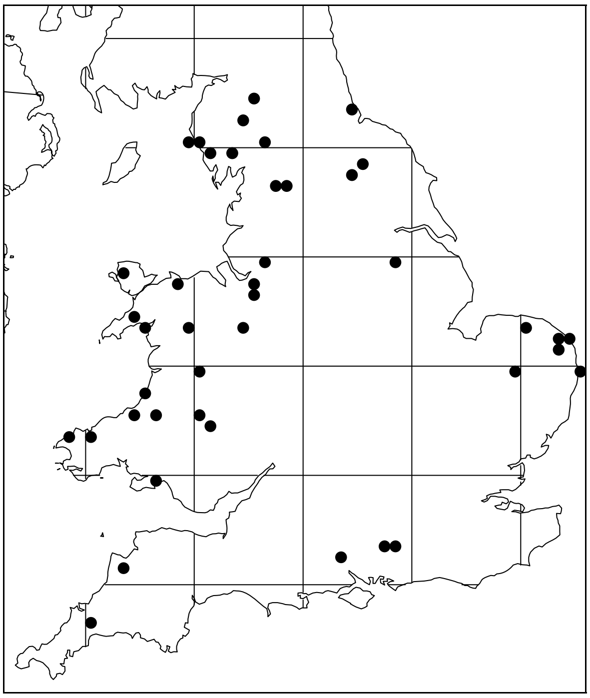
Table 9.1 Number of species recorded in stands of M5

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	154	20.2	0.19	7	43
Mire species (spp 4 m^{-2})	100	16.6	0.16	7	32
Rare mire species* (spp 4 m^{-2})	17	0.7	0.14	0	3

** these include: Calamagrostis canescens, Calliergon giganteum, Calliergon sarmentosum, Carex appropinquata, Carex aquatilis, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Lysimachia thyrsiflora, Osmunda regalis, Peucedanum palustre, Rhizomnium pseudopunctatum, Sphagnum subsecundum, Sphagnum teres, Stellaria palustris, Utricularia minor.*

9.1.3 Distribution

The community is rather localised and is mainly a feature of the North and West of Britain, with a few localities in the South and East. In England and Wales, it has been recorded from 50 wetland sites (Figure 9.2).



(data *from FenBASE database*)

Figure 9.2 Distribution of M5 in England and Wales

9.1.4 Landscape situation and topography

Essentially a community of topogenous (primarily rheo-topogenous) situations. It is particularly associated with small basins and, sometimes, open water fringes, but can occur in topogenous hollows in various contexts, including former peat cuttings, sometimes in valleyhead and floodplain systems.

9.1.5 Substratum

Mainly occurs on a buoyant infill within a basin or turf pond or as a vegetation raft on the margins of lakes and pools. Occasionally found on more solid peat, particularly where it is soft and spongy. Can be found in base-poor catchments where slates, shales and some kinds of schist predominate, but also sometimes associated with more calcareous rocks (see 9.2).

9.1.6 Zonation and succession

May form part of a sequence of vegetation types from open water and swamp through to drier mineral soils, or represent the development of more oligotrophic nuclei within stands of other communities, such as *Carex rostrata–Potentilla palustris* tall herb fen (S27) or *Carex rostrata–Calliergon cuspidatum/giganteum* mire (M9), or various swamp types (such as *Carex rostrata* swamp (S9), *Equisetum fluviatile* swamp (S10)). The buoyant surface provides a buffer against inundation and desiccation, thus allowing the spread of at least the more base-tolerant Sphagna, in association with poor-fen herbs and species characteristic of S9 or S27. In some sites, this community is restricted to the most unstable and buoyant surfaces, sometimes occurring just as very small floating patches. A feature of some of these is the occurrence of more dryland species such as *Holcus lanatus*; although developed in wet fen conditions, the surface of the mat can be relatively dry. Many examples of this community occur within sites that have been dug for peat (sometimes marl), or on surfaces that have been partly drained and then reflooded. In many such situations, the development of this community represents the first phase of acidification of a more base-rich fen. This process is promoted by the buoyant surface and appears largely independent of the base status of the water from which it arises. The formation of this community has been well documented in some of the calcareous basin mires of the Scottish Borders by Tratt (1998).

In one rather unusual development (at Pilmoor, North Yorkshire), this community forms an extensive superficial surface over former *Carex elata* swamp (S1), but without a buoyant raft. It is possible that this may be a legacy of a former, more buoyant surface, but it seems more likely to be a response to a lowering of the telluric water level within the mire, where the surface is now largely, if not exclusively, rain-water fed.

Many examples of M5 appear to be relatively recent in origin, and their subsequent development is poorly understood. Some stands appear to form a precursor phase for M4 or M2 development, but others are prone to scrub invasion, often to form a rather indeterminate wooded community, or one referable to *Salix pentandra–Carex rostrata* woodland (W3) or, in more base-poor conditions, *Betula pubescens–Molinia caerulea* woodland (W4).

9.2 Water supply mechanisms and conceptual model

Most of the M5 stands sampled occurred within basins or troughs. Thirty-eight per cent of samples were identified within WETMEC 13 (Seepage Percolation Basins such as Silver Tarn (Cumbria) and Shortheath Common (Hants)), with 25 per cent within WETMEC 20 (Percolation Basins such as Cors Gyfelog (Caernarfon) and Llyn y Fawnog (Denbigh)). Six per cent occurred within each of WETMECs 6, 11, 12, 14, 16 and 18.

The community is most typically associated with locations where a topogenous hollow is fed by water discharging around the margin, either by groundwater outflow from a mineral aquifer, or from surface water streams and run-off. Unless the water flow is intercepted (for example by drains), it percolates through the topogenous wetland, particularly over or near the surface, or along sub-surface preferential flow paths (for example beneath buoyant vegetation mats), to a (natural or artificial) outfall.

Elkington *et al.* (2001) suggest that this community can also be found around springs and seepage lines, but whilst some examples may occupy this situation, this is not at all common in our experience. Rodwell (1991b) points out that the community can be associated with soligenous inflows, but these appear to refer to rheo-topogenous situations rather than to sloping soligenous surfaces.

9.3 Regimes

9.3.1 Water regime

The community is typically found as a semi-floating raft, particularly in topogenous situations, and the water level is thus generally close to the surface year round, although there may be some shallow flooding, especially after heavy rain. Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 9.2, together with mean recorded values for summer water table associated with stands of M5.

Table 9.2 Mean rainfall, potential evaporation and summer water table for M5

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	1,050	616	1,828
Potential evaporation (mm a^{-1})	565	527	625
Mean summer water table (cm agl or bgl)	–4	–45	10

Specific time-series data for stands of M5 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Typically close to surface level year round.
- Association with buoyant basin or turf pond infill provides vertical mobility and thus some hydrological stability.
- The community usually occupies surfaces which are a little elevated above the limit of frequent inundation with more base-rich water. However, occasional flooding with base-rich water will prevent succession to community types associated with more acidic conditions. The community is therefore most likely to be persistent in more buoyant circumstances.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can be speculated that these would lead to a loss of wetland species and increased representation of dryland species. Drainage is likely to lead to a loss of Sphagna, and succession to a coarser vegetation type as the substrata are relatively fertile; it may also make the stands more prone to damage by burning, as well as permitting greater access by grazing animals.
- Autogenic accumulation of peat may lead either to some form of woodland or to the development of more weakly minerotrophic surfaces, such as support M4 or M2 vegetation; draining may speed this succession.
- Prolonged, deep inundation, particularly in the spring or summer months, is likely to kill some species and lead to development of less diverse swamp vegetation types (such as *Carex rostrata* swamp (S9), *Carex rostrata–Potentilla palustris* tall herb fen (S27)). However, such inundation may be very limited, especially in the more buoyant examples.

9.3.2 Nutrients/hydrochemistry

Figures for pH, conductivity and substratum fertility measured in stands of M5 are presented in

Table 9.3. However, the seral character of this community, often with a thin layer of acidic peat semi-floating over base-rich water, can result in steep and short vertical hydrochemical gradients which can make characterisation of the chemical environment associated with the M5 surface rather difficult (because samples of water or soil may partly represent conditions immediately below the M5 surface rather than the surface itself). The community is typically found in moderately base-poor and moderately fertile conditions, but it can occur over a fairly wide range. Shaw and Wheeler (1991) found that base enrichment was associated with an increase in species richness, while P enrichment was related to a decrease in numbers of principal fen species.

The community typically develops on a floating raft where flooding is limited, so that oligotrophic nuclei can develop over more base-rich conditions. Subsequent acidification by the Sphagna (for example, Clymo, 1967), may help to restrict the spread of more calcicolous species. It is not clear to what extent the base status of M5 surfaces is determined by the telluric water quality of the basin in which it develops, or by the processes associated with autogenic acidification. Tratt (1998) found that the development of acidic, *Sphagnum*-dominated surfaces (often M5) in the Border Mires was apparently independent of the base status of telluric water in the basins. In the Norfolk Broadland, Giller and Wheeler (1988) found that surface acidification leading to the development of a *Betulo-Dryopteridetum cristatae* community (an analogue of M5) could also occur in base-rich conditions, and in close proximity to eutrophic river water.

At Malham Tarn, Proctor (1974) reported dissolved calcium levels in the order of 5–15 mg l^{-1}.

A small number of examples of this community had eutrophic soils. The reason for this is not known. Quite high fertilities were found in some samples from Silver Tarn, which is adjoined by fertilised farmland, and at Shortheath Common, where the source of enrichment is not obvious.

Table 9.3 pH, conductivity and substratum fertility measured in stands of M5

Parameter	Mean	SE	Minimum	Maximum
Water pH	5.0	0.004	3.8	6.1
Soil pH	5.1	0.005	4.1	6.5
Water conductivity K_{corr} (µS cm^{-1})	175	1.0	64	355
Substratum fertility[1] (mg phytometer)	13.8	0.33	4	29

9.3.3 Management

Shaw and Wheeler (1991) found evidence for a small increase in species density with management of this community, with a trend towards increasing numbers of principal and rare fen species. Grazing can be difficult to control since the community typically forms a mobile, floating raft, and thus the degree of penetration by any stock will depend largely on the wetness of the site and stability of the substratum. In many sites grazing is neither practicable nor desirable, and the community generally occurs in locations with no positive management, where it often appears to be relatively stable.

Natural successional processes mean that where the community is established on a floating raft, conservation of this vegetation type may eventually require rejuvenation of hydroseral conditions (by excavation of the substratum) in order to permit re-establishment of the floating raft.

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

9.4 Implications for decision making

9.4.1 Vulnerability

The main threats are from drainage (or interception of water supply) and nutrient enrichment. Ongoing terrestrialisation is an eventual threat to many examples, as hydroseral succession can be associated with consolidation of buoyant surfaces.

The vulnerability of stands of M5 to changes in water supply depends considerably upon the precise water supply mechanism. Where the water level in basins with this vegetation is directly determined by aquifer water tables, the key question of vulnerability may be the degree of water level reduction which can be accommodated by the vegetation rafts before significant grounding and drying occurs. However, on sites developed over low-permeability deposits and where the water level is potentially controlled by the level of outfall as well as by rates of water inflow, the community is potentially less vulnerable to changes in groundwater supply. Conversely, such sites may be more vulnerable to any increased drainage of or in the fen, especially where groundwater inputs are weak.

Conservation management mainly involves ensuring moderate fertility and relatively base-poor conditions, and maintenance of spongy/hydroseral conditions (which may involve peat excavation). Heavy grazing is undesirable, as it would break up the bryophyte mats, although this is not usually a problem as livestock are usually reluctant to visit the unstable rafts. Figure 9.3 outlines some of the possible floristic impacts of changes to the stand environment.

The possible effects of environmental change on stands of M5

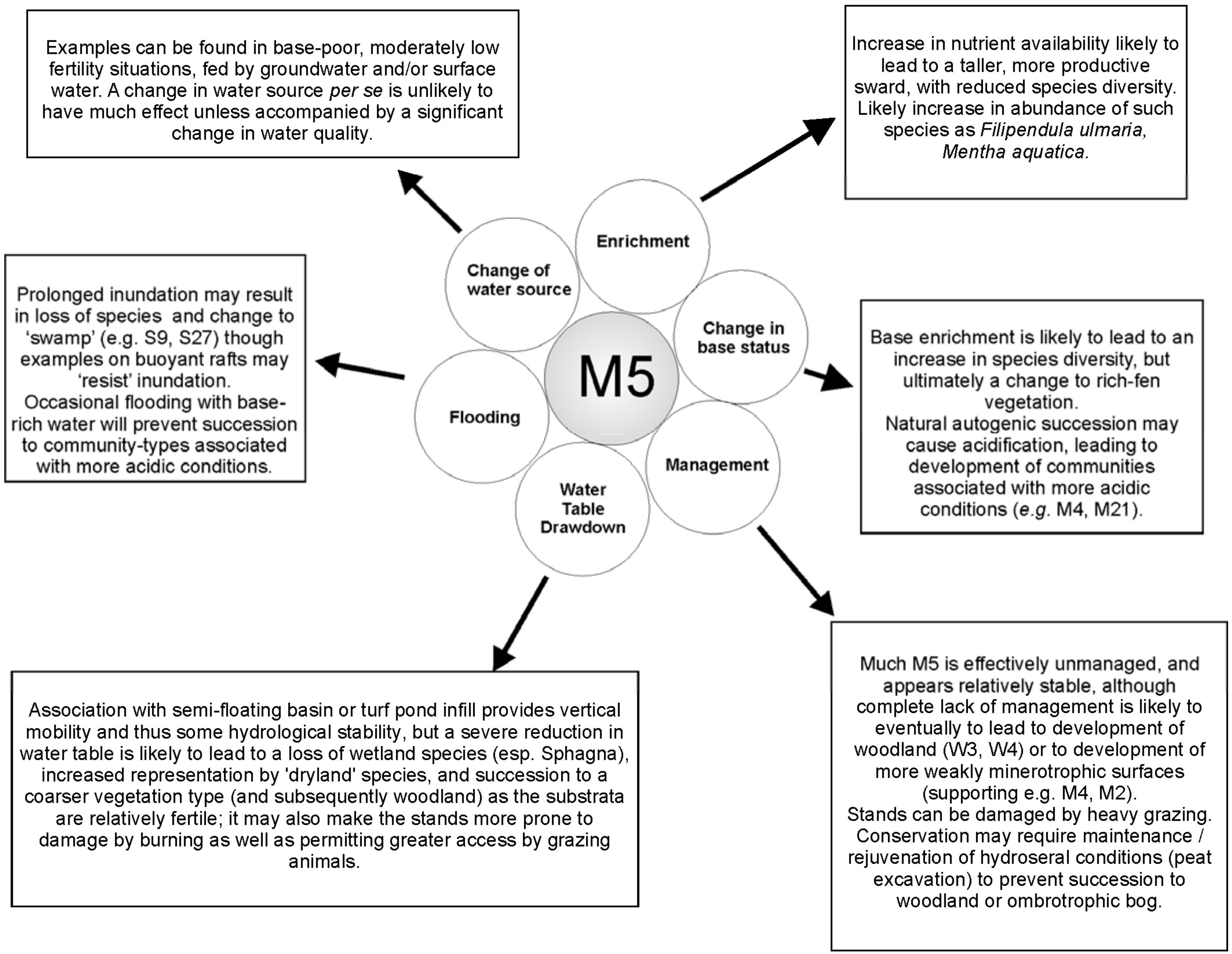


Figure 9.3 Possible effects of environmental change on stands of M5

9.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M5 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M5 in the short to medium term.
- Conservation of this vegetation type may require rejuvenation of the hydroseral conditions (re-excavation of turf ponds).
- Many examples of this community have developed spontaneously in reflooded peat (sometimes marl) workings, pointing to the possibility of restorability. However, the conditions in which re-colonisation of these workings took place, and under which raft formation was initiated, are not well known.

9.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- The data used here are largely based on information held within the FenBASE database.
- There are currently no data to better inform the temporal water table characteristics of M5 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M5 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- Data on the spatial extent of M5 are lacking.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.
- A more thorough assessment is required of the distinctiveness and compass of M5 as a vegetation unit, especially in relation to M4.

10 M9 (*Carex rostrata–Calliergon cuspidatum/giganteum*) mire

10.1 Limitations of M9

Practical experience, and multivariate analyses, suggests that the M9 unit of Rodwell (1991b) has a number of limitations. From the perspective of this project, one difficulty is that it encompasses samples from a range of situations, making it particularly difficult to make generalisations about the community as a whole, or to specify threshold values.

Full examination and resolution of difficulties encountered with M9 is outwith the scope of this project. However, some fairly simple changes are proposed and adopted which appear to alleviate some of the limitations of the unit. As this represents a significant departure from the *de facto* standard provided by NVC, a summary of the rationale and evidence for the proposed changes is given below.

10.2 Concept and status

The M9 unit was introduced by Rodwell as a simplified amalgam of various units identified by other workers, including some from Scotland (McVean and Ratcliffe, 1962; Spence, 1964; Birks, 1973). It also included the *Acrocladio-Caricetum diandrae,* identified by Wheeler (1980b) from England, Wales and the Scottish Borders, and which included much of a unit recognised from Malham Tarn by Proctor (1974). The current discussion refers just to material from England, Wales and the Scottish Borders, and is based mainly on provisional analyses of data from the Welsh Wetland Survey (Ratcliffe and Hattey, 1982), the Cumbria Mire Survey (Fojt, 1994) and a survey of the Scottish Border basin mires (Tratt, 1988), as well as the data collected by Wheeler (1975), Wheeler and Shaw (1987) and Shaw and Wheeler (1990, 1991) and various other data contributed to the FENBASE database (including a number of M9 samples from Wales provided by P.S. Jones). A full re-examination of the status of this syntaxon requires re-analysis of other data from Scotland and Northern Ireland, as well as that from England and Wales. Some useful insights have, however, been gained by an examination of MATCH coefficients and by DCA ordinations of samples of M9 and some related units (Figure 10.1, Figure 10.2)

10.2.1 M9a *versus* M9b

Rodwell (1991b) recognised two sub-communities in M9: M9a (*Campylium stellatum–Scorpidium scorpioides* sub-community); and M9b (*Carex diandra–Calliergon giganteum* sub-community). He tabulated the floristic composition of the two units, but gave no real indication of any environmental or hydrotopographical differences between them, so that it is difficult to determine to what, if any, distinctive ecological contexts they each refer.

M9b corresponded in quite large measure with Wheeler's (1980b) *Acrocladio-Caricetum* association. However, some of the material from that association was ostensibly re-allocated to M9a by Rodwell. Curiously, a MATCH analysis of Wheeler's original data showed that *all* except one of the samples used to create the *Acrocladio-Caricetum* had highest coefficients of MATCH with M9 (community level) or M9b, and not with the M9a to which Rodwell had apparently allocated some of them. This is also apparent on a DCA ordination (Figure 10.1), in which *all* of Wheeler's original samples cluster clearly within the 'M9b area', including those which Rodwell ostensibly moved to M9a.

Examination of the hydrotopographical location of the two M9 units (as identified by MATCH) showed, with few exceptions, the following patterns:

- The great majority of stands which had highest coefficients with M9a were all associated with soakways and water tracks, rather than with basins.
- Of the small number of M9a samples associated with basins, most (a) occurred near the edge of the basins, in apparent close association with telluric water inflow; and (b) on the DCA ordination plotted as close, or closer, to the M9b samples than to the soakway group of M9a (Figure 10.1).

Some samples that matched best with M9a had very close floristic affinities with M13 (Figure 10.2) and could be best allocated into that unit. Samples which did not correspond well to any sub-community of M9 or S27 had highest affinities at the community level.

On the basis of this and other analyses, we consider that there are indeed two fairly discrete units encompassed within M9, but that these seem to differ from the segregates recognised by Rodwell (1991b). In essence, there appears to be a soakway-based community (which essentially represents a cut-down version of M9a) and a basin-based community (which essentially represents samples of M9b plus most basin-based samples of M9a). We suggest that these are better units than those proposed by Rodwell (1991b), as far as the dataset analysed is concerned, because they have discrete floristic and hydrotopographical differences which, moreover, coincide.

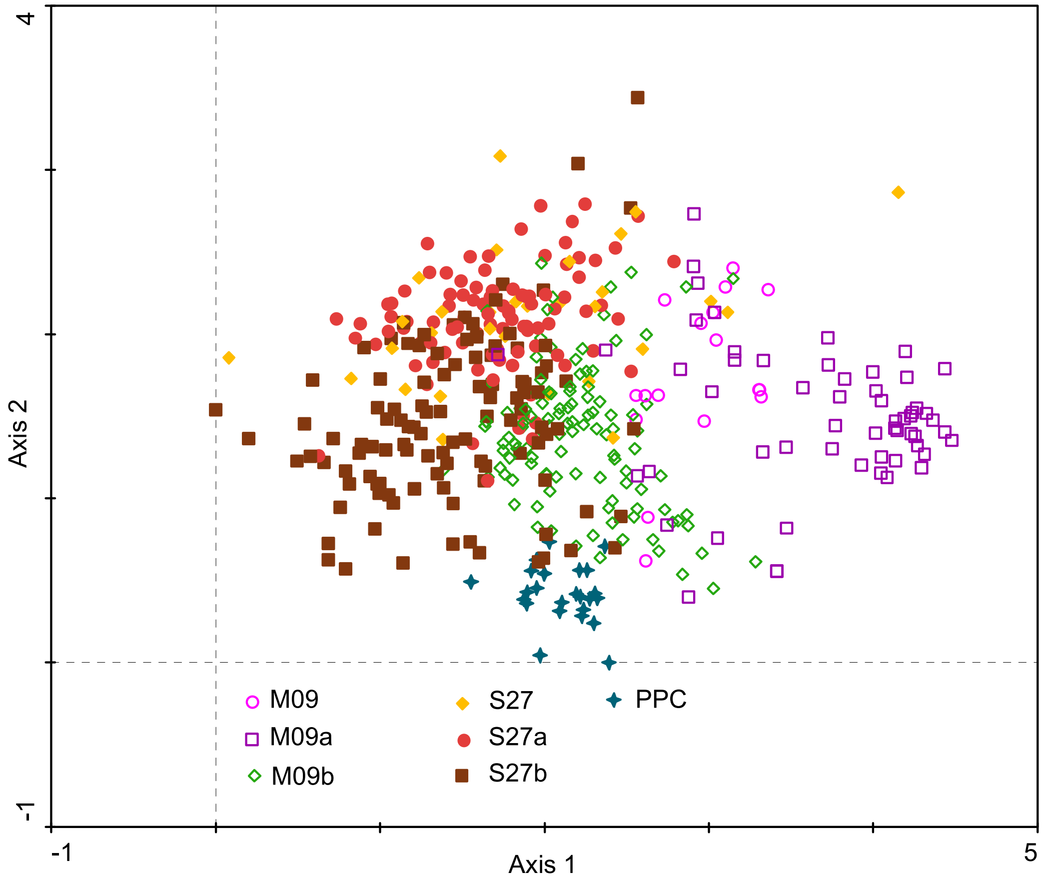


Figure 10.1 Axes 1~2 of a DCA ordination of samples referred to *Carex rostrata–Calliergon cuspidatum/giganteum* mire and sub-communities (M9, M9a, M9b), *Carex rostrata–Potentilla palustris* fen and sub-communities (S27, S27a, S27b) and to the '*Peucedano-Phragmitetum caricetosum*' (PPc) community of Wheeler (1980a)

10.2.2 M9a *versus* M14

When M9a is restricted to samples from soakways, this unit forms a hydrotopographical analogue of soakway-based examples of M14. It was thought possible that rather than being a sub-community of M9, these samples might be better positioned as a sub-community of a conflated M14. Existing data, however, suggest that the two communities occupy fairly discrete sectors of a DCA ordination (Figure 10.2) and that whilst they could be considered sub-communities of the same community, they could equally each be considered a separate one.

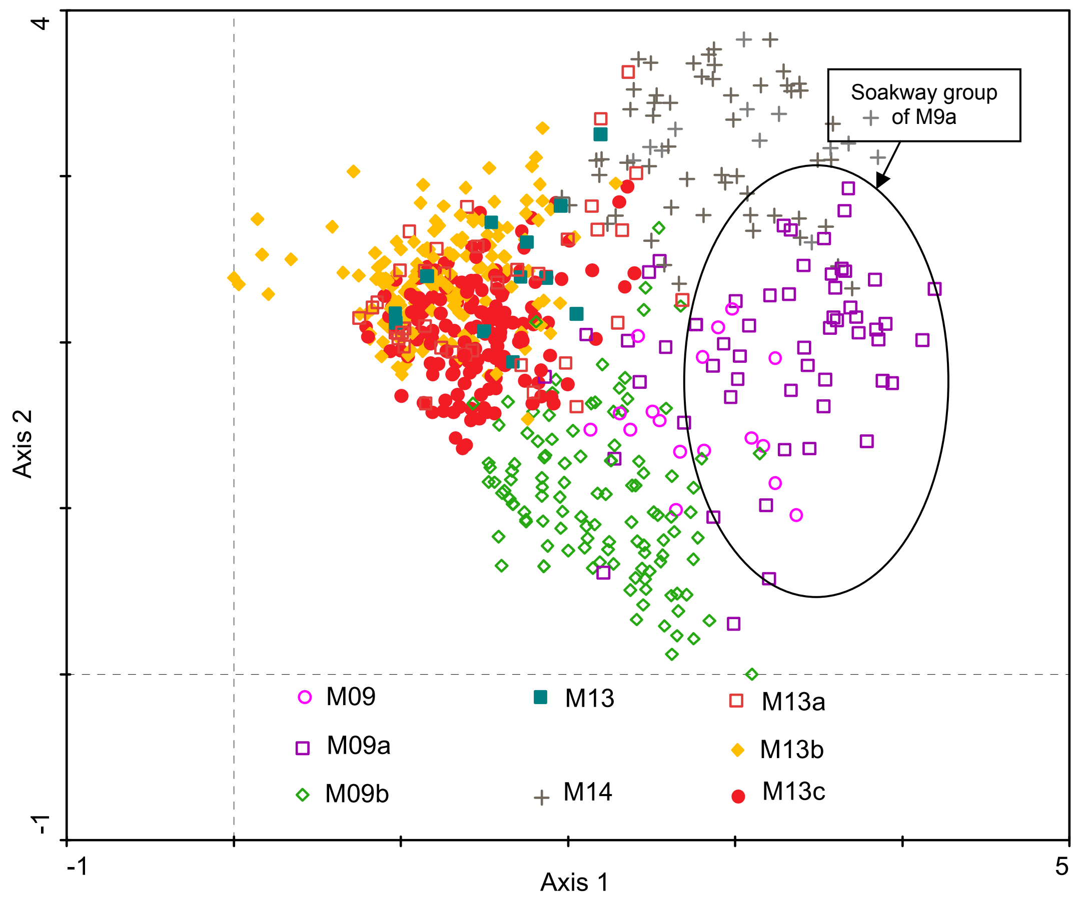
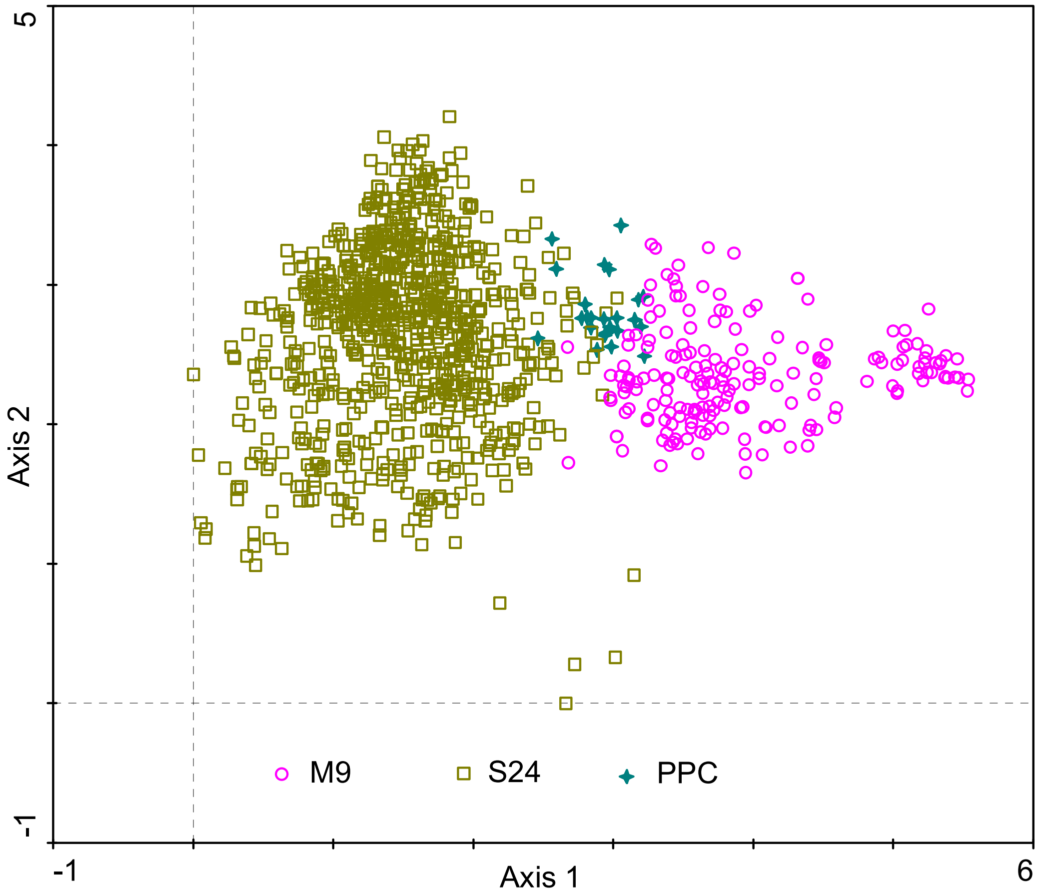


Figure 10.2 Axes 1~2 of a DCA ordination of samples referred to *Carex rostrata–Calliergon cuspidatum/giganteum* mire and sub-communities (M9, M9a, M9b), *Schoenus nigricans–Juncus subnodulosus* mire and sub-communities (M13, M13a, M13b, M13c) and *Schoenus nigricans–Narthecium ossifragum* mire (M14)

10.2.3 M9 *versus* PPc

This *Peucedano-Phragmitetum caricetosum* community (PPc), which is both uncommon and restricted to turf ponds in the Norfolk Broadland, was described by Wheeler (1980a), who noted that it was transitional floristically between the units now known as S24 and M9. As discriminant analysis showed that its greatest affinities were with the *Peucedano-Phragmitetum,* it was classified as a sub-community of that association. Rodwell (1995) took the contrary view and considered it "better placed within the *Carex rostrata–Calliergon* fen" (M9). However, whilst mentioned in his account of M9 (Rodwell, 1991b), no data from the Broadland examples were included in the floristic tables or distribution maps, nor were they allocated to a separate sub-community of M9 (which, in view of their floristic distinctiveness, they undoubtedly demand). Thus, this distinctive and conservationally important community type is not formally represented within the NVC scheme.

The relationship of PPc samples to M9b samples (Figure 10.1) and to M9 and *Peucedano-Phragmitetum* (S24) samples (Figure 10.3) confirm that the community is floristically transitional between S24 and M9 and that, within M9, it forms a discrete cluster most closely allied to the M9b samples. There is, however, a tendency for the PPC stands to be slightly closer to samples of M9 than S24, supporting Rodwell's contention that it may be "better placed within the *Carex rostrata–Calliergon* fen".



With the exception of the PPc, allocation of samples to communities was on the basis of their greatest MATCH coefficient.

Figure 10.3 Axes 1~2 of a DCA ordination of samples referred to *Carex rostrata–Calliergon cuspidatum/giganteum* mire (M9), *Peucedanum palustre–Phragmites* tall herb fen (S24) and to the '*Peucedano–Phragmitetum caricetosum*' (PPc) community of Wheeler (1980a)

10.2.4 M9b *versus* S27

In Wheeler's original classification, the *Acrocladio-Caricetum* (more or less equal to M9b) was a coherent, discrete unit which could usually be distinguished clearly from his *Potentillo-Caricetum rostratae* (more or less equal to S27), though there was some small overlap. This situation has changed considerably in the NVC classification, which has resulted in considerable overlap between M9 and S27 and blurring of their definitions. The cause of this may be due to the incorporation of a number of less species-rich samples (particularly from Scotland) into M9 (rather than S27), and a consequence is that M9 has become a rather nebulous and ill-defined unit, for which it is difficult to specify environmental thresholds.

10.3 Proposals for change

For the purposes of this report, the following proposals are made:

i. M9a is (re-)defined on floristic grounds (for details, see Section 11.1.2) as an apparently smaller and more cohesive unit than that described by Rodwell. This means that it is largely restricted to containing samples from soakways and allied situations. As explained above, this reduction in compass is perhaps more apparent than real. It is possible that this unit could be considered to be a sub-community of a conflated M14, but this is considered premature and the soakway-based ‘M9a’ is regarded here as a separate community: M9-1, *Carex lasiocarpa–Scorpidium* mire.

ii. M9b contains the samples of M9 that occur in basins. It includes all of M9b and some stands apparently allocated to M9a by Rodwell (1995), but which have closest floristic affinities with M9b. It corresponds fairly closely with Wheeler’s original concept of *Acrocladio-Caricetum diandrae.* It is here regarded as a separate community: M9-2, *Carex diandra–Calliergon* mire).

iii. The PPc is floristically transitional between M9 and S24 but, as Rodwell (1995) suggested, it is probably better considered as a relative of M9 than S24 (this is certainly the case on ecohydrological grounds). It could be considered as a sub-community of M9-2, but for simplicity is regarded here as a separate community: M9-3, *Carex diandra–Peucedanum palustre* mire.

iv. There is a need to resolve better the relationship between M9-2 and S27, but this is not feasible within the constraints of the present study.

To avoid confusion, the units as recognised here have been given separate identities (M9-1, M9-2, M9-3) rather than regarded as M9a and M9b with revised compass.

11 M9-1 *Carex lasiocarpa–Scorpidium mire*

11.1 Context

Examples of the M9-1 community have been included in the “calcium-rich spring water-fed fens”, SAC feature, as well as “transition mire and quaking bog”, and “chalk-rich fen dominated by saw sedge”. [See Tables 3.1 and 3.3]

11.1.1 Concept and status

The rationale for the recognition of M9-1 as a vegetation unit has already been discussed (Section 10). In essence, it is composed of almost all of the vegetation samples which had highest affinities with M9a in MATCH analyses. It does not, however, correspond exactly with the scope of M9a as described by Rodwell (1991b). This is because Rodwell has included within the synonymy (and therefore his view of the compass) of M9a a number of described communities which contain samples that have highest affinities with M9b (based on MATCH and other analyses). Nonetheless, it is possible that the difference between M9-1 and M9a is more apparent than real: the solution proposed here is further removed from Rodwell’s statement of the compass of M9a than it is from the actual compass of M9a as revealed by his data tables. However, another reason for distinguishing M9-1 as a separate unit is because together, M9a and M9b constitute a heterogeneous unit (M9) which it is particularly difficult to characterise ecohydrologically. In contrast to the impression given by Rodwell’s synonymy, M9-1 is not particularly associated with calcareous conditions: indeed, it contains some of the more base-poor samples of M9.

The identification of M9-1 should be seen as the first step in a better resolution of the vegetation classification in the area of M9, rather than as a definitive solution. Preliminary analyses suggest that it may well be possible to identify sub-communities within M9-1, in effect further subdividing the community with respect to base status. The relationships of M9-1 with M14 and M29 also need to be further explored and clarified. A DCA ordination shows that all three communities occupy fairly discrete sectors of the ordination, but with some overlap and transitions.

Whilst our proposals may help clarify the segregation between samples referred to M9-1 and M9-2, as with many community comparisons some stands transitional between the two units still occur. For example, at Cors Gyfelog (Caernarfon) some of the vegetation has strong affinities with M9-1, M9-2 and M29 and remains difficult to resolve syntaxonomically.

11.1.2 Floristic composition

A distinct type of vegetation of sluggish soakways, water tracks and some gentle soligenous slopes. It corresponds broadly, but not exactly, to the sub-community M9a of Rodwell (1991b).

The most constant species are: *Carex rostrata, Carex panicea, Eriophorum angustifolium, Molinia caerulea, Potamogeton polygonifolius* and the bryophytes *Aneura pinguis, Campylium stellatum, Drepanocladus revolvens* and *Scorpidium scorpioides.*

The vegetation is moderately species-rich (10 to 46 species per sample; Table 11.1), usually dominated by sedges of medium height, often presiding over an open stand of vegetation, with bare mud and open water, often with extensive carpets of bryophytes. *Carex rostrata* is the most typical and constant species of sedge (*Carex lasiocarpa* occurs quite frequently but only in about 30 per cent of the samples and *Carex diandra* is not very characteristic (10 per cent of samples)), However, some stands lack a medium sedge layer and lower-growing species predominate. The most widespread of these is *Carex panicea,* but a variety of other cyperaceous species can also occur, including *Eleocharis multicaulis, E. quinqueflora* and, sometimes, *Schoenus nigricans.* A total of 25 rare mire species were recorded within this vegetation type (Table 11.1).

The bryophyte layer is often well developed. *Campylium stellatum, Drepanocladus revolvens* and *Scorpidium scorpioides* are the most constant and, very often, most abundant species, but Sphagna are also often well represented, especially those species that are particularly tolerant of base-rich conditions. Both the widespread *S. subnitens* and the rarer *S. contortum* were each recorded in about half of the samples, often with quite high cover. Other *Sphagnum* species occur with lower constancy, such as *Sphagnum auriculatum, S. palustre, S. recurvum.*

Table 11.1 Number of species recorded in stands of M9-1

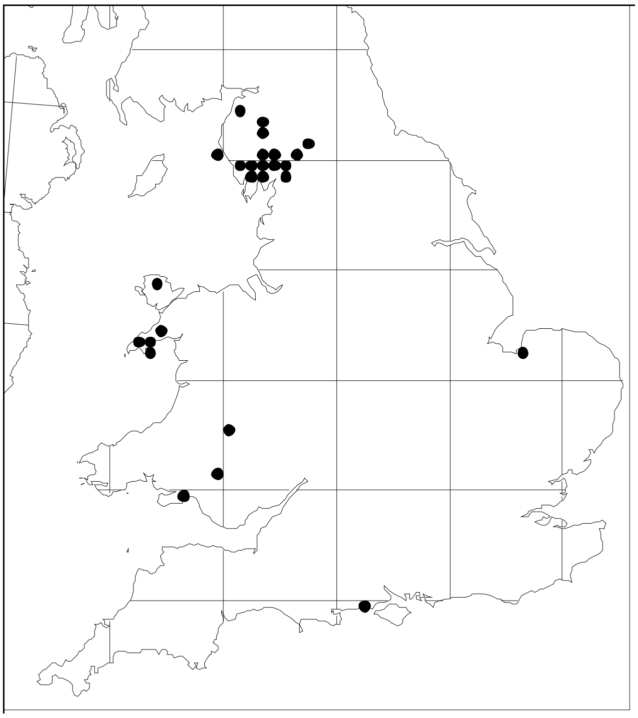
	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	191	25.7	0.17	10	46
Mire species (spp 4 m^{-2})	129	23.5	0.15	10	41
Rare mire species* (spp 4 m^{-2})	25	2.4	0.11	0	8

** These include: Andromeda polifolia, Calliergon giganteum, Calliergon sarmentosum, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Cladium mariscus, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Drosera intermedia, Epipactis palustris, Eriophorum gracile, Eriophorum latifolium, Hammarbya paludosa, Oenanthe lachenalii, Osmunda regalis, Rhizomnium pseudopunctatum, Selaginella selaginoides, Sphagnum contortum, Sphagnum subsecundum, Sphagnum warnstorfii, Thuidium deliculatum, Utricularia intermedia, Utricularia minor.*

11.1.3 Distribution

M9-1 is widely distributed, but uncommon in England and Wales (recorded from 52 wetland sites, Figure 11.1). The greatest concentration of sites is in the North and West, particularly from parts of South Cumbria, such as Subberthwaite Common, where it may be a vicariant of M14. The samples from East Anglia and the New Forest are transitional to M14 and some other samples from these sites have been allocated to M14. The M9-1 samples differ from their M14 counterparts by the absence of *Schoenus* and *Narthecium*, but the distinction is small and a case could be made for allocating these samples to M14. The community typically occupies flow lines and soligenous slopes irrigated with fairly base-rich water, though in many instances the water is not as base-rich as in locations supporting M9-2.

Some (rather anomalous) examples of this community have been recorded from Crymlyn Bog (Glamorgan) (such as alongside the head of the Glan-y-Wern canal), and these contribute important populations of some less common species (such as *Carex limosa, Eriophorum gracile*).



(data from FenBASE database)

Figure 11.1 Distribution of M9-1 in England and Wales

11.1.4 Landscape situation and topography

Most characteristic of valleyhead sites, where it occurs in small runnels, soakways or, occasionally, on soligenous slopes. Some examples are associated with valleyhead basins, on the slopes and small valleys feeding into the basins, but a few examples are known in the basin proper. In this situation, M9-1 mainly occurs near the margins and associated with localised water inflows, but in a few cases it occupies a soakway across part of the basin (*cf.* M29).

11.1.5 Substratum

In most sites the vegetation forms a fairly soft mat. In some it is quaking and semi-floating, though the degree of solidity and the depth of fluid peat/water beneath it varies (values of 30 to 50 cm are typical). Beneath the upper horizons, peat depth varies from more than three metres depth in some valleyhead troughs to a skeletal deposit. Some examples of the community, especially on or adjoining soligenous slopes, have developed over a soft, often muddy, deposit rather than a quaking one. Examples from Crymlyn Bog occupy a quaking surface over some six metres of peat, but these are exceptional.

Most examples of the community are not specifically associated with calcareous rocks (an example from Tarn Moor (Sunbiggin) is an exception). The Cumbrian examples are mostly associated with various Silurian deposits, and this applies also to some examples from Wales. However, the community is associated with a range of deposits, and in some cases (such as Rhyd-y-Clafdy, Cors Geirch (Caernarfon)) it is apparently fed by groundwater from a sand and gravel minor aquifer.

11.1.6 Zonation and succession

Many examples of M9-1 typically occur as soakways and water tracks within valleyhead mires, and their zonation depends strongly on their hydrotopographical context. Examples sometimes occur as more or less isolated mire units, bordered by drier habitats, but the majority are embedded within a wider mire habitat. Adjoining communities depend upon the topographical context and base status, and can include M10, M13 or M22. However, the less base-rich examples are typically flanked by M21 vegetation, where they may form part of a clear axial zonation from a watercourse through M9-1 to soligenous slopes. In certain circumstances M9-1 forms fairly discrete trails within topogenous hollows, probably marking zones of greater water flow, and in these circumstances it may be flanked by various topogenous communities, including M9-2 and various poor-fen surfaces.

Little information is available on successional trends in this community. Most examples are so small that they have not received consideration separate from the larger, flanking mires, and the development of this community is probably inextricably bound with these (see 18.1.6). It is possible that many examples of M9-1 may be too wet for scrub encroachment, but their frequently narrow width means that they could easily become overtopped by a canopy of woody plants developed on drier terrain alongside, a process which would probably result in loss of the community as a distinctive entity, as most of its species are heliophiles.

In the small number of locations where M9-1 occurs in topogenous locations, it appears to form part of the hydroseral process, albeit one that may be disruptive of the generic hydroseral pattern. The vegetation of the north-western arm of Cors Gyfelog (Caernarfon) contains stands that have closest affinities to M9-1 (though they are also closely related to M9-2 and M29). This site seems likely to be a reflooded turbary and the M9-1 stand trails may perhaps be seen as units that are emerging in the hydroseral succession, and in this context they may be vulnerable to surface acidification or scrub encroachment (or both). However, they are not good examples of M9-1 (or, indeed, of any other described community) and may be considered anomalous. Nonetheless, it is clear that some examples of good M9-1 are late-successional derivatives of terrestrialisation in lake basins. As is the case with M21 (18.1), examples of M9-1 in the valleyhead troughs of Southern Cumbria in some cases occupy troughs which have developed over, and expanded beyond, former lake basins. The peat infill has sometimes obliterated any surface evidence for the former lake basin and the water flow which supports the stands of M9-1 occurs across the surface of what is now a gently sloping trough of peat, superimposed upon the former lake basin.

11.2 Water supply mechanisms and conceptual model

Forty-five per cent of samples were identified as occurring within WETMEC 19 (Flow Tracks, such as many of the Subberthwaite Common mires (Cumbria)), with 20 per cent within WETMEC 15 (Seepage Flow Tracks, such as Tarn Moor, Sunbiggin (Cumbria)). Ten per cent occurred within each of WETMECs 10, 13 and 18.

The examples of M9-1 examined are mainly associated with axial soakways embedded within valleyhead systems, and these are often flanked by Percolation Troughs or soligenous slopes. In a few cases M9-1 occupies flow lines within soligenous slopes, and very occasionally it forms the greater part of a gently sloping soligenous surface.

Some M9-1stands are unquestionably primarily groundwater-fed, including those at Cors Geirch, Tarn Moor (Sunbiggin) and the examples transitional to M14 on the Lower Greensand in Norfolk and Eocene deposits in the New Forest. In many other cases the role of groundwater is much less certain, and this is reflected in the allocation of the majority of samples to the flow tracks of WETMEC 19. These are all in locations where hydrogeological, hydrotopographical and climatic circumstances suggest that if groundwater supply occurs at all, it is likely to be supplemented significantly by surface water inflow into the mires. This is particularly the case for the important examples in South Cumbria. These are largely located upon Silurian deposits, the importance of which for groundwater supply is little understood. In many instances, fracturing of the upper horizons of these deposits may form a minor aquifer that contributes to the water budget of the mires. It is tempting to suggest that groundwater outflow from such rocks may provide the main source of base-enrichment associated with M9-1, if not necessarily the main source of water.

Examples of M9-1 are mostly associated with summer-wet conditions. Four mechanisms appear to contribute to this, though not all necessarily occur in each example: (i) a fairly consistent water supply, provided by high rates of groundwater outflow, or high rainfall (or both); (ii) association with surface water flow lines, either through the community or as small water tracks or watercourses alongside it; (iii) a quaking surface which probably has some hydroregulatory function; (iv) semi-fluid substratum below the surface, which may provide a preferential flow path.

11.3 Regimes

11.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 11.2, together with mean recorded values for summer water table associated with stands of M9-1.

Table 11.2 Mean rainfall, potential evaporation and summer water table for M9-1

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	1,447	1,030	1,831
Potential evaporation (mm a^{-1})	547	454	646
Mean summer water table (cm agl or bgl)	3	–25	36

The water table is normally consistently high beneath M9-1 stands, usually just above or below the surface, sometimes forming shallow swamp (especially in winter or after heavy rain). Although a few examples with low summer water tables were recorded, they are exceptional (only four per cent of samples had a summer water table less than one cm bgl) and the cause of this is unknown, though they were all associated with more solid peat infills than is usually the case. The highest water tables were associated with unconsolidated surfaces and were probably, in part, an artefact associated with depression of the vegetation raft during sampling.

Specific time-series data for stands of M9 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Typically, consistently at or just above surface level year round, particularly where forming a floating raft.
- Association with a buoyant surface provides some vertical mobility and hydrological stability.
- In some of the broader, flatter examples, flooding of the surface with base-rich water may be important in constraining the extensive development of

ombrotrophic nuclei and succession to community types associated with more acidic conditions.

- Some examples of this community have been recorded in low water conditions, but these are exceptional, and probably not in equilibrium with the water regime.
- Examples of this community appear to be associated with water movement, occurring either in soakways, alongside water tracks, or (occasionally) near the margins of some basins where water inflow is apparent or suspected. Water flow data are not available, but are generally likely to be greater than in M9-2 and M9-3.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can therefore be speculated that these would lead to a loss of wetland species and increased representation by dryland species. In instances where the community occupies axial soakways it can be, and in some locations almost certainly has been, destroyed by ditching.
- Prolonged, deep inundation leading to stagnation, particularly in the spring or summer, is likely to kill some species and lead to development of less diverse vegetation types.

11.3.2 Nutrients/hydrochemistry

Typically found in situations of intermediate to fairly high base status with respect to the main rich and poor-fen communities, although it covers a wide range. It is very likely that it would be possible to divide the community into two floristic sub-communities that would correspond respectively to samples from intermediate and fairly high base-status locations, but this is outwith the scope of the present project. Conditions are generally of low or moderate fertility, and on average samples are slightly, but significantly, less fertile than those of the related M9-2.

Figures for pH, conductivity and substratum fertility measured in stands of M9 are presented in Table 11.3.

Table 11.3 pH, conductivity and substratum fertility measured in stands of M9

Variable	Mean	SE	Minimum	Maximum
Water pH	6.0	0.03	5.0	6.9
Soil pH	5.8	0.04	4.8	7.4
Water conductivity (K_{corr} µS cm^{-1})	249	1.8	33	1051
Substratum fertility[1] (mg phytometer)	6.7	0.15	4	14

11.3.3 Management

Many examples of this community are potentially exposed to grazing by livestock, but the importance of this in maintaining the character of the vegetation is not known. In most cases,

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

management of examples of M9-1 is inextricably dependent on management of the wider mire habitats in which the stands are embedded. Likewise, seral processes may be dominated by events on adjoining surfaces, and a woodland canopy may be able to overtop examples of M9-1 from shrubs growing alongside the community more readily than scrub can colonise it directly.

11.4 Implications for decision making

11.4.1 Vulnerability

M9-1 is likely to be particularly vulnerable to a prolonged overall lowering of water tables, and some of the narrower examples could be completely destroyed by ditching. In addition, a reduction of base-rich water inflow is likely to be detrimental to the community, even in contexts where the overall water level within the vegetation is little changed. The weakly buffered character of the less base-rich examples of this community may mean that they are particularly vulnerable to processes of acidification within its catchment, and its specific characteristics suggest that it may be among the most sensitive of all mire communities to acid deposition.

This low-fertility community is likely to be sensitive to eutrophication, and examples fed by surface water could be particularly vulnerable to this. However, many examples are in remote, rough grazing locations that are not obviously subject to a significant eutrophication threat.

It is possible that ungrazed examples of this community could become colonised by woody plants, especially in the small number of stands from topogenous locations. In many of the smaller stands, a bigger seral threat could come from overtopping by woody plants that have colonised unmanaged surfaces adjoining the M9-1 stands.

Figure 11.2 outlines some of the possible floristic impacts of changes to the stand environment.

The possible effects of environmental change on stands of M9-1

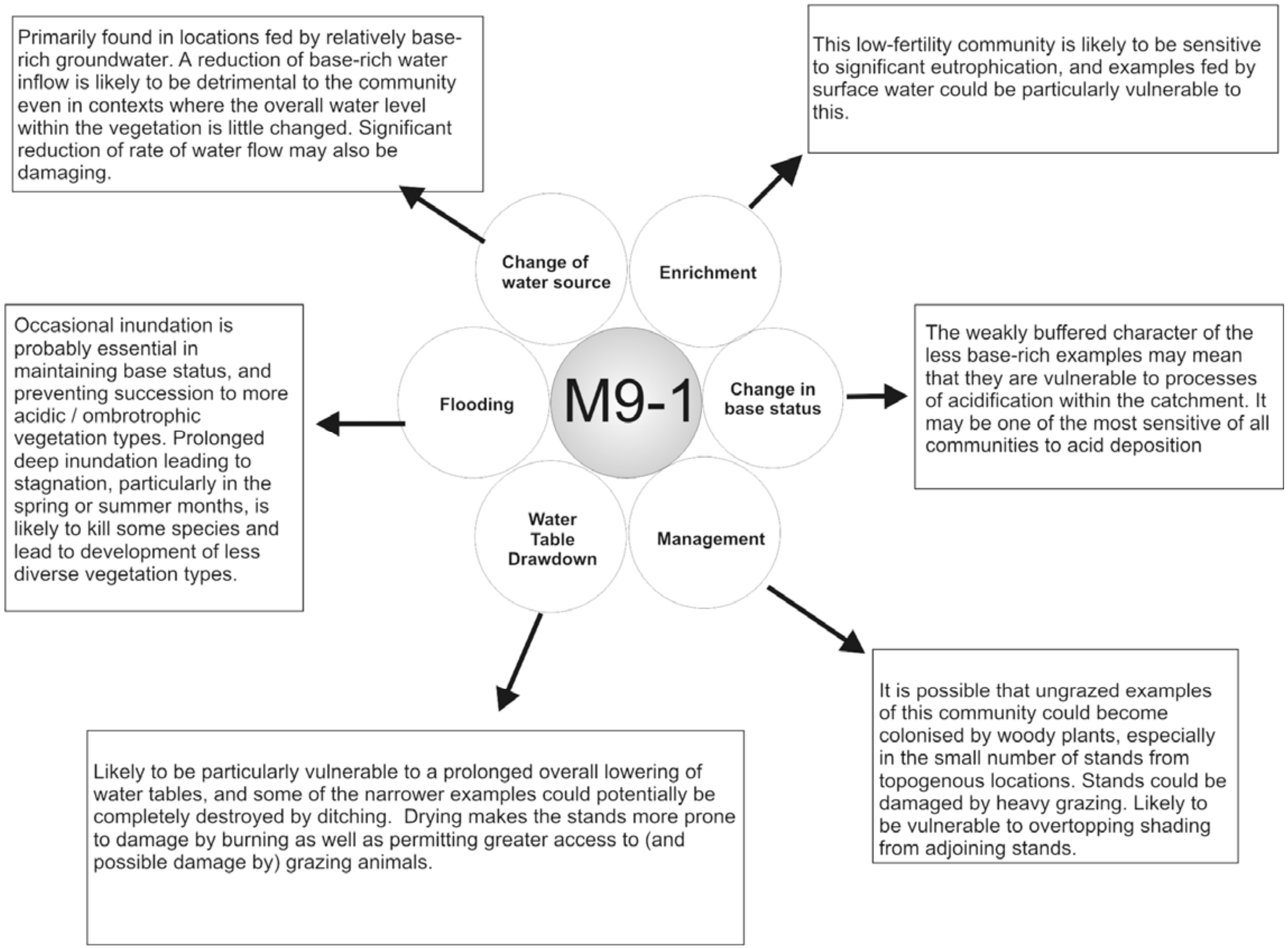


Figure 11.2 Possible effects of environmental change on stands of M9-1

11.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage, and how far the starting conditions deviate from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M9-1 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M9-1 in the short to medium term.
- Prolonged water drawdown, which has resulted in loss of water flow and mineralisation of nutrients from the peat, may require many years to reverse.

11.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here related to M9-1 include the following.

- There are currently no data to better inform the temporal water table characteristics of M9-1 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M9-1 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This is especially the case in locations where the role of groundwater is uncertain and may require detailed ecohydrological investigations at representative sites.
- The relationship of M9-1 to M14 and M29 merits further clarification, along with the possible identification of sub-communities within M9-1.
- Data on the spatial extent of M9-1 are lacking.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

12 M9-2 *Carex diandra–Calliergon* mire

12.1 Context

Examples of the M9-2 community have been included in the "calcium-rich spring water-fed fens", SAC feature, as well as "transition mire and quaking bog", and "chalk-rich fen dominated by saw sedge". [See Tables 3.1 and 3.3]

12.1.1 Concept and status

The rationale for the recognition of M9-2 as a vegetation unit has already been explored (Section 10). In essence, it conforms largely to the compass of the *Acrocladio-Caricetum diandrae* unit recognised by Wheeler (1980b), but it does not include the *sphagnetosum* sub-association. [Stands from this sub-association have closest floristic affinities elsewhere, and some are perhaps best seen as a lowland version of the montane *Carex rostrata–Sphagnum warnstorfii* mire (M8)]

The identification of M9-2 should be seen as an early step in a better resolution of the vegetation classification in the area of M9, rather than as a definitive solution. Preliminary analyses suggest that it may well be possible, and desirable, to identify sub-communities within M9-2, but this has not been attempted here. An additional problem outwith this project is the considerable overlap between M9-2 and S27, which is similar to that between M9 and S27. In this respect M9-2 is no worse than M9, but nor is it significantly better.

12.1.2 Floristic composition

A distinct type of vegetation of rheo-topogenous, mainly lowland locations, which broadly corresponds to the sub-community M9b of Rodwell (1991b).

Typically quite species-rich vegetation, but rather variable, and with a wide range of species per sample (mean 29, range nine to 69 species per sample; Table 12.1). The community is usually dominated by Cyperaceae (such as *Carex diandra, C. lasiocarpa, C. rostrata* and *Eriophorum angustifolium*), but sometimes with much *Cladium mariscus* or *Phragmites australis*. There is usually a rich variety of associates, most commonly *Potentilla palustris* and *Menyanthes trifoliata.* Bryophytes, mainly "brown mosses" (especially *Calliergon* species and *Drepanocladus revolvens*), are conspicuous in many examples of this vegetation, and can form a large proportion of the autumn standing crop (Shaw and Wheeler, 1991). Some stands support nationally uncommon or rare fen species such as *Carex appropinquata, C. limosa, Eriophorum gracile, Sphagnum contortum* (Table 12.1).

The most constant species (from the England and Wales dataset) are *Galium palustre, Juncus subnodulosus, Mentha aquatica, Menyanthes trifoliata, Potentilla palustris* and the bryophyte *Calliergon cuspidatum.* Of these species, only *Menyanthes* is similarly constant in M9-1, and these species alone provide an indication of some of the floristic differences between the two communities. Other differences include much more *Carex diandra* in M9-2 samples (73%) than M9-1 (2%); less *C. lasiocarpa* (19% *versus* 27%); much less *Scorpidium scorpioides* (13% *versus* 72%) and more *Calliergon giganteum* (35% *versus 7%*) and, particularly, *C. cuspidatum* (98% *versus* 43%) *Sphagna* are generally poorly represented in this community, with *Sphagnum subnitens* (4%), *S. palustre* (1%) and *S. contortum* (0.5%).

Table 12.1 Number of species recorded from stands of M9-2

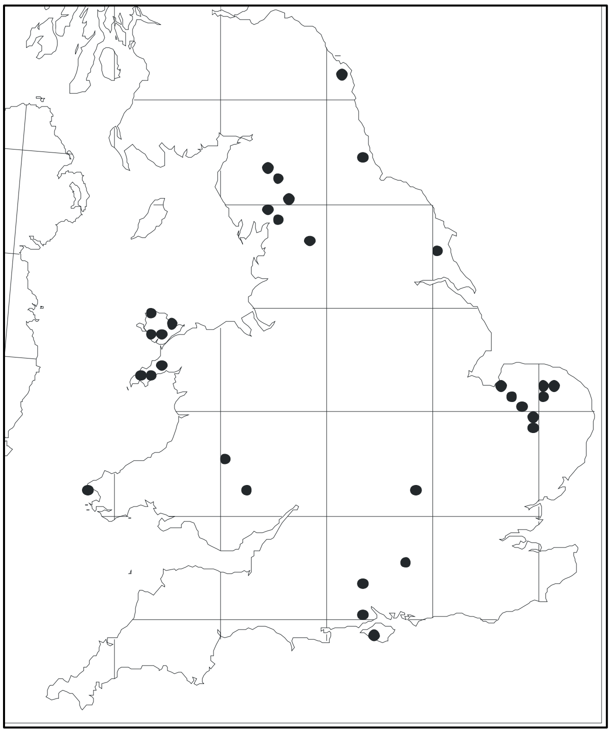
	Total	Mean	SE	Min	Max
All species (spp 4 m^{-2})	243	28.9	0.18	9	69
Mire species (spp 4 m^{-2})	151	24.1	0.16	7	55
Rare mire species (spp 4 m^{-2})	29	2.6	0.10	0	9

** These include: Calamagrostis stricta, Calliergon giganteum, Campylium elodes, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Carex viridula ssp viridula, Cladium mariscus, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Eleocharis uniglumis, Epipactis palustris, Eriophorum gracile, Eriophorum latifolium, Hypericum undulatum, Oenanthe lachenalii, Philonotis calcarea, Plagiomnium elatum, Plagiomnium ellipticum, Potamogeton coloratus, Primula farinosa, Pyrola rotundifolia, Ranunculus lingua, Rhizomnium pseudopunctatum, Sphagnum contortum, Stellaria palustris, Thelypteris palustris*

12.1.3 Distribution

Widely distributed in lowland England and Wales (recorded from 37 sites; Figure 12.1), but very scattered; mainly found in the North and West but rare in the South and East. The main centres of distribution of this community are in regions with shallow ground basins irrigated by base-rich water, for example, in some basins in the Carboniferous Limestone and some other deposits in Anglesey and in a few places in North-West England (such as Malham Tarn, Sunbiggin Tarn). The examples from East Anglia are mainly from small ground hollows (pingos) or other basins, including some very small depressions within seepage slopes. Most of these examples are small and fragmented, not in good condition, and the distribution map exaggerates the importance of M9-2 in this region. Some of the best examples of this community occur in the basin mires of the Scottish borders, but these are outwith the compass of the current project.

It is likely that this type of vegetation was once more widespread in Eastern England than it is at present, but it is often difficult to distinguish former occurrences of this vegetation from those of M13 on the basis of past species records, because of shared floristic features. However, there is strong reason to suspect that M9-2-type vegetation once occurred along the margins of some small floodplains, where there were significant groundwater inputs, especially in reflooded turbaries (such as Blo' Norton Fen (Norfolk), Tuddenham Turf Fen (Suffolk)).



(Data from FenBASE database)

Figure 12.1 Distribution of M9-2 in England and Wales

12.1.4 Landscape situation and topography

Particularly characteristic of basin mires, including some ground ice hollows, but also associated with natural sumps, reflooded peat pits or even occluded drains within a variety of wetland contexts, including floodplain and valleyhead fens. A few examples occur in tiny depressions embedded within wet soligenous slopes, or around the margins of open water (such as Sunbiggin Tarn, Cumbria).

12.1.5 Substratum

In nearly all sites, except for some partly drained examples, the vegetation forms a soft mat. In some it is quaking or semi-floating, though the degree of solidity and the depth of fluid peat/water beneath it varies considerably: at East Walton Common (Norfolk), there is about one metre of very fluid material beneath M9-2 rafts; at Great Cressingham Fen (Norfolk) it is about 40 cm. Beneath the upper horizons, peat depth is also variable. In many sites there is only a shallow accumulation of lower peat, but in some of the deeper basins the peat infill is correspondingly deeper. Many of the basins are clearly hydroseral, with lake muds or more frequently, marl at depth. In other sites the peat is underlain by silty sands or sands and gravels; examples at Stockbridge Fen (Hants) are in old turbaries embedded within the rather complex alluvial infill of the River Test.

Some examples are clearly associated with strongly calcareous rocks (Carboniferous Limestone or Chalk), but others are associated with base-rich Drift (such as Irish Sea Till in Pembrokeshire).

12.1.6 Zonation and succession

Examples of M9-2 occur in a variety of contexts and can be closely, if sometimes unconformably, associated with other vegetation types (such as M10, M13, M22, M24). Some examples, such as those in the turbaries of Stockbridge Fen (Hants), are abruptly embedded within alluvial grassland. Even some of the larger examples show little evidence of natural zonations, probably because of drainage initiatives (such as Great Cressingham Fen) or peat extraction. At Cors y Farl (Anglesey), M9-2 occurs as small fragments peripheral to a large area of *Cladium* swamp (S2) which occupies most of the basin. S2 and M9-2 are also juxtaposed at Cors Goch (Anglesey), where in general S2 is in the wettest locations, sometimes around small pools, and flanked by some quite extensive stands of M9-2. In other basin contexts, M9-2 may occupy almost all of the shallow depression (such as Bryn Mwcog, Anglesey) or adjoin, more or less directly, upon open water (such as East Walton Common (Norfolk), Sunbiggin Tarn (Cumbria)), though usually with a narrow band of separating swamp. In only a few of these examples does M9-2 form part of a clearly interpretable hydroseral zonation pattern, which may be due either to the natural vagaries of the sites, or the fact that most of them have been disturbed by past peat extraction (though to an extent that is often not obvious). This contrasts with the more consistent hydroseral patterns of M9-2 in some of the basin mires of the Scottish Borders (though many of these also have been dug extensively for peat and marl).

Stratigraphical examination of successional sequences in the Border Mires (Tratt, 1998) suggests that M9-2 normally arises hydroserally from a preceding phase of (usually *Carex rostrata* or *Equisetum fluviatile*) swamp, typically as a buoyant raft which can sometimes be rather extensive. This may be quite persistent or may become colonised by scrub (usually to form the W3 community) or become invaded by *Sphagnum* and acidify. *Sphagnum* areas may be initiated on particularly buoyant rafts, but in the majority of cases these consolidate to form a central zone of acidic fen (M5 and then M4) surrounded by a moat of M9-2, which can be seen as a proto-lagg around an incipient ombrogenous surface. In a few locations, however, there is little evidence for the development of M4 and M5 surfaces, but multinucleate acidification occurs within M9-2, to form a species-rich mosaic of *Sphagnum* hummocks (often with prominent *S. warnstorfii*) separated by a base-rich depressions and pools. This vegetation was regarded by Wheeler (1980b) as a *sphagnetosum* sub-association of his *Acrocladio-Caricetum diandrae*, but Rodwell (1991b) allocated it to M9a.

Current data analyses suggest that such vegetation is indeed not part of M9-2, but nor is it very close to M9-1 – rather, it is best seen as a lowland version of M8 (*Carex rostrata–Sphagnum warnstorfii* mire), a community which Rodwell (1991b) describes as being restricted to the 'montane zone'. Tratt (1998) presents evidence that these two main pathways of acidification may relate to the character of the surface mat: succession to M5 and M4 is often concentrated towards the centre of the basins and is associated with the gradual consolidation of a buoyant raft, whereas succession to M8 is associated with more stable surfaces, or rafts upon only a shallow depth of fluid material. In the development of M5 and M4, the buoyancy of the raft quickly isolates the surface from inundation with base-rich water and provides an appropriate environment for the accumulation of a quite thick *Sphagnum* peat, whereas in the M8 succession much of the surface is persistently inundated with base-rich water, and any acidification is not buoyancy-dependent but is determined more by the localised establishment of *Sphagnum* hummocks in niches above the telluric water, such as may be provided by tussock-forming plants. However, in both instances it seems likely that the ultimate end point of the succession will be an ombrotrophic surface.

Examples of M9-2 in England and Wales rarely show the clear acidification zonations found in the Border Mires, but elements of the succession can sometimes be found. For example, at Cors Goch (Anglesey) localised acidic surfaces occur within the fen, which have developed as seral innovations from M9-2, probably on buoyant surfaces. In other sites, however (such as Newton Reigny Moss, Cumbria), elevated acidic surfaces associated with

M9-2 more often represent the residual baulks left within turbaries. A number of the M9-2 localities in North-West England are in peat workings within former small raised bogs, though in most cases there is little residual ombrogenous surface. It is quite possible that other sites such as Cors Goch may also be former raised bogs in which the ombrogenous peat has been so comprehensively removed that there is no residual stratigraphical evidence for their former status. In some apparently undisturbed basins in the Scottish Borders, M9-2 occupies a narrow lagg around slightly Domed Ombrogenous Surfaces.

12.2 Water supply mechanisms and conceptual model

Fifty-nine per cent of samples were identified as occurring within WETMEC 13 (Seepage Percolation Basins, such as Cors Goch (Anglesey), East Walton Common (Norfolk), Newton Reigny Moss (Cumbria)), with 18 per cent within WETMEC 18 (Percolation Troughs such as Cliburn Moss (Cumbria)) and nine per cent in WETMEC 20 (Percolation Basins such as Dowrog Common (Pembrokeshire)). There were a few occurrences within WETMECs 7, 8, 9, 14, and 19.

The majority of examples of M9-2 are in basins that are primarily groundwater-fed. Inputs of rain-generated run-off may occur in certain situations, but are probably of little consequence to the summer water balance (though some storage may occur). Two of the stands in East Anglia (Badley Moor and Booton Common) are associated with strongly artesian chalk aquifers and are effectively depressions embedded within a mainly soligenous system. In the Phase 1 analysis these were clustered as a variant form of seepage slopes, but in the present analysis they have been clustered as a sub-unit of WETMEC 13, to which conceptually and functionally they clearly belong, despite their small size and situation.

Examples of M9-2 associated with Carboniferous Limestone in Ynys Môn (such as Cors Goch, Cors y Farl) also appear to be primarily groundwater-fed, though the topography of the basins which contain the community may mean that high water levels are maintained by constraints on drainage and rainfall, and that the proportionate contribution of groundwater may be much less than in the more soligenous systems. Other examples of this community occur in fen complexes which are undoubtedly fed primarily by groundwater, but where the stands of M9-2 are not necessarily fed by direct groundwater outflow, but are associated with surface water drainage (such as some examples at Malham Tarn, Yorkshire). In some others, surface water supply appears to predominate, though this may be largely groundwater-sourced, as in the case of some examples associated with the St David’s Heaths in Pembrokeshire (although in some instances, such as a small depression with M9-2 at Waun Llandruidion, the precise water source is far from obvious). It is possible that in some high rainfall areas, shallow depressions upon calcareous clays might provide appropriate conditions for the development of M9-2 without significant telluric inflows, other than rain-generated run-off. The majority of stands, however, appear to be essentially rheo-topogenous, with clear evidence for consistent water throughflow, from whatever telluric source.

There appear to be two mechanisms by which the high, relatively stable water table is maintained (which can operate in combination): (i) a shallow topogenous hollow within a permanent seepage face, where the high water table is maintained by soligenous inputs in conjunction with the topography; examples of this usually support a littoral community; and (ii) a deeper topogenous hollow with a semi-floating raft of vegetation, where the raft has an important hydroregulatory function and where a loose, transmissive infill beneath this may facilitate water supply. The rafting mechanism is particularly important in larger topogenous sites on deep peat or marl, where the substratum is of rather low permeability so that significant groundwater inputs are primarily by lateral flow from the mire margins. The transmissive layer beneath the raft permits the ready penetration of groundwater into the vegetation to a greater extent than might be the case with a solid peat infill, especially when the hydraulic gradient is relatively weak. In some instances this subirrigation system has been provided artificially, where the vegetation has developed upon reflooded peat workings (such as Thelnetham West Fen), but it is not known how many examples have been similarly disturbed (for example, it has not been possible to determine, from peat stratigraphical examination, whether the M9 stand at Great Cressingham Fen is upon former turbary).

12.3 Regimes

12.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 12.2, together with mean recorded values for summer water table associated with stands of M9-2.

Table 12.2 Mean rainfall, potential evaporation and summer water table for M9-2

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	1,012	646	1,679
Potential evaporation (mm a^{-1})	565	467	646
Mean summer water table (cm agl or bgl)	4.5	–14	24

The water table is consistently high beneath M9 stands, usually just above or below the surface, sometimes forming shallow swamp (especially in winter or after heavy rain). The highest water tables are associated with unconsolidated surfaces and are probably, in part, an artefact associated with depression of the vegetation raft during sampling; the lowest water tables are associated with comparatively solid surfaces, which either never had a buoyant vegetation mat or where this has grounded

Specific time-series data for stands of M9-2 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Typically, consistently at or just above surface level, particularly where forming a floating raft, although some examples may experience considerable fluctuations in water level.
- Association with semi-floating raft or turf pond infill can provide some vertical mobility and comparative hydrological stability.
- In some locations (such as some of the Limestone basins in Anglesey), the community can be exposed to naturally low water tables during occasional summer droughts, though data on the depth and duration of low water tables are not available.
- Some examples of this community seem able to persist in low water conditions, but this is not typical and it cannot be assumed that they are in long-term equilibrium with the drier conditions.
- Occasional flooding of the surface, particularly with base-rich water, may be important in preventing the extensive development of ombrotrophic nuclei and succession to community types associated with more acidic conditions (such as *Carex rostrata–Sphagnum squarrosum* mire (M5), *Carex rostrata–Sphagnum*

recurvum mire (M4)) and/or invasion by scrub. Buoyant surfaces may be particularly prone to acidification.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can therefore be speculated that these would lead to a loss of wetland species and increased representation by dryland species. Partial drainage, if accompanied by vegetation management, may lead to an increase in species richness as a form of fen meadow becomes established. Further water drawdown (including grounding of a floating raft) leading to peat drying and subsequent degradation would lead to development of rank fen, rapidly becoming wooded without management.
- Autogenic accumulation of peat can ultimately lead to some form of woodland or, in some sites, *Sphagnum* surfaces; draining may speed the succession to woodland.
- Prolonged, deep inundation, particularly in the spring or summer months, is likely to kill some species and lead to development of less diverse vegetation types, reflecting natural transitions to swamp conditions.

12.3.2 Nutrients/hydrochemistry

Typically found in situations of intermediate base status with respect to the main rich and poor-fen communities, although the community covers a wide range. Soil fertility is generally of low to moderate fertility (and similar to of M9-3, but generally higher than in M9-1, and lower than many examples of S27). Figures for pH, conductivity and substratum fertility measured in stands of M9-2 are presented in Table 12.3.

Table 12.3 pH, conductivity and substratum fertility measured in stands of M9-2

Variable	Mean	SE	Minimum	Maximum
Water pH	6.2	0.03	5.0	8.0
Soil pH	6.1	0.04	5.0	7.4
Water conductivity (K_{corr} µS cm^{-1})	294	1.3	70	916
Substratum fertility[1] (mg phytometer)	13.5	0.27	5	39

Shaw and Wheeler (1991) found that the variation in water level was relatively small in this community, and apparently of less importance in determining the floristic variation than base status or fertility. The most species-rich stands, and those with most rare fen species, are of very low fertility, and this is almost certainly essential to their optimal development and maintenance of their floristic character. The vegetation may retain its essential floristic composition even in quite enriched conditions, but this may only be a short-term response due to inertia, as the enriched stands tend to have lower species densities and a prominence of eutrophic species such as *Agrostis stolonifera* (Shaw and Wheeler, 1991).

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

12.3.3 Management

The community may be managed, but many examples appear to be floristically relatively stable without management. Many examples are open to grazing livestock, but the wetness of the substratum may mean that stands are infrequently grazed. However, Shaw and Wheeler (1991) found that lightly grazed stands included those with the highest numbers of rare fen species (and principal fen species). It is possible that some stands were once mown for marsh hay, but this is no longer practised.

Natural successional processes mean that where the community is established on a floating raft, conservation of this vegetation type may eventually require rejuvenation of the hydroseral conditions (by excavation of the substratum) in order to permit re-establishment of the floating raft, and in some circumstances reverse seral acidification.

12.4 Implications for decision making

12.4.1 Vulnerability

A community of low fertility, wet, topogenous situations, usually of moderate to high base status. Particularly vulnerable to lowered water tables and eutrophication, although floating rafts may provide some accommodation. Conservation management involves ensuring low fertility, relatively high base status and relatively high water levels. Ongoing terrestrialisation is an eventual threat to many examples, by which a poor-fen surface (with *Sphagnum* development) or a form of woodland (such as *Salix pentandra–Carex rostrata* woodland (W3)) may ultimately develop; their conservation may thus require rejuvenation/maintenance of hydroseral conditions (peat excavation). However, some examples occupy reflooded turbaries, sometimes within former raised bogs, and in this circumstance it is a moot point as to what constitutes the favourable condition or the most desirable conservation end-point. In other cases, the natural status of M9-2 locations is uncertain. Some of the pingo sites in East Anglia are particularly problematic in this respect – there seems to be little known evidence for past peat removal from them, but if such disturbance has not occurred, it raises the interesting question of why such shallow basins have not long-since fully terrestrialised.

Eutrophication leads to impoverishment and loss of rare species, with an increased prominence of such species as *Agrostis stolonifera* and *Phragmites australis,* and probable replacement by a more eutrophic vegetation type.

The vulnerability of stands of M9-2 to changes in water supply depends considerably upon the precise water supply mechanism. Where the water level in basins with this vegetation is directly determined by aquifer water tables, the key question of vulnerability may be the degree of water level reduction which can be accommodated by the vegetation rafts before significant grounding and drying occurs. However, in other sites developed over low-permeability deposits (such as marl) and where the water level is potentially controlled by the level of the outfall as well as by rates of water inflow, a reduction of aquifer water tables may not have such a direct effect. However, this same feature may make sites and communities more vulnerable to increased drainage, especially if groundwater inputs are not strong. Although it is difficult to marshal hard evidence, it seems likely that the biggest single cause of loss of this community in East Anglia may have been over-deepening of rivers: this certainly seems to have affected examples formerly located along the upland margin of some small floodplains (such as Blo' Norton Fen, Tuddenham Turf Fen (Norfolk)).

The grounding of former rafts not only means that a capacity for raft-based hydroregulation is lost, it also leads to the loss of water storage capacity and the water flow path that was provided by the semi-fluid deposits beneath the buoyant surface. This can reduce water sub-irrigation and can induce positive feedback towards a dry surface. Unless the raft can reform when the water table increases, the former water supply mechanism may be permanently disrupted. In this event, and in suitable topographical circumstances, high water tables may lead to surface inundation. It is not known to what extent, and within what water level limits, this process is likely to be beneficial to the M9-2 community, or damaging.

Figure 12.2 outlines some of the possible floristic impacts of changes to the stand environment.

The possible effects of environmental change on stands of M9-2

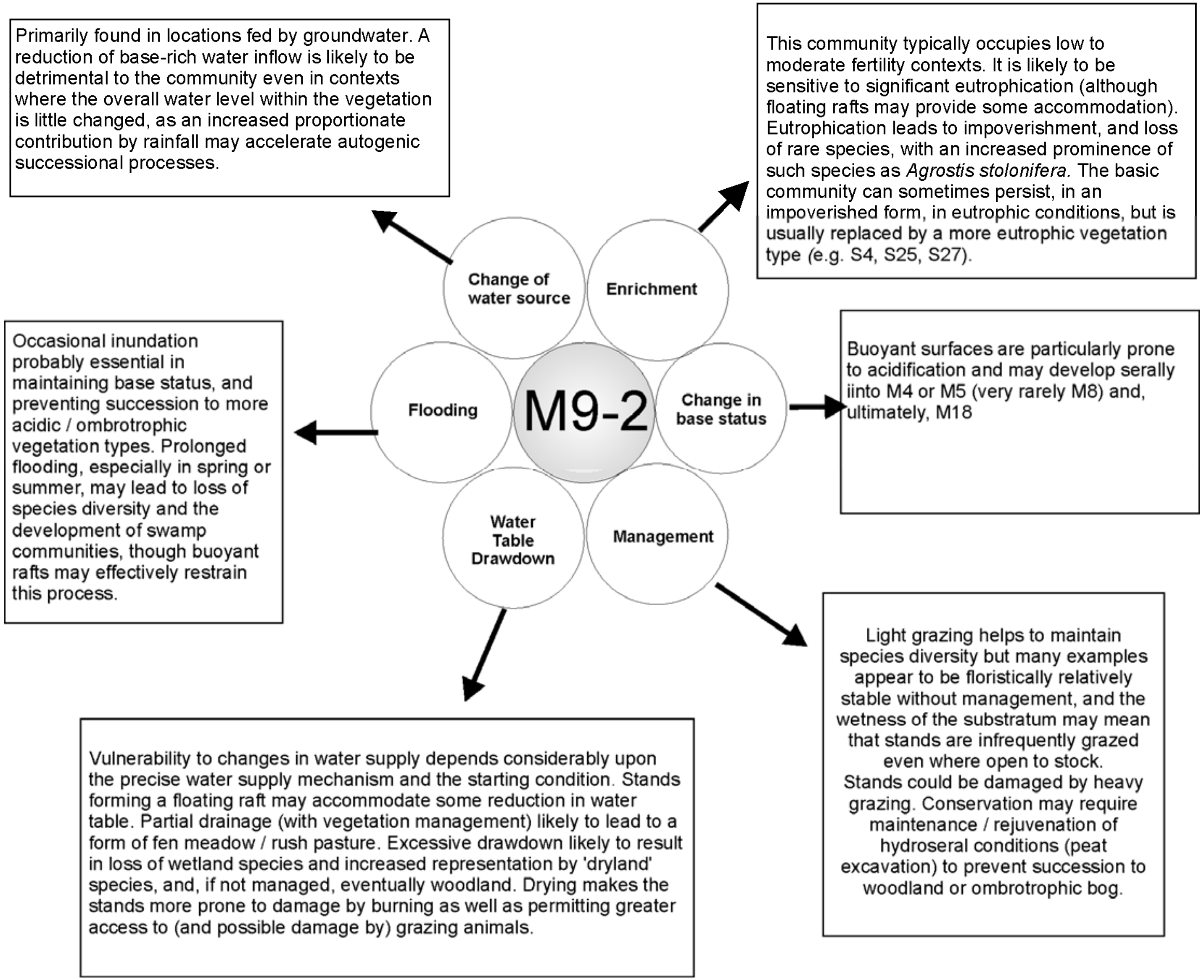


Figure 12.2 Possible effects of environmental change on stands of M9-2

12.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M9-2 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M9-2 in the short to medium term.
- Prolonged water drawdown which has resulted in both the grounding of the floating raft, and mineralisation of nutrients from the peat, may require many years and major operations such as peat removal to reverse.
- Many, perhaps most, known examples of M9-2 in lowland England and Wales occupy peat, clay or marl workings. Some of them were undoubtedly dug within ombrogenous peat (such as Newton Reigny Moss, Cumbria), others probably just in fen peat (such as Blo' Norton and Thelnetham Fens (Norfolk/Suffolk)). This artificial origin points to the potential restorability of M9-2, but the conditions which once favoured this are not really known, and may no longer occur.

12.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently no data to better inform the temporal water table characteristics of M9-2 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M9-2 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- Data on the spatial extent of M9-2 are lacking.
- Some samples of M9-2 vegetation show much floristic overlap with samples of S27. It would be useful to clarify the relationship between these two units. Preliminary examination suggests that there may not be any obvious discontinuity between the two types, in which case the identification of an arbitrary boundary would be helpful, providing it could be defined and recognised.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

13 M9-3 *Carex diandra–Peucedanum palustre* mire

13.1 Context

Examples of M9-3 have been included within the 'chalk-rich fen dominated by saw sedge' SAC interest feature. [See Tables 3.1 and 3.3]

13.1.1 Concept and status

Wheeler (1980a) first described this vegetation as the distinctive *caricetosum* sub-association of his *Peucedano-Phragmitetum* community, and noted that it was floristically transitional to his *Acrocladio-Caricetum diandrae* (more or less equivalent to M9-2, see above). Rodwell (1995) took the opposite view, and decided it was best incorporated into his M9b community, but curiously did not include it within either his distribution maps or tables. The DCA ordination (Figure 10.1) confirms the transitional status of this unit and we concur, partly on ecohydrological grounds, with the allocation of the unit to the former M9 group of communities rather than S24. It could be seen either a sub-community of M9-2 or a separate unit but here, until the relationships of M9-2 with S27 are better clarified, we have provisionally considered it to form an independent unit.

13.1.2 Floristic composition

A rare herbaceous fen community, apparently confined to Broadland, that is characteristically species-rich (mean 33, range 28–42 species per sample; Table 13.1) with an abundance of small sedges and brown mosses. *Carex diandra* and *C. lasiocarpa* are often both prominent, but the main dominant species is *Cladium mariscus.* M9-3 is particularly notable for supporting populations of the internationally rare fen orchid (*Liparis loeselii*) in Broadland, and supporting a particularly high (10) mean number of rare species per sample (Table 13.1). The community is floristically transitional between M9 and S24 and is not adequately represented by the NVC.

Table 13.1 Number of species recorded in stands of M9-3

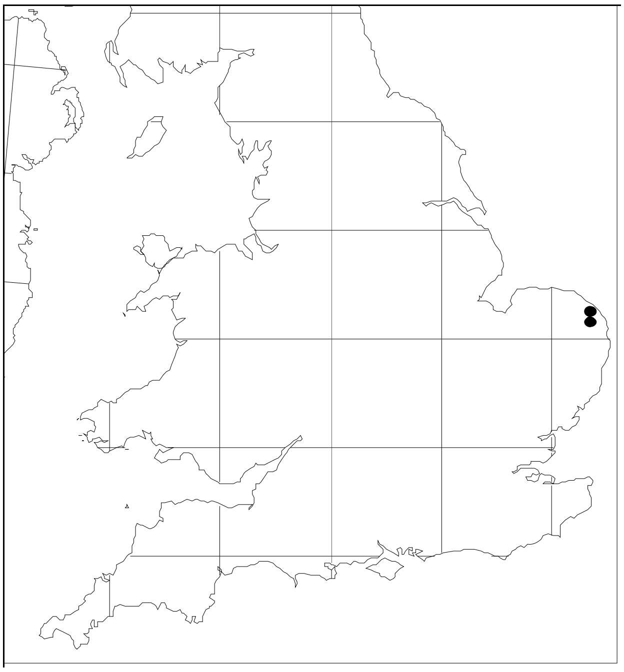
	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	77	33.1	0.32	28	41
Mire species (spp 4 m^{-2})	68	31.1	0.29	27	38
Rare species (spp 4 m^{-2})	19	10.0	0.20	8	12

** Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Cicuta virosa, Cladium mariscus, Dactylorhiza praetermissa, Epipactis palustris, Liparis loeselii, Oenanthe lachenalii, Peucedanum palustre, Ranunculus lingua, Rhizomnium pseudopunctatum, Stellaria palustris, Thelypteris palustris, Utricularia intermedia.*

13.1.3 Distribution

The community is confined to Broadland (Figure 13.1) where, currently, it is known from the valleys of the Ant (Broad Fen (Dilham), Sutton Broad and Catfield Fen) and Bure (Woodbastwick Fen, Ranworth Broad and Upton Fen). There are former records for what appears to have been this community from Decoy Carr (Acle), Strumpshaw Fen and Shallam

Dyke. Stands of S24 that have strong floristic affinities to this unit are more widespread in Broadland than M9-3, but are often developed only as fragments.



(data from FenBASE database)

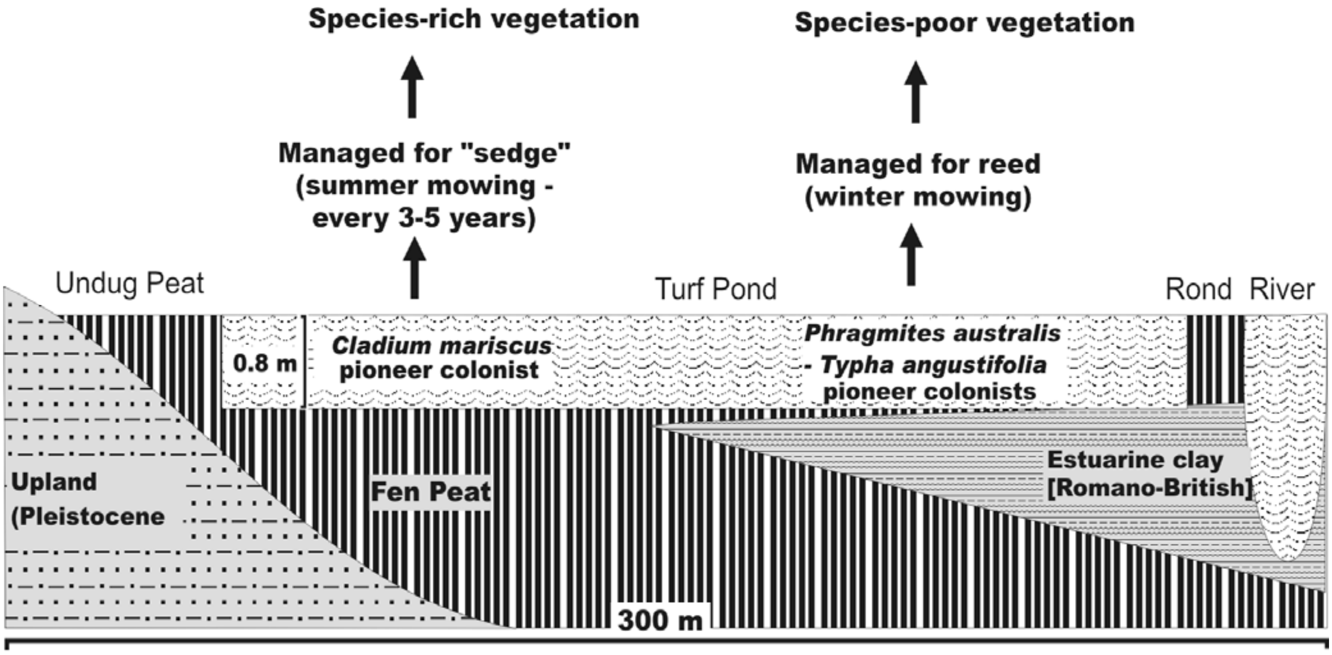
Figure 13.1 Distribution of M9-3 in England and Wales

13.1.4 Landscape situation and topography

All examples of M9-3 occur in floodplain fens. Stands are usually localised. Many of them are located close to the upland margin of the fen, but stands at Woodbastwick (and some former stands elsewhere) are located deep within the fens. Most occur as isolated stands, but at Sutton Broad they form a (mostly narrow and discontinuous) zone along much of the upland margin.

13.1.5 Substratum

All of the stands occupy parts of reflooded peat workings, either deep medieval excavations (the Broads) or shallower eighteenth to nineteenth century turf ponds, where they form a quaking, hydroseral mat. In a few stands the peat has been removed almost to the underlying mineral ground (Sutton Broad), but in most cases there is some two to five metres of peat (mostly dense brushwood peat) below the floor of the peat cutting. In some, perhaps most, sites (such as Great Fen, Catfield) the peat is separated from the underlying Crag by a layer of soft grey clay. As is reflected in the relatively low values of water conductivity (see below), in no known cases is the peat cutting underlain by estuarine clay of the Romano-British transgressive overlap (turf ponds underlain by estuarine clay support a quite different vegetation, normally dominated by *Phragmites australis* or *Typha angustifolia,* as illustrated in Figure 13.2).



Phragmites australis and *Typha angustifolia* are the usually primary recolonists where the turf pond is floored with estuarine clay, but *Cladium mariscus* is often the main recolonist over continuous fen peat. The identity of the initial colonist species appears to determine the subsequent management and species richness of these different parts of turf ponds, although. *Cladium* sometimes invades the reedbeds at a later phase of the successional process.

Figure 13.2 Schematic diagram of recolonisation of reflooded, shallow turf ponds in Broadland

13.1.6 Zonation and succession

Most examples of M9-3 occupy turf ponds that are embedded unconformably within undug fen, and tend to be adjoined by baulks or more extensive surfaces of solid peat. As a consequence, stands of M9-3 can be proximate to various drier communities, but mainly to examples of S24. Within individual turf ponds, there is only occasionally a clear spatial zonation of communities: instead, M9-3 usually occurs in a spatial patchwork of communities, juxtaposed with wetter (for example, S2 *Cladium mariscus* swamp), drier (for example, S24 *Phragmites–Peucedanum* fen) and, sometimes, more acidic (for example, *Betulo-Dryopteridetum cristatae*) surfaces. This appears to represent a hydroseral patchwork, where different patches represent somewhat different stages of terrestrialisation of the shallow, more or less flat-bottomed peat workings. However, in locations where an individual turf pond is located partly over Romano-British estuarine deposits and partly over continuous peat (such as Great Fen, Catfield), a clear zonation can sometimes be observed with reed-dominated vegetation (S4 or S24) over the clay grading into *Cladium*-dominated vegetation (including M9-3) over the continuous peat.

Sutton Broad is considerably deeper than the nineteenth century turf ponds and has a clear hydroseral gradient, from open water through reedswamp to fen. At this site M9-3 does show a clear zonation, occurring as a discontinuous band close to the upland margin, and bordered on the drier side by fen meadow (M22) or fen carr.

Various stratigraphical investigations (Giller and Wheeler 1986a, 1988) have shown that M9-3 appears to have developed in turf ponds from a preceding wetter phase (typically *Cladium* swamp). In some locations M9-3 persists to the present day, but in others it has clearly been replaced serally by a less diverse vegetation, either a form of S24, *Salix* scrub (W2) or, locally, acidic fen surfaces. The specific triggers to acidification are not well understood, and it is not clear if this is likely to be a pervasive or just local late-successional development of the M9-3 community. The more open acidic surfaces are often referable to the *Betulo-Dryopteridetum cristatae*, but these generally develop rapidly into the more dense scrub of *Betula pubescens–Molinia caerulea* woodland (W4). Peat workings at Upton Fen have been particularly prone to acidification, and here locally extensive *Sphagnum* carpets have been maintained by mowing management. In many instances, these appear to represent a successional development from M9-3 and can contain some residual M9-3 species (such as *Carex lasiocarpa*), as well as providing an important habitat for *Pyrola rotundifolia*.

13.2 Water supply mechanisms and conceptual model

Most examples of M9-3 are restricted to percolating fens fed by surface water or groundwater: most samples (74 per cent) were identified as occurring within WETMEC 6 (Surface Water Percolation Floodplains such as Catfield Fen), with 22 per cent in WETMEC 13 (Seepage Percolation Basins such as Upton Fen). Only one example (an old record from East Ruston Common) occurred in WETMEC 9 (Groundwater-Fed Bottoms).

The identity of the main water sources to stands of M9-3 has attracted some attention, partly because of a presumption that stands of this community are groundwater-fed, because of their localised occurrence, frequent association with the upland margin and occurrence of seepage indicator species[1] within the vegetation. In fact, hydrological investigations at selected sites found little evidence for any direct groundwater input and instead emphasised the importance of the surface water system as a primary water source (Van Wirdum *et al.,* 1997). There can be little doubt that many sites receive river water inputs, apparently stripped of nutrients, and in some cases this seems to be the primary source of telluric water. An exception is provided by Upton Fen, where the main source of telluric water to the fen appears to be groundwater outflow into the broads, which is distributed to the stands of M9-3 *via* the dyke system (WETMEC 13d: distributed seepage percolation surfaces). It thus appears that, providing the water is fairly base-rich but not rich in nutrients or sea salts, its exact provenance is unimportant. In most stands, telluric water is supplied by lateral flow through very loose peat beneath the quaking mat from nearby sources such as feeder dykes, at least during low water conditions.

The factors responsible for the localisation of M9-3 in peat cuttings in Broadland are not really known, especially as the potentially convenient explanation of localised groundwater upflow does not appear to be valid. Restriction of M9-3 to turbaries beyond the limit of estuarine clay, however this is caused, helps to account for much of the macro-distribution of the community, but even with this constraint the community does not necessarily occur in all locations which would appear to be suitable for it. It is possible that this discrepancy could result from historical management events, coupled with the vagaries of recolonisation by appropriate species (for example in the Berry Hall Fens, or parts of the Catfield fens distant from the river, it is possible that past drainage may have been inconducive to the subsequent establishment of M9-3).

[1] Species which occur in some valleyhead fens and are believed to be diagnostic for groundwater inputs.

13.3 Regimes

13.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Figure 13.3, together with mean recorded values for summer water table associated with stands of M9-3.

Table 13.2 Mean rainfall, potential evaporation and summer water table for M9-3

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	611	604	616
Potential evaporation (mm a^{-1})	625	625	625
Mean summer water table (cm agl or bgl)	–7.3	–26.2	3.2

Summer water tables do not show much variation between stands, and are consistently near or at the fen surface. However, the microtopographical variation found within most stands makes the specification of a mean water table difficult and potentially misleading. In many stands, it is possible to find hollows with standing water in the summer and low hummocks/tussocks (less than 20 cm) above the water level. Indeed, the variation in conditions combines to provide a complex of microhabitats that contributes greatly to the species diversity of high-grade stands. The semi-floating nature of turf pond infill gives the fen surface a degree of vertical mobility and hence hydrological stability (though in winter and spring, sites with river connections can become inundated).

Specific time-series data for stands of M9-3 are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal water regime:

- Most often associated with a mean water table at or near the surface all year round. Its confinement to quaking or buoyant turf pond infill may provide some vertical mobility and thus hydrological stability. The loose peat, and semi-fluid material below the vegetation mat, may provide significant storage and facilitate sub-irrigation with water from adjoining dykes.
- Episodic flooding, including relatively deep inundation, may occur in the winter – and occasionally summer – at river-connected sites.

Sub-optimal or damaging water regime:

- Persistent deep inundation in the summer months is likely to lead to the development of less diverse swamp communities.
- Low sub-surface water tables (except as a consequence of natural microtopographical variation) are not generally a feature of the community and tolerance of protracted water table drawdown is probably very limited. Consolidation, elevation and some drying of the surface can occur serally and are associated with the gradual loss of M9-3 vegetation.

13.3.2 Nutrients/hydrochemistry

The substratum (fen mat) is always of rather low fertility (oligotrophic or low mesotrophic). This contrasts with the mats over estuarine clay which are normally mesotrophic or eutrophic and which support other vegetation types. Where a M9-3 stand occurs close to a eutrophic river, as is sometimes the case, it is presumed that the river water does not significantly penetrate or flood the stand, that any flood water does not have high nutrient loading or much entrained sediment, or that a process of nutrient-stripping is operating.

Mean water pH is 6.4, which is below the threshold at which calcite precipitation can occur. Highest pH values have been measured at Upton Fen, where some biogenic calcite precipitation has been observed in fen pools (which generally have pH values some 0.5 units higher than within the fen mat).

The pH, conductivity and substratum fertility measured in Broadland stands of M9-3 are given in Table 13.3 below.

Table 13.3 pH, conductivity and substratum fertility measured in stands of M9-3 in Broadland

Variable	Mean	SE	Minimum	Maximum
Water pH	6.4	0.17	6.2	6.8
Soil pH	6.6	0.36	6.3	7.3
Water conductivity (K_{corr} µS cm^{-1})	676	197	486	1,067
Soil fertility[1] (mg phytometer)	6.5	1.81	5.0	10.0

Wheeler and Shaw (1991) report a mean increment (April to September) in dry weight of above ground standing crop of only 299 g dry wt m^{-2}, which reflects the low substratum fertility.

13.3.3 Management

Management is necessary for the long-term persistence of the community, but it can withstand several years of dereliction without serious floristic consequences (probably because of the low substratum fertility). Some stands are dominated by *Cladium mariscus* and are mown for sedge (such as Catfield Fen), whilst others receive rather little management or are mown specifically for conservation objectives. An example of M9-3 at Sutton Broad was formerly managed by occasional burning, which helped suppress development of scrub and was not obviously detrimental to the herbaceous vegetation (it may even have been beneficial to a population of *Liparis loeselii*). M9-3 stands are prone to scrub invasion where management is abandoned for long time periods.

13.4 Implications for decision making

13.4.1 Vulnerability

Conservation management involves ensuring low fertility and relatively base-rich conditions, periodic vegetation management (summer mowing), and (ultimately) maintenance of hydroseral conditions (peat excavation). Figure 13.3 outlines some of the possible floristic impacts of changes to the stand environment.

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[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

The possible effects of environmental change on stands of M9-3

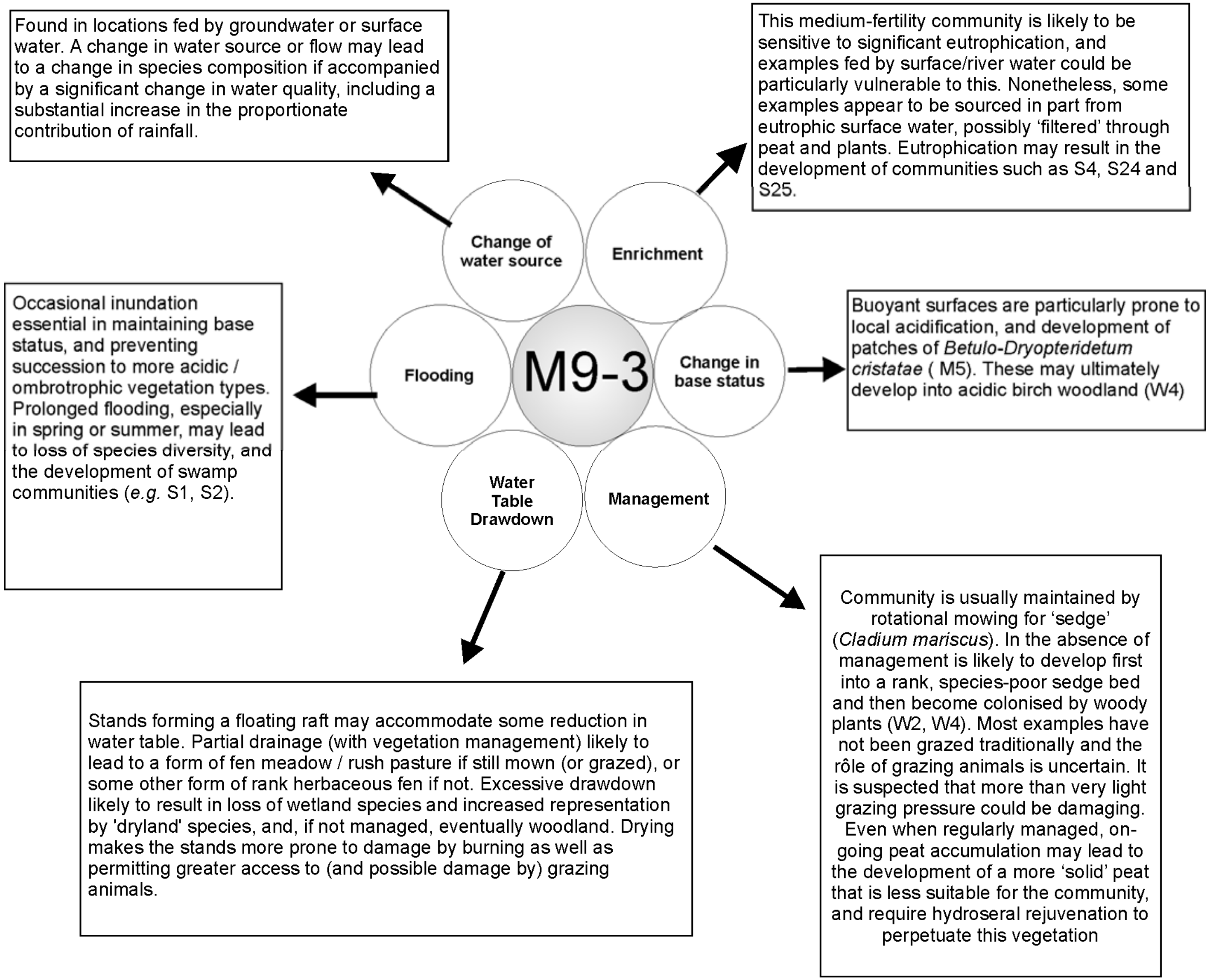


Figure 13.3 Possible effects of environmental change on stands of M9-3

Terrestrialisation

All examples of M9-3 represent a transient phase of the terrestrialisation of turf ponds or deeper peat diggings. Terrestrialisation is manifest in two ways: (i) elevation of the surface by growth of hummock/tussock-forming species and accumulation of decomposing litter; and (ii) accumulation of sub-surface material. The rate of the first of these processes can be considerably reduced by regular mowing (and removal of the mown material); the rate of the second is much less affected by this. Continued growth of rooting structures and formation and consolidation of peat is likely to be detrimental to the water supply mechanism for this vegetation, where it results in a reduction of the vertical mobility of the quaking mat and of the transmissivity of the peat infill. Stratigraphical data indicate that examples of M9-3 can gradually dry out and become similar to the less rich vegetation of uncut peat surfaces. Conservation of this vegetation type may therefore ultimately require rejuvenation of hydroseral conditions (re-excavation of turf ponds).

Acidification

Acidification is sometimes an eventual outcome of terrestrialisation, which occurs when the fen mat ceases to be inundated by base-rich water, but remains sufficiently wet to support *Sphagnum* species. Acidification often occurs on buoyant fen mats and can therefore occur at an earlier stage in the terrestrialisation process than changes induced by substratum solidification. Acidification is extremely localised in examples of M9-3 that are periodically inundated by river water (for example, a few patches are known at Catfield Fen) but is prevalent at Upton Fen where there is little surface flooding by telluric water.

Nutrient enrichment

The low fertilities typically associated with this community mean that stands are potentially vulnerable to nutrient enrichment, especially those partly irrigated by river water. In general, there is little evidence for current detrimental enrichment from river sources, either because nutrients are stripped from the water during summer sub-irrigation or because winter floodwaters are dilute. However, the M9-3 at Sutton Broad is separated from the river by a rather narrow band of reed that may offer only limited protection from penetration by river water. The possible interaction between sub-surface transmission of river water against any groundwater inputs at this site is not known, but could be important in regulating the ingress of enriched surface water into M9-3 stands.

Groundwater abstraction

The impact of groundwater abstraction on this community is difficult to predict with present information.

- For many sites the importance of groundwater, if any, to the maintenance of the summer water table is not known, especially where supply appears to be indirect.
- In river-connected sites, other water sources may be able to compensate for any reduction of groundwater inputs, though such sources will only be suitable for the community if they are naturally nutrient-poor or if nutrients are stripped from them by passage through the peat/rhizome mixture (direct input of river water via dykes would be damaging).

- Even in sites which are exclusively groundwater-fed, a small reduction in water level can probably be mitigated by a compensatory movement of the peat mat.

13.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M9-3 stands, but the following observations can be made:

- To perpetuate M9-3 in Broadland, it is likely to be necessary to provide new or re-excavated turf ponds to maintain appropriate hydroseral conditions. However, the potential for restoring M9-3 and appropriate starting conditions is largely unknown, though there is no doubt that past turf ponds have become colonised spontaneously with M9-3 vegetation.
- Scrub removal and re-instatement of vegetation management may help to temporarily restore M9-3 vegetation that has been left unmanaged for a while.

13.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here are as follows:

- The information presented here is based on knowledge of wetland sites supporting M9-3 in Broadland (to which region this community is confined).
- There are currently virtually no hydrometric data to better describe the temporal water table characteristics of M9-3 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions about the vulnerability of M9-3 stands to water resource management and water quality in the wider environment it will be necessary, on a site-specific basis, to investigate the key water supply mechanisms to M9-3 stands and to establish the relative importance of groundwater versus land drainage water and river water.
- Data on the areal extent of M9-3 appear to be lacking.
- The potential for restoring M9-3 is largely untested (although some trials have begun).
- It would be desirable to clarify the relationships between M9-3, M9-2 and S27.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

14 M10 (*Pinguicula vulgaris–Carex dioica*) mire (lowland)

14.1 Context

Examples of the M10 community have been included in the “calcium-rich spring water-fed fens” SAC interest feature. [See Tables 3.1 and 3.3]

14.1.1 Concept and status

The community which forms the essential basis of M10 was first recognised by Jones (1973), who conflated her own data from Upper Teesdale with earlier units that had been recognised by other workers into a broadly based *Pinguiculo-Caricetum dioicae.* The scope of this community was subsequently somewhat amended by Wheeler (1980b) and Rodwell (1991b), but the unit largely persists as ‘M10’ as conceptualised by Jones.

M10 is a widespread, and broadly based, unit with considerable internal variation. The data available here cover a smaller range than the whole unit, lacking samples and species from the higher altitudes and latitudes. The community has clear affinities with *Schoenus nigricans–Juncus subnodulosus* mire (M13) and *Schoenus* itself is prominent in some examples of M10 vegetation. However, whilst the DCA ordination of M10 and M13 data (Figure 14.1) shows some overlap, samples from the two units mostly occupy discrete sectors of the ordination.

Despite their fairly discrete ranges on the ordination, it is not easy to specify clear floristic differences between M10 and M13. M10 is generally more species-poor than M13, and often more open and lower growing. M13 is usually structurally more complex than M10, but some examples of the *Briza media–Pinguicula vulgaris* sub-community (M13b) can be difficult to separate from examples of M10. The two communities show fairly clear geographical differences, with M10 primarily a northern and western unit and M13 more of a southern and eastern community. This is reflected in the phytogeographical affinities of some of the component species: for example, the mainly southern species *Epipactis palustris* (marsh helleborine orchid) is much more characteristic of M13 than of M10, though it grows in both communities.

In some places along the broad geographical boundary between the two communities, both units can be found in fairly close proximity. This is particularly evident in the North York Moors where some calcareous seepage fens (such as Seive Dale Fen) support good examples of M13, whilst others (such as Ashberry Pastures) support M10. The co-occurrence of the two communities as distinct entities in the same geographical area suggests that the differences between them are not primarily phytogeographical. One edaphic point of distinction is that the mean soil fertility of M10 is slightly less (6.6 mg) than that of M13 (7.5 mg), but this difference is rather small. Mean soil and water pH is lower in M10, and some stands of M10 undoubtedly support a greater range of acidophilous species than M13. However, others can be just as calcareous as examples of M13 and, for example, M10 flushes fed from the Carboniferous Limestone at Sunbiggin (Cumbria) have similar hydrochemical characteristics to some Anglesey examples of M13, also on Carboniferous Limestone. M10 stands are often on a more skeletal substratum than M13, and may be more strongly flushed, though no quantitative data are available on water flow rates.

A few stands classified as M10 have been recorded from the New Forest. Some of these are on particularly calcareous, soligenous slopes, usually fed by water that has been associated with the relatively base-rich Headon Beds. Their classification is particularly problematic – MATCH analyses give high coefficients with M10, M13 and M14, but the samples fit none of these units particularly well. Similarly, examples of this syntaxon recorded from some soakways have strong affinities with M9-1 and M14 communities (which, in terms of their normal hydrotopography, are more appropriate for the stands in question than is M10).

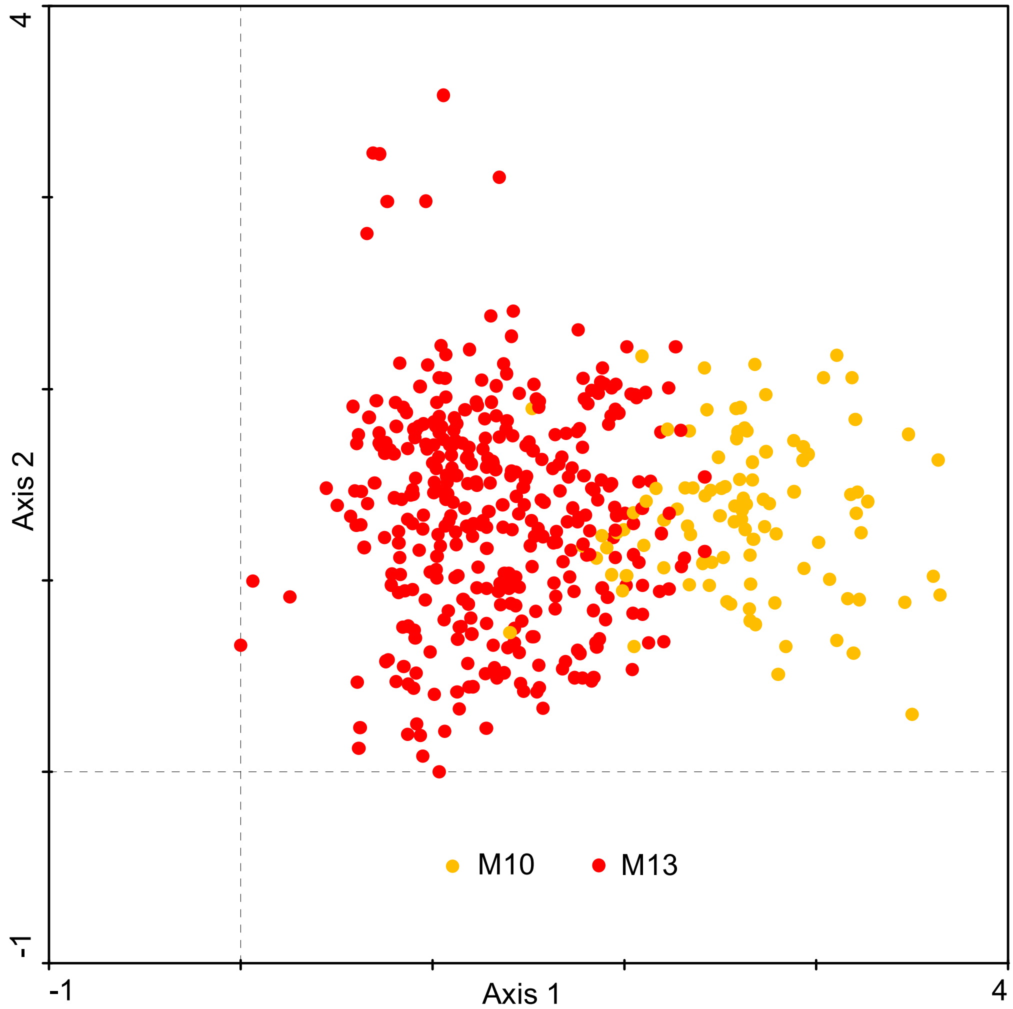


Figure 14.1 Plots of samples of *Carex dioica–Pinguicula vulgaris* mire (M10) and *Schoenus nigricans–Juncus subnodulosus* mire (M13) on Axes 1~2 of a DCA ordination

14.1.2 Floristic composition

Mostly low-growing vegetation with an open sward, typically dominated by low-growing monocotyledons (mainly sedges), but including *Schoenus nigricans* at some sites. *Molinia* and/or rushes are sometimes prominent; there is often an extensive bryophyte component and a wide range of associated short herbs. Much of the considerable floristic variation of M10 lies outwith the scope of this study, which has been largely restricted to lowland sites. The community is particularly important in supporting several rare and uncommon fen species (Table 14.1), including some with a northern distribution that are otherwise rather rare in England and Wales (such as *Carex dioica, Primula farinosa*), as well as some national rarities (such as *Moerkia flotowiana and Homalothecium nitens*).

Rodwell (1991b) recognised three sub-communities of M10: *Carex demissa–Juncus bulbosus/kochii* (M10a), *Briza media–Primula farinosa* (M10b), *Pinguicula vulgaris–Carex dioica* mire, and *Gymnostomum recurvirostrum* (M10c).

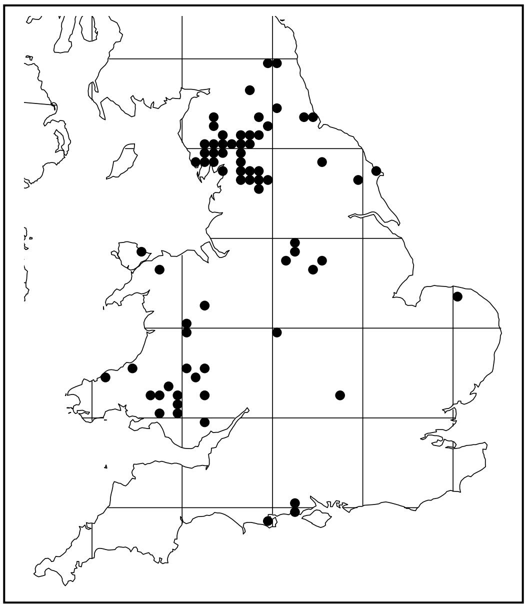
Table 14.1 Number of species recorded from stands of M10

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	264	32.0	0.15	10	55
Mire species (spp 4 m^{-2})	136	23.5	0.11	10	37
Rare mire species* (spp 4 m^{-2})	32	2.1	0.12	0	8

* These include: *Bartsia alpina, Blysmus compressus, Calliergon giganteum, Calliergon sarmentosum, Carex dioica, Dactylorhiza traunsteineri, Drosera intermedia, Drosera longifolia, Eleocharis uniglumis, Epipactis palustris, Equisetum variegatum, Eriophorum latifolium, Euphrasia pseudokerneri, Homalothecium nitens, Juncus alpinoarticulatus, Kobresia simpliciuscula, Moerckia hibernica, Philonotis calcarea, Pinguicula lusitanica, Plagiomnium elatum, Preissia quadrata, Primula farinosa, Rhizomnium pseudopunctatum, Saxifraga aizoides, Selaginella selaginoides, Sphagnum contortum, Sphagnum subsecundum, Sphagnum warnstorfii, Thuidium deliculatum, Tofieldia pusilla, Utricularia intermedia, Utricularia minor.*

14.1.3 Distribution

A very widespread community recorded from 121 sites, mainly in Western, Northern and upland Britain, although some records have been made in the South. The distribution of M10 in lowland England and Wales is shown inFigure 14.2.



(data from FenBASE database)

Figure 14.2 Distribution of M10 in lowland England and Wales

14.1.4 Landscape situation and topography

In the lowlands, the community usually forms small stands in isolated locations, often within sloping pastures, but sometimes within heathland or woodland or flanked by more acidic peat. It often forms a rather small elongated zone below springs and flush-lines, although larger aggregated flushed slopes supporting this community can occur (such as Great Close Mire (Yorkshire)). A few individual flushes with M10 can be quite large, with a particularly fine example at Pont-y-Spig (Monmouth). Occasionally found along the sloping margins of topogenous fens (basins or channels) (such as Sunbiggin Tarn, Malham Tarn (Cumbria)).

The stands are usually open, often with muddy depressions and runnels separating turfy hummocks and providing a range of microhabitats.

14.1.5 Substratum

Associated with a wide range of soil types, but typically found on shallow, sometimes skeletal, flushed organic or mineral soils where there is little or no stagnation. Peat, if present, is usually less than 50 cm deep, and often strongly decomposed and humified. Water flow may help constrain the accumulation of organic material, and in some strongly flowing instances may remove it by scouring. The turfy hummock–runnel microtopography found in some sites is probably a product of these processes in conjunction with poaching by grazing animals.

The community is usually associated with calcareous water supply, and some examples have marl, sometimes tufa, precipitated either spontaneously or biogenically (mostly in association with bryophytes, which often become calcified). Some examples contain quite well-developed tufa mounds (such as Tarn Moor, Sunbiggin), but although such mounds may arise in association with M10 stands, they do not themselves always support M10.

14.1.6 Zonation and succession

Many examples of M10 occur in localised, discrete groundwater-fed locations that may be largely unconformable with surrounding habitats, in some cases including other mire habitats. M10 surfaces can therefore show an abrupt transition to a number of adjoining habitats and vegetation types. In some instances, the transition between the M10 stands and drier conditions is marked by a zone of *Molinia*-dominance (such as M24 or M25) or of fen meadow (such as M23). Drier conditions sometimes occur downslope of M10 stands, as well as alongside or above it, but the community may grade downslope into various types of (usually) rheo-topogenous mire, and merge into communities such as M9-1, M9-2, M29, S10, and S27. Some examples of M10 occur within more acidic peaty habitats, sometimes occupying localised patches of base enrichment. Examples of the community have been recorded embedded within stands of M15, M17, M19 and M21. The small number of examples recorded from soakways may show transitions to M9-1 or M29, and can be difficult to distinguish from these.

14.2 Water supply mechanisms and conceptual model

M10 is largely confined to soligenous slopes, fed by groundwater from semi-confined or unconfined bedrock or drift aquifers, either directly (as seepages) or by downslope flow of groundwater over an (often superficial) aquitard (flushes). A few examples occur in base-rich water tracks and soakways, but these tend to be peripheral to the central concept of M10, and transitional to either M9-1 or M14.

Fifty-seven per cent of samples were identified as occurring within WETMEC 10 (Permanent Seepage Slopes such as Pont y Spig (Monmouth), Crosby Gill (Cumbria)), with 29 per cent within WETMEC 17 (Groundwater-Flushed Slopes such as Acres Down (New Forest), Banc y Mwldan (Cardigan)). The remainder (10 and five per cent respectively) occurred within WETMEC 15 (Seepage Flow Tracks such as Widden Bottom (New Forest)) and WETMEC 19 (Flow Tracks such as Knott End Moss, Cumbria).

14.3 Regimes

14.3.1 Water regime

M10 is most commonly found in the cool and wet climate of the North-West, where the high annual rainfall and number of wet days help to maintain the conditions of constant flushing. The community tends to be replaced by M13 in the warmer and drier South and East. Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 14.2, together with mean recorded values for summer water table associated with stands of M10.

Table 14.2 Mean rainfall, potential evaporation and summer water table for M10

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	1,182	627	1,831
Potential evaporation (mm a^{-1})	539	462	614
Mean summer water table (cm agl or bgl)	–1.5	–16.2	3.4

The varied microtopography, as well as the effects of trampling and water-scouring, generates subtle but ecologically important differences in water regime within individual stands, providing a complex of microhabitats that contributes considerably to the high species diversity that is characteristic of M10. Consequently, **mean water table values have limited value, are potentially misleading and should be interpreted with caution**.

Specific time-series data for stands of M10 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Most of the examples of M10 examined had summer water tables that were at or very close to the fen surface (–5 to +1 cm). Only 15 per cent had measured summer water tables of more than 5 cm bgl. The lowest value was from Henllys Fen (Monmouth) but this site, and some others with the lowest water tables, did not have especially small numbers of fen species, nor of characteristic species (*cf.* M13). A seasonally sub-surface water table may be the natural condition of those stands occupying intermittent seepages or fed by groundwater sourced from fractures with short flow paths.

- Flushing by groundwater discharge is a feature of most high grade M10 sites. Slopes generally prevent surface accumulation of water, except in small shallow pools that probably experience considerable water throughput. Stagnant, strongly reducing conditions have not been encountered, even in the wettest examples of the community.

- The normal range of winter water tables is not well known, but in many sites in wetter regions is probably not much higher than summer water tables, due to the slope of the site.

- The varied microtopography provides a range of niches suitable for different species; for example, calcifuge species (such as *Erica tetralix, Carex demissa*) can occur on surfaces raised above the level of direct irrigation by the base-rich waters, whilst species such as *Utricularia minor* and *Eleocharis multicaulis* are found in areas of higher water table.

Sub-optimal or damaging water levels

- Whilst shallow pools and runnels are a natural feature, strong flushing and scouring can cause erosional damage (though it is not known to what extent this may lead to significant species loss). Widespread inundation, particularly in the summer, is likely to be damaging, but is unlikely to occur in most locations because of their sloping character.
- A seasonally sub-surface water table may be the natural condition of some stands.
- A long-term reduction of the summer water table beneath high quality stands of M10, to the extent that water no longer oozes underfoot in a non-drought summer, may result in some loss of botanical interest. The response of M10 to prolonged drying may be similar to that observed for M13, but no comparable data are available for M10.

14.3.2 Nutrients/hydrochemistry

This community is typically found in conditions of relatively high base status but low fertility (Table 14.3). Dissolved calcium concentrations are typically high, and calcite sometimes precipitates as marl or tufa. The community is associated with groundwater discharge from calcareous bedrocks and Drift. Various bedrocks are associated with this community, but it is particularly a feature of groundwater outflows from the Carboniferous Limestone in Northern England and parts of Wales. In Wales, some examples of this community are fed from calcareous faces of Old Red Sandstone.

The community has a tendency to occur in locations of slightly lower fertility and base status than M13, but the differences are not great and there is much overlap between the two communities. Some more acidic versions of the community occur, which were not sampled here, and overall the mean pH for the syntaxon as a whole is likely to be lower than that found within the samples examined. M10 pH values are often slightly lower than M13 and many samples of M10 show a smaller propensity for spontaneous calcite precipitation and, in the least base-rich examples, little biogenic calcite precipitation. Shaw and Wheeler (1991) found that an increase in base richness was associated with an increase in the number of rare species recorded, but fewer rare species were found in the most fertile stands.

Table 14.3 pH, conductivity and substratum fertility measured in stands of M10

Variable	Mean	SE	Minimum	Maximum
Water pH	6.7	0.03	4.9	7.7
Soil pH	6.6	0.04	4.4	7.6
Water conductivity (K_{corr} µS cm^{-1})	399	1.3	101	875
Substratum fertility[1] (mg phytometer)	6.5	0.18	3	18

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

14.3.3 Management

Most sites supporting M10 are grazed or have a history of grazing. In most cases, grazing is probably necessary for the maintenance of the community but it need only be light, and it is possible that some examples are self-maintaining. The presence of a mosaic of stable and disturbed areas supporting different species may actually increase species diversity, although very heavy grazing may be detrimental (14.4.1).

14.4 Implications for decision making

14.4.1 Vulnerability

Conservation management primarily involves ensuring conditions that are wet, flushed, of low fertility and base-rich, with at least occasional management. The main threats to M10 are similar to those to *Schoenus nigricans–Juncus subnodulosus* mire (M13), as in its base-rich, lowland, rich-fen form it is more or less vicariant for M13 in Northern and Western Britain. However, many M10 stands are less likely to experience lower summer water tables than M13 (because of their location in regions with higher rainfall and lower potential evaporation), less (if any) significant groundwater abstraction and, generally, less attempted drainage. Nonetheless, some concerns have been expressed about lowering groundwater tables (in some cases associated with nearby quarrying operations, such as Cwm Cadlan). The association of many examples of this community with groundwater outflows from Carboniferous Limestone can make it particularly difficult to predict the likely impact of operations that could affect the water table: Carboniferous Limestone generally has insignificant primary permeability, but supports fracture flow along joints and fissures. The fractures are not regular or extensively interconnected, so that groundwater flow paths can be variable, but tend to be local and short, and spring flows can vary significantly with time. This feature means that some examples of M10 in the drier parts of its range on Carboniferous Limestone may experience more frequent, and perhaps more severe, natural droughting than groundwater-fed slopes on some other aquifers.

The majority of M10 sites are surrounded by rough pasture, moorland or low-intensity grassland, and are unlikely to be threatened by substantial enrichment. However, some examples are juxtaposed with improved pasture or arable land (such as Hulam Fen, Durham) and may be threatened by eutrophication, but the threat appears not to be as great as for M13.

The community can clearly maintain its character without grazing for a considerable period of time, presumably because of the very low substratum fertility and high water tables. Ultimately, in the absence of management gradual species impoverishment will occur, and perhaps scrub invasion, especially if there is some enrichment. However, in some very stressed sites (such as Widdybank Pastures, Durham) where low fertility is accompanied by additional constraints on growth provided by a harsh climate, M10 vegetation seems very stable, even without grazing. In a natural landscape, it is possible that larger flushes may have supported M10-like vegetation with woodland glades.

In some sites, heavy grazing pressure has damaged (by poaching) both substratum and vegetation, an effect which is felt most in the least fertile sites (which have the least resilience to damage because of severe re-growth constraints imposed by low fertilities). It can also lead to a marked loss of individual plants of a particular species per unit area, but it is not known to what extent this may result in significant species loss from the stand. The community is often found on shallow, well-flushed peat which exacerbates the effects of heavy grazing, making the stands more prone to a scouring effect when water levels and flow rates are high.

An increase in fertility, resulting from direct nutrient input, is likely to lead to invasion by a range of taller, more vigorous, herbs, especially in the absence of grazing. This may lead to the loss of many typical M10 species. There is some evidence that this has occurred in a few sites (such as those which support the *Cirsium palustre* variant of M10b). It is not clear whether significant nutrient release occurs as a result of substratum mineralisation following prolonged lowering of the water table, partly because the low-fertility soils often have a small starting nutrient capital and can contain little organic material.

Figure 14.3 shows some of the possible floristic impacts of changes to the stand environment. However, the concept of ‘vulnerability’ is complex and depends upon the starting conditions (including floristic composition), sensitivity of the stand and sensitivity of the site to the pressure of change. Some stands may be regarded as *sensitive* to change but not necessarily *vulnerable.* For this reason, **accurate assessment of vulnerability is likely to require careful site-specific investigations**.

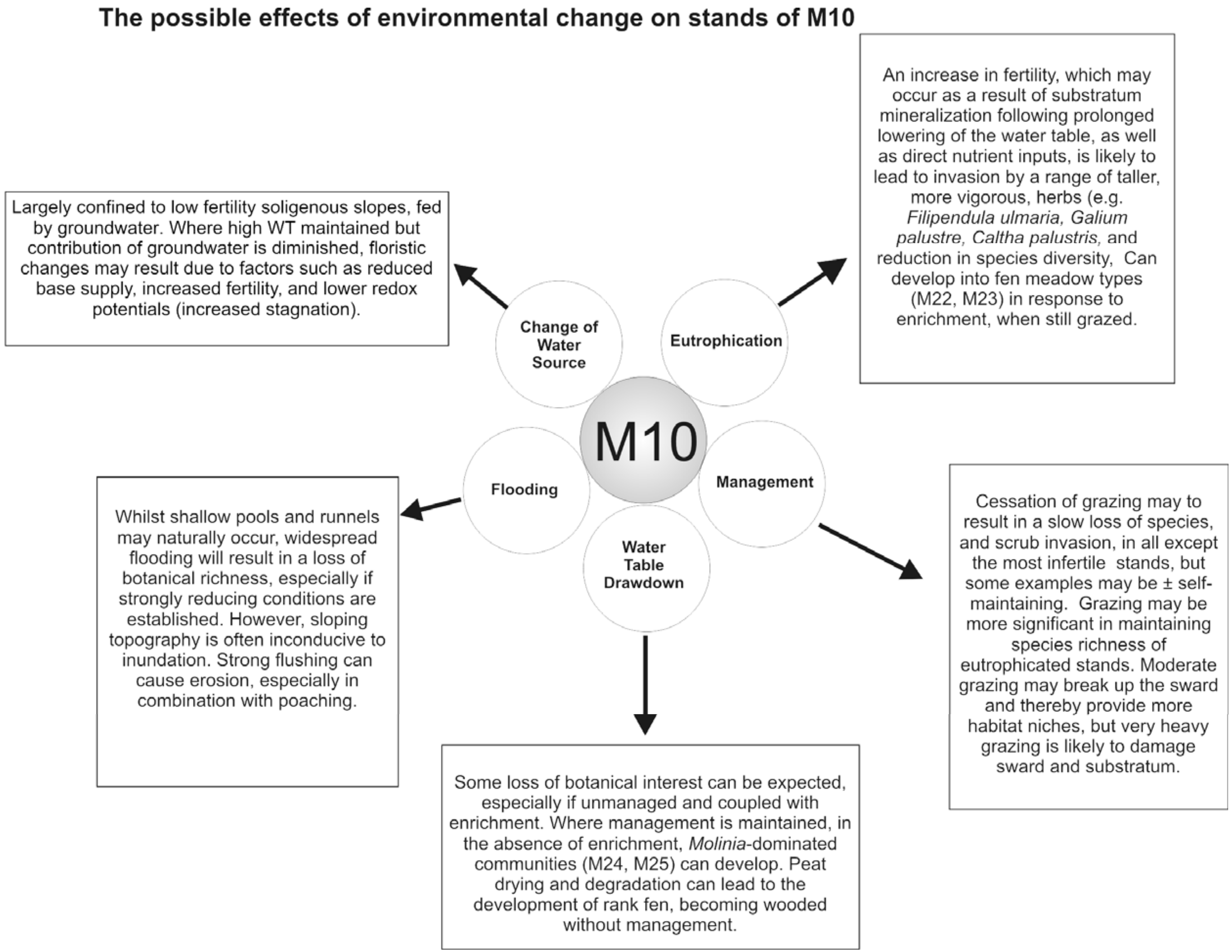


Figure 14.3 Possible effects of environmental change on stands of M10

14.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Little information is available on the restoration of M10 stands, doubtless because few examples of this community are known to have experienced significant damage, but the following comments can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M10 in the short to medium term.
- Scrub removal and re-instatement of vegetation management may help to restore M10 vegetation that has been left unmanaged for a while, provided other conditions have not changed irreversibly.
- The potential for restoring high grade stands on dehydrated sites through the re-establishment of groundwater supply is unknown.
- Attempts to increase the wetness of M10 stands by blocking outflows could be detrimental to the vegetation if they result in stagnant, strongly reducing conditions.

14.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- Examples of the community from upland locations have not been examined.
- There are currently virtually no hydrometric data to better describe the temporal water table characteristics of M10 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M10 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at representative sites.
- Data on the spatial extent of M10 are lacking.
- Possible differences in environmental conditions influencing the three sub-communities have not been explored here.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

15 M13 (*Schoenus nigricans–Juncus subnodulosus*) mire

15.1 Context

Examples of the M13 community have been included within the 'calcium-rich spring water-fed fens' SAC interest feature. Some also fit the 'chalk-rich fen dominated by saw sedge' SAC interest feature. [See Tables 3.1 and 3.3]

15.1.1 Concept and status

Compass and sub-communities

M13 was first identified in Britain by Wheeler (1980b) and was adopted subsequently by Rodwell (1991b), with some modifications. Wheeler originally described six sub-associations, whereas Rodwell subsumed these into three sub-communities, with a concomitant loss of detail. Very similar vegetation occurs in parts of France, and as the community appeared to be synonymous with *Schoeno-Juncetum subnodulosi* described and named by Allorge (1922), Wheeler (1980b) used the same name for the examples from England and Wales. A feature of the community that was specifically recognised by Allorge, and which is also true for the UK, is that whereas *Schoenus* and *Juncus subnodulosus* are normally both prominent in this vegetation, some stands occur in which one or the other is absent. Likewise, there are many stands of vegetation which have prominent *Schoenus* or *J. subnodulosus,* but which are not referable to M13.

One of the three sub-communities created by Rodwell was the *Festuca rubra–Juncus acutiflorus* sub-community (M13a), which seems to have been used to contain a range of species-poor M13-like stands. Rodwell's statement of synonymy indicates that this was based partly on Wheeler's *typicum* sub-association, but curiously almost all of Wheeler's samples allocated to his *typicum* have highest MATCH coefficients with M13c, not with M13a. It is thus not clear on just what data the M13a synonymy is based. It appears to represent impoverished, sometimes rather dry, examples of M13 and to include some stands that Wheeler allocated to the *Carex lepidocarpa* nodum of his 'rich-fen meadows' community (more or less equivalent to M22). This matter is important because, as Wheeler and Shaw (2000a) demonstrate, the threshold values of water tables associated with M13 is critically dependent upon the precise compass of the community.

Examination of the distribution of M13a on DCA ordinations (Figure 15.1) suggest that M13a is not a very coherent sub-community (consideration of DCA Axes 1 and 3, not illustrated, does not materially change the relationships shown for Axes 1 and 2). Most M13a samples occupy the ordination space of either M13b or M13c, suggesting that they have little floristic distinctiveness. Moreover, because they are typically impoverished, they blur the compass of M13 as a unit and create a difficulty in assigning meaningful environmental thresholds to M13 that is even greater than is usually the case for vegetation units.

One important modification made by Rodwell (1991b) to Wheeler's original *Schoeno-Juncetum* was the re-allocation of some of the vegetation Wheeler had referred to a rather heterogeneous, acidic *ericetosum* sub-association to his newly created M14 syntaxon. However, whilst this was generally an appropriate modification, not all of the stands originally included within Wheeler's *ericetosum* sub-association belong to M14, or are even obviously transitional to it. These include some quite important Schoeneta, such as those that occupy much of Beeston Bog (Norfolk). In the NVC scheme, these stands do not obviously belong either to M13 (Figure 15.1) or M14.

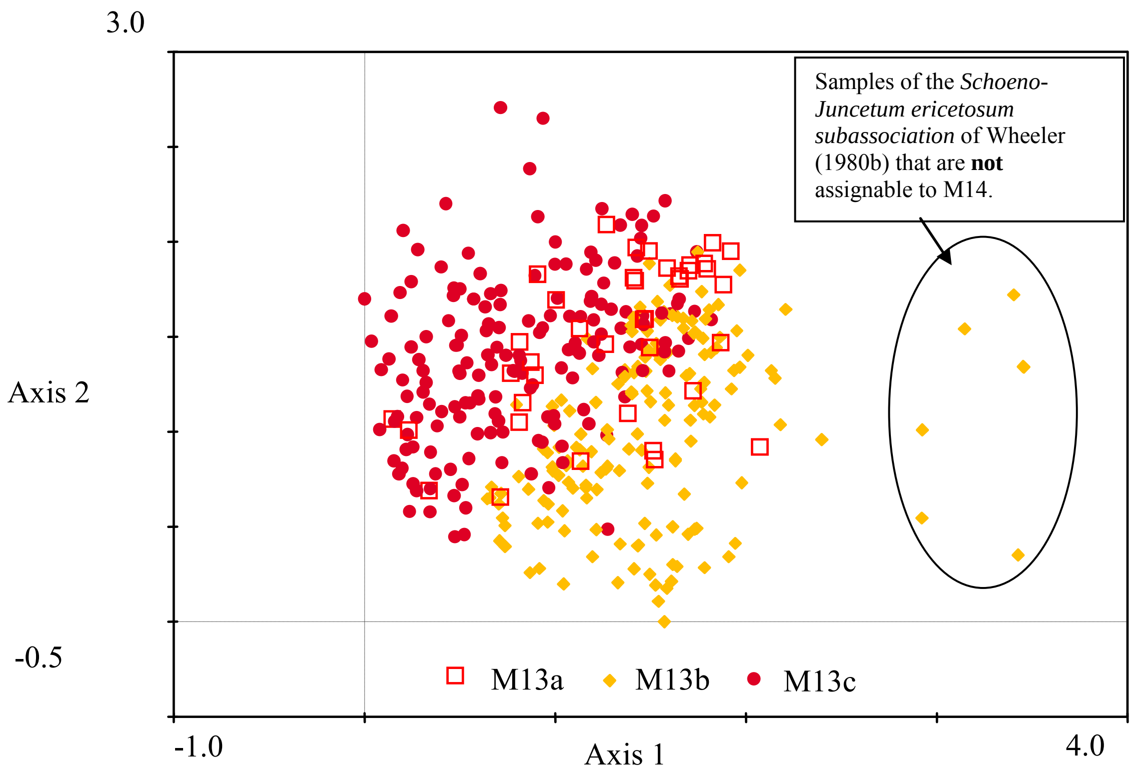


Figure 15.1 Plots of samples of the sub-communities of *Schoenus nigricans–Juncus subnodulosus* mire (M13) on Axes 1~2 of a DCA ordination

The problem of community compass is common to a number of communities, namely how best to deal with stands that are peripheral to the main concept of a community, or transitional to another. There is often no simple or correct solution to this, especially when different community types show more or less continuous intergradation, and the approach adopted by different workers is likely to vary. However, the precise compass of the community that is identified is critical to the specification of appropriate environmental regimes.

Relationship of M13 to M22 and M24

M13 *sensu* Rodwell (1991b) has some floristic overlap with M22, but this is generally not great (Figure 15.2). Stands that occupy the transition include those that Wheeler (1980b, c) allocated to the rich-fen meadow *C. lepidocarpa* nodum rather than to the *Schoeno-Juncetum.* They could be allocated equally to either syntaxon. An advantage of Wheeler's solution is that it helps make M13 a more clearly defined and delimited unit. It does, of course, increase the variability of M22 – but this is a variable and rather ill-defined unit anyway.

The bigger problem with overlap is between M13 and M24, as a good deal of the ordination space of fen samples of M24 overlaps with that of M13, and any dividing line is likely to be rather arbitrary (Figure 15.2 – note that the consideration of Axes 1 and 3 (not illustrated) does not improve the separation of the communities). This problem doubtless reflects a number of influences on vegetation composition. M24 frequently develops from M13 as a consequence of drying, which could be a result of drainage or natural seral processes, or it replaces it spatially along a water table gradient; it is inevitable that numerous intermediate types of vegetation occupy these intergrading circumstances. It does, however, mean that it is difficult to set a water table limit for M13 *versus* M24, because the floristic limits of the two units are nebulous.

In addition, the intergradation between M13 and M24 samples is sometimes a simple consequence of the mosaiciform nature of most examples of M13, where tussock tops and tumps within the fen tend to be occupied by plant species with affinities to M24. The proportion and abundance of typical M24 species within the vegetation can therefore be a reflection of the microtopography of individual stands of M13; those with the greatest area of elevated surface have overall affinities that may be greater to M24 than to M13 – even though the associated water table may be within the range of optimal development of M13. This occasionally happens in an extreme form, when robust tussocks of *Schoenus* and *Molinia* merge to form an elevated platform occupied largely by *Molinion* species, to form a stand from which many typical M13 species are largely absent. In some instances, the size and area of the tussocks is related to low intensities of trampling damage, so that lack of management can sometimes make M13 stands develop floristically towards M24 surfaces, without any associated reduction in the absolute level of the water table. This problem could partly be avoided by sampling separately the various components of the microtopographical mosaic, but this does not form part of normal sampling protocols (and, if adopted, might well introduce as many problems as it solves).

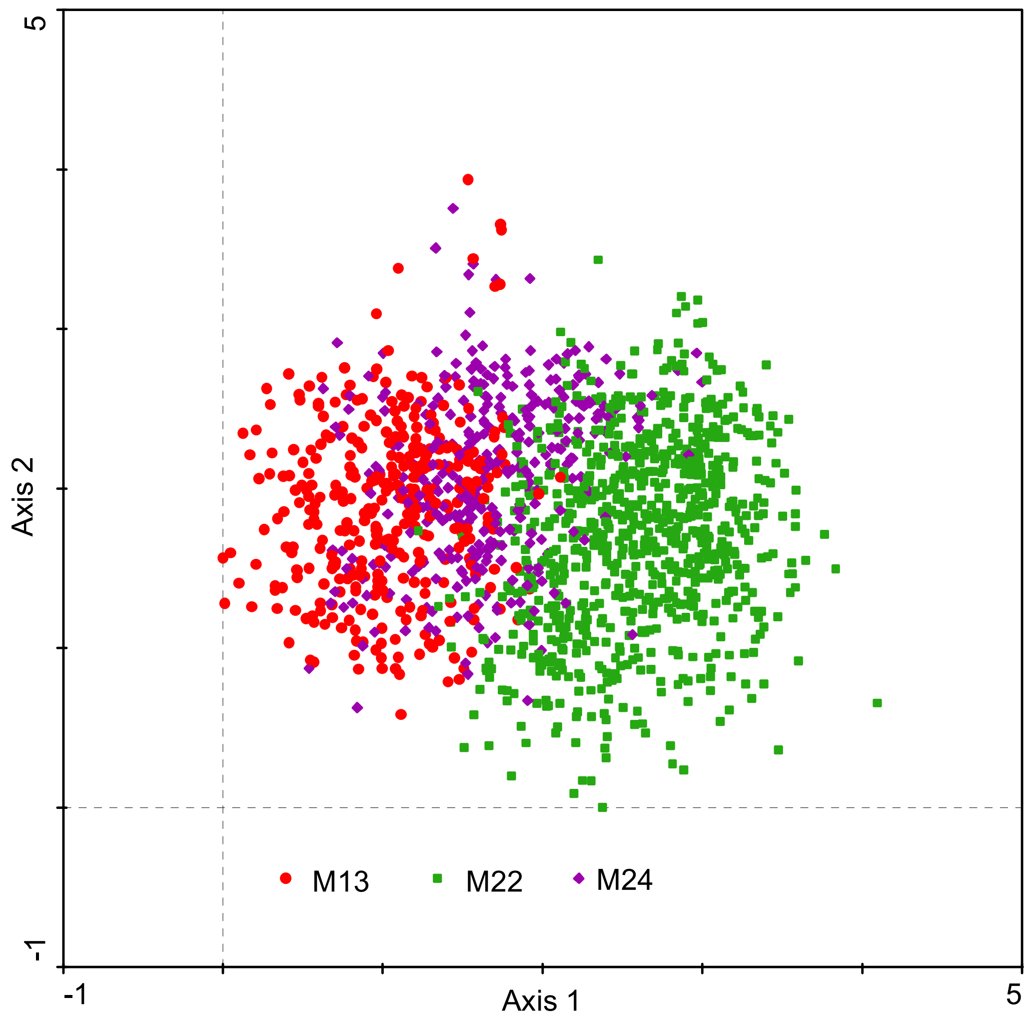


Figure 15.2 Plots of samples of *Schoenus nigricans–Juncus subnodulosus* mire (M13), *Juncus subnodulosus–Cirsium palustre* fen meadow (M22) and *Molinia caerulea–Cirsium dissectum* (M24) on Axes 1~2 of a DCA ordination

15.1.2 Floristic composition

Schoenus nigricans and *Juncus subnodulosus* usually dominate, with a rich range of associated species, though neither dominant necessarily occurs. Unless heavily grazed, both *Schoenus* and *J. subnodulosus* are of moderate height, but in most sites there are lower-growing surfaces amongst the dominants, and there can be small runnels or pools. The community is typically species-rich(Table 15.1) and important in supporting several rare species, and other infrequent fen species, in some parts of lowland Britain. Much of the floristic interest of the community is associated with areas of lower growth.

Table 15.1 Number of species recorded from stands of M13

	Total	Mean	SE	Min	Max
All species (spp 4 m^{-2})	367	30.9	0.11	7	65
Mire species (spp 4 m^{-2})	154	22.2	0.11	3	53
Rare mire species* (spp 4 m^{-2})	39	2.3	0.08	0	13

* These include*: Calamagrostis canescens, Calamagrostis stricta, Calliergon giganteum, Campylium elodes, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Cladium mariscus, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Drepanocladus vernicosus, Drosera longifolia, Eleocharis uniglumis, Epipactis palustris, Eriophorum latifolium, Liparis loeselii, Moerckia hibernica, Oenanthe lachenalii, Peucedanum palustre, Philonotis calcarea, Pinguicula lusitanica, Plagiomnium elatum, Plagiomnium ellipticum, Potamogeton coloratus, Preissia quadrata, Primula farinosa, Pyrola rotundifolia, Ranunculus lingua, Rhizomnium pseudopunctatum, Selaginella selaginoides, Sphagnum contortum, Sphagnum russowii, Sphagnum subsecundum, Sphagnum teres, Thalictrum flavum, Thelypteris palustris, Thuidium deliculatum, Utricularia minor.*

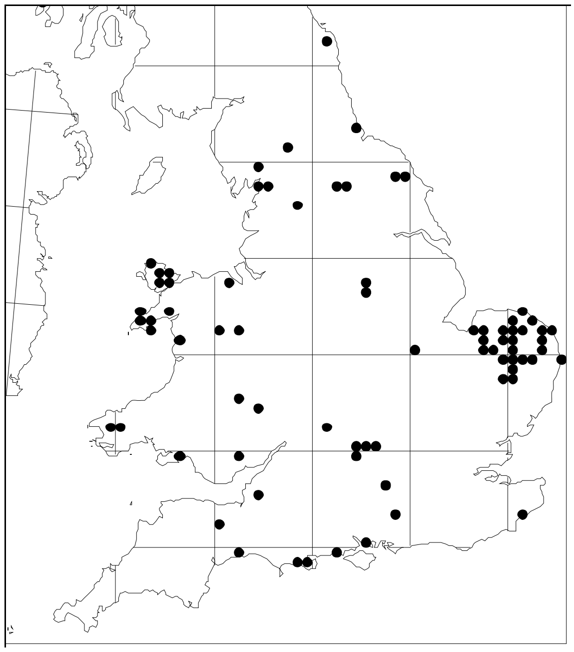
Species which are particularly characteristic of M13, and which help separate it from other communities, are listed in Table 15.2. Not all of these are confined to M13, nor are they all '*Caricion davallianae* species'. The number of 'M13 characteristic species' recorded from a vegetation sample can be used to assess its goodness of fit to M13 (the more, the better). The greater the number of M13 characteristic species present, the greater the representation of rare and regionally rare species. Stands with *Schoenus* and *J. subnodulosus,* but only a few other species, are usually better referred to M22 (or M24) rather than M13.

Table 15.2 Species characteristic of M13

Characteristic species		
Anagallis tenella	*Dactylorhiza traunsteineri*	*Pedicularis palustris*
Aneura pinguis	*Drepanocladus lycopodioides*	*Pellia endiviifolia*
Bryum pseudotriquetrum	*Drepanocladus revolvens (s.l.)*	*Philonotis calcarea*
Campylium elodes	*Drepanocladus vernicosus*	*Philonotis fontana*
Campylium stellatum	*Drosera longifolia*	*Pinguicula vulgaris*
Carex dioica	*Eleocharis quinqueflora*	*Plagiomnium elatum*
Carex hostiana	*Epipactis palustris*	*Plagiomnium ellipticum*
Carex pulicaris	*Eriophorum latifolium*	*Potamogeton coloratus*
Carex viridula ssp brachyrrhyncha	*Euphrasia pseudokerneri*	*Preissia quadrata*
	Fissidens adianthoides	*Riccardia chamedryfolia*
Cladium mariscus	*Gymnadenia conopsea*	*Riccardia multifida*
Cratoneuron commutatum	*Listera ovata*	*Sagina nodosa*
Dactylorhiza incarnata	*Moerckia hibernica*	*Schoenus nigricans*
Dactylorhiza praetermissa	*Parnassia palustris*	*Scorpidium scorpioides*

15.1.3 Distribution

This vegetation is widely scattered in England and Wales (recorded from 117 sites; Figure 15.3), but uncommon except in a few regions. Its two main centres are in East Anglia and North Wales (especially Ynys Môn), but there are important outliers elsewhere (such as Cothill basin, Oxfordshire; North Yorkshire). The community is essentially lowland and southern. It is largely absent from Scotland and from upland locations, where comparable habitats are generally occupied by M10.



(data from FenBASE database)

Figure 15.3 Distribution of M13 in England and Wales

15.1.4 Landscape situation and topography

The majority of stands occur on (gently to quite steeply) sloping ground in valleyhead fens, mostly near the headwaters of small streams, but the community also occurs on soligenous slopes around small basins or (occasionally) at upland margins of floodplains. In a few locations the community occupies topogenous sites, usually where there is particularly strong groundwater inflow, and sometimes forming trails along flow lines rather than large stands.

15.1.5 Substratum

Substratum usually a shallow (less than 50 cm) organic deposit (sometimes virtually none), though a small number of examples (such as Cothill Fen (Oxfordshire), Smallburgh Fen (Norfolk)) have a deeper infill of peat (and, very often, marl). Most often overlying permeable sands and gravels or a sandy silt, and occasionally occurs directly upon the bedrock at outcrop. A few examples are known over less permeable basal substrata, but in general these tend to be drier than other examples.

The bedrock associated with stands of M13 is variable, but is normally calcareous and most of the stands examined appear to be fed primarily from Chalk, or from Carboniferous or Jurassic Limestones. A few examples in Norfolk are associated with deposits of Crag, and some appear to be sourced from minor aquifers from within base-rich drift deposits (such as glaciofluvial sand and gravel at Cors Geirch and some other sites on Lleyn peninsula). In some instances (such as Beeston Bog, Norfolk), the source of the irrigating water (drift *versus* bedrock) is contentious and the subject of ongoing investigations.

15.1.6 Zonation and succession

Many examples of M13 occur in localised, discrete groundwater-fed locations, including old peat pits, which may be largely unconformable with surrounding habitats. M13 surfaces can therefore show an abrupt transition to a number of adjoining habitats and vegetation types. In some instances, the transition between the M13 stands and drier conditions is marked by a zone of *Molinia*-dominance (such as M24) or fen meadow (such as M22). M22 tends to occur when the surroundings of M13 are more fertile than in the M13 patch; they may or may not also be drier. M24 tends to occur when the surroundings are of similar fertility to the M13 patch, but are drier. Fairly dry conditions can sometimes occur downslope of M13 stands, particularly where any surface outflow from the stands becomes funnelled into small streams, but the community can also grade downslope into various types of (usually) rheo-topogenous mire, and merge into communities such as M9, M29, S10, and S27.

In a few sites, stands of M13 form part of a clear valleyside zonation. For example, in parts of Scarning Fen (Norfolk) there is a fairly clear downslope zonation of dry grassland > M24 > M13 > a basal, reed-dominated soakway. However, even in sites with quite large stands of M13, there is a tendency for zonations to be interrupted by other habitats such as springs or tumps of drier ground. In some sites, a discontinuous zonation of M13 can sometimes be traced, with varying degrees of difficulty.

In some sites where contrasting mineral substrata are exposed on the valleyside, or where there are contrasting groundwater sources, M13 can participate in some quite complex zonations, sometimes with acidic fen communities (such as M6) forming a band (usually above, but occasionally below) zones of M13. Buxton Heath (Norfolk) still shows a fairly complete downslope zonation of dry heath > wet heath > M24 > M13 > M22 soakway, and this was apparently once more widespread. Elements of this are also evident at Beeston Bog (Norfolk) (though here the M13 is not typical M13) and Roydon Common (where the M13 is probably best regarded as M14). Acidic mire communities apparently once occurred above M13 at Redgrave Fen (Suffolk), and probably elsewhere in the Waveney–Ouse Fens, but have since been lost. Some intriguing zonations involving M13 and other mire communities occur on some valley slopes in the North York Moors (such as Troutsdale Fen, Jugger Howes Beck), possibly in response to the presence of outcrops of contrasting Jurassic substrata, but this region was not considered in the *Wetland Framework*.

Rodwell (1991b) notes that the sub-communities of M13 can themselves sometimes show a fairly clear zonation, with M13a on the drier ground, M13b the moister and M13c the lower, wetter areas. This sequence can indeed sometimes be found, but: (a) it can sometimes be reversed; (b) whilst the mean water table associated with M13c is higher than that associated with M13b, there is much overlap between the two units and in some sites, M13c occupies *drier* locations than M13b; and (c) whereas some stands of M13a occupy relatively dry ground, others have a water table at or near the surface. Overall, the ecohydrological basis for the three sub-communities of M13 is not very clear, but there is some evidence that M13c is associated with slightly more fertile soils than is M13b.

Where M13 occupies the slopes of shallow basins and troughs, it can grade downslope into various communities of rheo-topogenous habitats (such as M9-2, S2), as at Cors Goch and Cors y Farl (Anglesey). In these sites M13 is not really part of the hydrosere of the basin proper, but some examples of the community are known from hydroseral contexts, including some reflooded peat workings. In a very few cases (such as Cothill Fen), there is evidence of some *de novo* M13 colonisation of shallow open water, but this is not at all common and most examples of M13 in topogenous basins appear to have developed from an former phase of M9-2, perhaps as a consequence of environmental change. At Smallburgh Fen (Norfolk), stratigraphical data (Wheeler, Shaw and Wells, 2003) suggest that the current patches of M13-like vegetation represent a fairly recent development from a long phase of alternating shallow swamp and wet fen, which was probably occupied by communities analogous to S2 and M9-2. The trigger for the development of M13 at this site is not known: it could perhaps be due to a slight natural drying of the surface in response to autogenic peat accumulation, but an alternative possibility is that it represents a response to slight drainage of the fen basin consequent upon the excavation of dykes and interception of spring flow. Similar stands of vegetation with strong affinities to M13 also occur at Upton Fen, in a groundwater-fed remnant mire at the margin of the floodplain of the River Bure. This is now separated from the river by drained levels and in a sense now represents a large, very gently sloping seepage face. From this perspective, Upton Fen is ecohydrologically not so very different from some of the gently sloping seepages on shallow peat that support M13 in some valleyheads (moreover, much of the M13 is floristically transitional to M9-3, which also occurs at Upton Fen).

15.2 Water supply mechanisms and conceptual model

Strongly soligenous, often with visible springs. Typically fed by lateral or vertical groundwater discharge from a semi-confined or unconfined aquifer (principally chalk or limestone, but sometimes from calcareous drift), often with a positive piezometric head in the supporting aquifer. Some examples are strongly artesian (piezometric head >1 m agl), but some drier stands also occur, fed by intermittent seepages[1]. Topogenous examples are usually found at the margins of mire systems, where they are fed by direct groundwater outflow from the mineral aquifer or by flow of surface water sourced from springs and seepages on adjoining slopes. A few wet examples are known over low-permeability mineral deposits, on slopes flushed by groundwater outflow above the stand (such as Banc y Mwldan (Cardiganshire), Nantisaf (Anglesey)), but this is less often the case than with M10.

Forty-nine per cent of M13 samples were identified as occurring within WETMEC 10 (Permanent Seepage Slopes such as Scarning Fen (Norfolk), Cors Bodeilio (Anglesey)), with 29 per cent within WETMEC 13 (Seepage Percolation Basins such as Cors Nantisaf (Anglesey), Cothill Fen (Oxfordshire)). Most of the remainder occurred within WETMECs 9 (6%), 11 (7%), 15 (2%) and 17 (5%). One rather anomalous example was recorded in WETMEC 12 (Fluctuating Seepage Basins) on the edge of a pingo at East Walton Common (Norfolk).

15.3 Regimes

15.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 15.3, together with mean recorded values for summer water table associated with stands of M13. Water conditions for M13 are difficult to specify quantitatively, partly due the lack of detailed time-series data, but more importantly because different versions of the community are associated with rather different water regimes. This has been examined in some detail for Eastern England by Wheeler and Shaw (2000a). In addition, microtopographical variation generates subtle but ecologically important differences in water regime within individual stands. Runnels, lawns and hummocks provide a complex of microhabitats that contributes greatly to the species diversity of high-grade stands. Consequently, **mean water table values have limited value, are potentially misleading and should be interpreted with caution**.

Table 15.3 Mean rainfall, potential evaporation and summer water table for M13

[1] A seasonally negative piezometric head could result from groundwater abstraction but may also be a natural feature of some systems.

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	724	558	1,050
Potential evaporation (mm a^{-1})	613	564	646
Mean summer water table (cm agl or bgl)	–4.6	–38.6	8.4
Mean summer water table [Eastern England] (cm agl or bgl)	–9.5	–38.6	5.0

Specific time-series data for stands of M13 are not available for the majority of sites. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal water levels

- Most examples of M13 are characterised by water tables at or close to the fen surface (–5 to +1 cm). The richest examples (with more than 20 characteristic species, see Table 15.2) occur exclusively in locations that exhibit a water table generally at the fen surface in winter and summer. As a rough guide, good examples of M13 mostly occur in sites with visible surface water (but not inundated) or where water oozes from the soil underfoot during the summer months of a normal (non-drought) year. However, a seasonally sub-surface water table may be the natural condition of some (less rich) stands occupying intermittent seepages.

- Mean summer water tables for M13 in Eastern England (Wheeler *et al.,* 2004, see Table 15.3) are lower than mean values for England and Wales as a whole. The reason for this is not known: it may relate both to the drier character of this region and the greater impact of abstractions on groundwater table. It is not known whether the examples of M13 in Eastern England are in a stable equilibrium with their apparently lower summer water levels, or whether an ongoing process of floristic change, and possible impoverishment, is likely to occur.

- Some examples of M13 are supplied with water sourced primarily by fracture flow in deposits with limited primary porosity (such as Carboniferous Limestone). These can be particularly susceptible to episodic low water tables during drought periods, especially examples fed from flow paths that are short and with limited interconnection. It is possible that some examples may be naturally subject to frequently lower summer water tables than, say, some examples fed from the Chalk. This may go some way to explaining the distinctive composition of M13 in many Anglesey fens (as detailed by Wheeler, 1980b), including the general scarcity of uncommon bryophytes in these stands.

- Most high grade M13 sites are strongly soligenous. Slopes prevent surface accumulation of water except in small shallow pools (and these may experience considerable water throughflow).

- The normal range of winter water tables is probably of little importance, except when associated with inundation (see below). As in many instances the water table in M13 stands is slope-controlled, winter water tables are frequently little different to summer ones, except in summer-dry examples.

Sub-optimal or damaging water levels

- Unusually wet sites (summer water table usually above-surface between tussocks) tend to be less species-rich than those that are slightly drier, though the mosaiciform character of many examples of M13 means that often many species can co-exist, even in very wet conditions. However, whilst shallow pools and runnels are a natural feature, widespread inundation leading to prolonged stagnation, particularly in the summer, is likely to be damaging to a community which usually experiences considerable water throughflow.

- A few examples of M13 that receive particularly strong groundwater outflow may be subject to species impoverishment as a consequence of scouring. This is not generally as much of a problem as with stands of M10, but it is sometimes exacerbated considerably through poaching by livestock.
- The highest quality stands do not usually occur at sites where summer water tables are consistently around 10 cm below ground level (bgl) (often only mediocre or low grade stands with less than 10 characteristic species are found). However, examples of the community can withstand, or recover from, periodic summer droughts (of at least three years duration) when water tables may be 30 cm bgl.
- Apparently low water tables (relative to the surface) can occur naturally in parts of some stands, where tussocks of *Schoenus* and *Molinia* coalesce to form an elevated peaty platform. In some cases, surface water can still be found around the bases of the tussocks, but with the main vegetation surface elevated some 20 cm above this.
- A seasonally sub-surface water table may be the natural condition of some (less rich) stands occupying intermittent seepages. It is often difficult to know to what extent summer-dry stands are natural or represent remnants of formerly better, wetter M13.
- A long-term reduction of the summer water table beneath high quality stands of M13, to the extent that water no longer oozes underfoot in a non-drought summer, can be expected to result in some loss of botanical interest.
- Summer water tables deeper than 30 cm bgl in non-drought years are associated with particularly low grade stands of M13. In this context, a further reduction in water table is likely to have little impact. This may be the natural condition of some stands or may represent remnants of formerly better, wetter M13.

A detailed discussion of the relationships between hydrological conditions and floristic variation within M13 stands can be found in Wheeler and Shaw (2000a).

15.3.2 Nutrients/hydrochemistry

Flushing by groundwater discharge is a feature of most high grade M13 sites, but slopes generally prevent surface accumulation of water except in small shallow pools that probably experience considerable water throughput. Stagnant, strongly reducing conditions have not been encountered even in the wettest examples of the community.

Irrigating waters are typically base-rich/high pH and often supersaturated with $CaCO_3$. Substratum is usually base-rich, as implied by calcite precipitation which is generally visible, sometimes forming tufaceous concretions (such as Badley Moor). Occurrence of ochre is very rare, and usually indicative of water contribution from a drift aquifer. Wheeler and Shaw (1991) report a mean increment (April to September) in dry weight of above ground standing crop of 200 g dry wt m^{-2}. This low productivity reflects the typically low fertility of the substratum.

presents the pH, conductivity and substratum fertility measured in stands of M13.

Table 15.4 pH, conductivity and substratum fertility measured in stands of M13

Variable	Mean	SE	Min	Max
Water pH	7.0	0.002	5.7	8.3
Soil pH	7.1	0.02	5.4	7.5
Water conductivity (K_{corr} µS cm^{-1})	565	0.7	301	928
Substratum fertility[1] (mg phytometer)	7.0	0.15	2	18

Irrigating waters are typically oligotrophic and P-limited (in some cases due to adsorption of P onto calcite particles (Boyer and Wheeler, 1989)). Concentrations of soluble reactive phosphorus (SRP) are often below detection limits but concentrations of N are very variable, with values in excess of 30 mg l^{-1} NO_3–N in some seepage waters. There is some evidence that, although still oligotrophic, the most species-rich stands are not the most infertile (very mild enrichment, such as may be associated with natural seral eutrophication or limited cultural activity, may enhance diversity).

Table 15.5 presents mean ion data for interstitial water samples for a limited selection of sites recorded by Boyer and Wheeler (1989).

Table 15.5 Mean ion data for interstitial water samples

Limits	pH	Ca^{2+}	Mg^{2+}	K^+	HCO_3^-	SRP	NH_4^+	NO_3^-	SO_4^{2-}
Lower	7.0	97.0	3.0	1.4	285.0	5.0 $\times 10^{-3}$	0.13	0.85	17.0
Upper	7.4	146.0	38.0	3.0	406.0	27.0 $\times 10^{-3}$	0.32	32	73.0

All figures (apart from pH) are in mean concentration mg l^{-1}.

15.3.3 Management

The most species-rich examples of M13 are managed, generally by occasional burning, summer mowing or light episodic grazing. Lack of management, or overgrazing, may be detrimental to species diversity, although the effect may depend on the substratum fertility and water table. Management is generally least important in low fertility, summer-wet stands and it is possible that some of these are largely self-maintaining.

The management needed to maintain stands of M13 depends partly on the identity of associated species. Examples with a robust, stress-tolerant, potential dominant species such as *Cladium mariscus* are particularly vulnerable to floristic loss associated with dereliction, as the sedge forms progressively more rank, extensive and impoverished patches within the M13. From such perspectives, abundant *C. mariscus* can be considered more of a nuisance than desirable.

Some examples of the community, particularly around strong springs, consist of dense tussocks of *Schoenus nigricans,* and can be very species-poor. The interlocking tussocks can prevent the growth of lower-growing associates in the runnels amongst the tussock

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

bases. This condition appears to be particularly associated with strong spring flow coupled with low-grazing intensities and is not a feature of all unmanaged stands.

15.4 Implications for decision making

15.4.1 Vulnerability

Figure 15.4 shows the possible floristic impacts of changes to the stand environment. However, the concept of 'vulnerability' is complex and depends upon the starting conditions (including floristic composition), sensitivity of the stand and sensitivity of the site to the pressure of change. For example, a wet, species-rich stand of M13 would be particularly sensitive to a fall in summer water table. However, if water supply to such stands is supported by a strong piezometric pressure, the impact of abstraction on water levels may be negligible. In such a context, the stand could be regarded as *sensitive* to change but not necessarily *vulnerable.* For this reason, **accurate assessment of vulnerability is likely to require careful site-specific investigations**.

The possible effects of environmental change on stands of M13

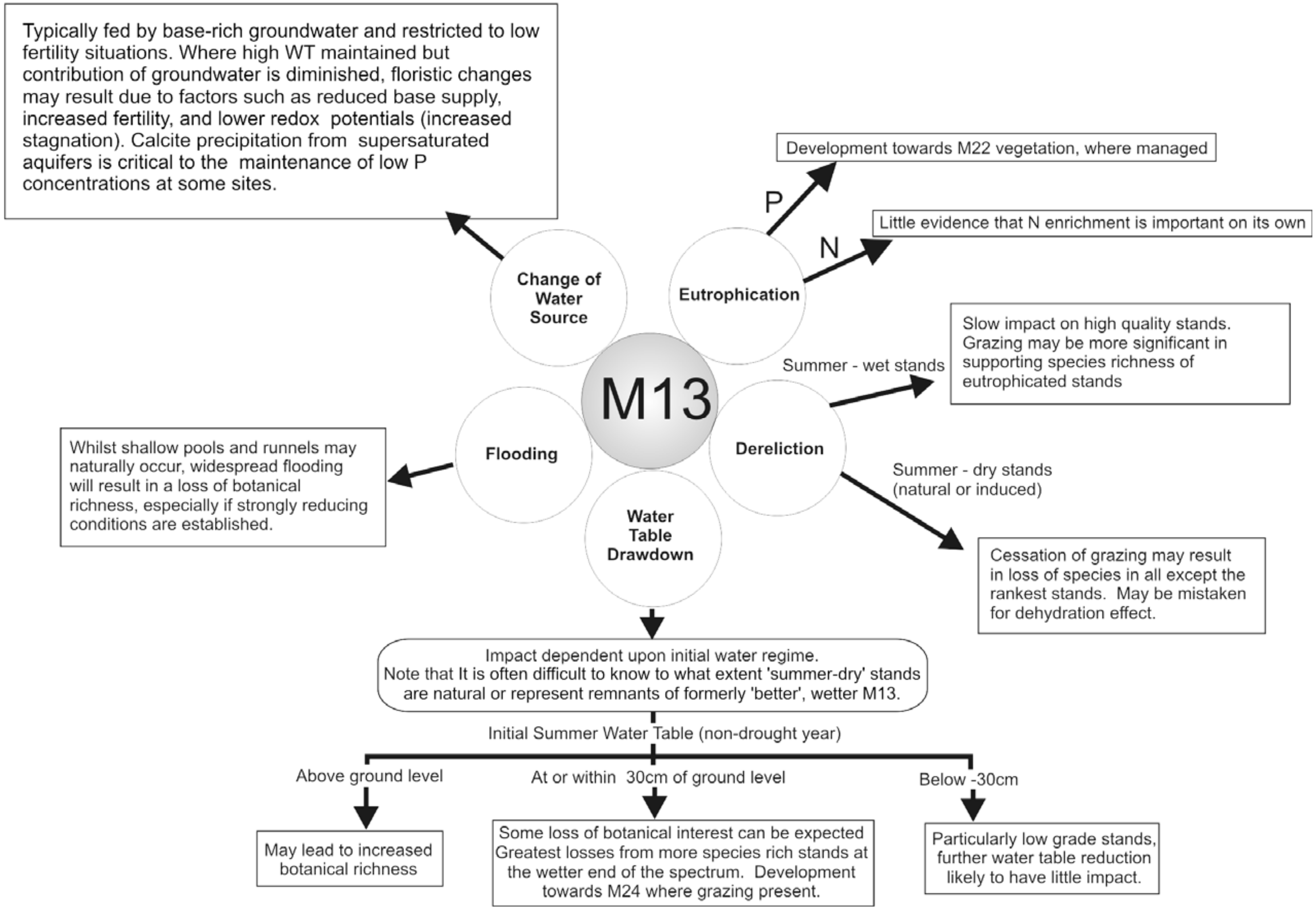


Figure 15.4 Possible effects of environmental change on stands of M13

15.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M13 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M13 in the short to medium term.
- Vegetation management may increase the representation of certain M13 species in drier stands.
- Scrub removal and re-instatement of vegetation management may help to restore M13 vegetation that has been left unmanaged for a while, provided that other conditions have not changed irreversibly. However, scrub removal peripheral to stands of M13 can sometimes be peripheral to the hydrogeological circumstances that support M13 and may not lead to an increase in this community, which is unlikely to expand into unsuitable hydrogeological conditions.
- The potential for restoring high grade stands on dehydrated sites through the re-establishment of groundwater supply is not well known. However, irrigation of partly drained fen surfaces from which the top soil has been removed by calcareous water has been used to induce the spread of M13-like vegetation (such as Cors Erddreiniog), and this approach may possibly be used to expand the area of M13 onto surfaces which have not naturally supported this community. In a few situations, M13-like vegetation has developed spontaneously in appropriate, newly created groundwater-fed habitats proximate to a source of appropriate species (such as Dry Sandford Pit, Cothill).
- Attempts to increase the wetness of M13 by blocking outflows could be detrimental to the vegetation if they result in strongly reducing conditions.

15.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently few data to better inform the temporal water table characteristics of M13 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M13 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at representative sites.
- Data on the spatial extent of M13 are lacking.
- Possible differences in environmental conditions influencing the three sub-communities have not been explored here.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

16 M14 (*Schoenus nigricans–Narthecium ossifragum*) mire

16.1 Context

Examples of the M14 community have been included in the “chalk-rich fen dominated by saw sedge” and “transition mire and quaking bog” SAC interest features. [See Tables 3.1 and 3.3]

16.1.1 Concept and status

The M14 syntaxon was first identified by Rodwell (1991b). Previously, Wheeler (1980b) had sampled a small number of stands of this vegetation and classified them as part of an *ericetosum* sub-association to his *Schoeno-Juncetum subnodulosi* (more or less equivalent to M13). Rodwell (1991b) appropriately reallocated the relevant samples to the new M14. However, whilst potentially a valuable unit, M14 suffers from uncertainties about its compass and its relationships to certain other community types. The unit was created on the basis of only 15 samples, all from a small geographical compass (Southern England and East Anglia), and it is not clear to what extent Rodwell rigorously explored its wider relationships.

Uncertainties about the scope of M14 are manifest in various vegetation surveys. The constancy tables presented in Rodwell (1991b) clearly show calcicolous bryophytes to be a constant feature of the community, and some surveyors consider these to be an essential component of the community (a view supported by MATCH analyses). However, other surveyors have tended to allocate all *Schoenus* stands in relatively base-poor fens to M14, perhaps encouraged by comments that the transition from M14 to M21 is “marked by the disappearance of *Schoenus* and the extension of the carpet of peat-building *Sphagna*” (Rodwell, 1991b). We hold the view that, as the NVC tables suggest, M14 is a meaningful unit only insofar as it is specifically restricted to stands with some calcicolous species in addition to *Schoenus*, and that other occurrences of *Schoenus*-rich stands in acidic fens are better seen as *Schoenus*-rich variants of M21, or of another community.

Although Rodwell (1991b) describes M14 essentially as a community of the South and South-West of England, it has clear analogues elsewhere. For example, in parts of South Cumbria (particularly in the Subberthwaite Common area) base-enriched soakways occur (usually within M21) which are ecologically strongly analogous to the M14 soakways of the South and which share many of their species (but do not have *Schoenus nigricans*). MATCH analyses suggest that the highest coefficient of MATCH for these stands is usually with M9a (M9-1), but in some instances it is with M14, with examples of M9a and M14 both occurring in the same site. This points to considerable similarity between the units, and a DCA ordination shows some overlap, though for the most part the two units occupy discrete parts of the ordination. Interpretation of these relationships is confounded by uncertainties about the desirable compass of M9a (see 10.2), but it seems likely that the M9a (M9-1) and M14 soakways represent vicariant units in different parts of Britain. Floristic differences are probably partly phytogeographical in origin: for example, the *Pinguicula lusitanica* of M14 is replaced by *P. vulgaris* further north and *Schoenus* by *Carex lasiocarpa.*

In parts of Scotland, soakway communities similar to M14 occur quite widely and, recognising their affinities, Shaw and Wheeler (1991) assigned these to a separate provisional sub-community of M14. Soakways also occur as part of some blanket mire macrotopes in the North-West of Scotland. Rodwell (1991b) considers these to be analogues of M14 but allocates them to a sub-community of *Scirpus cespitosus–Erica tetralix* wet heath (M15). Some seepage versions of M14 also have strong affinities to some soligenous forms of M15a (and to some types of M10).

These considerations suggest that the current M14 is perhaps not the most useful segregate of this sector of mire vegetation, but that it may be the basis, probably as a sub-community, of a somewhat broader unit which has less overall floristic cohesion but greater ecohydrological integrity and utility. As more data are now available for M14 (and related communities) than were available to Rodwell (1991b), some reconsideration of these inter-relationships may be appropriate. It is difficult to avoid the view that there is a valuable floristic unit, perhaps encompassing M14 and elements of M9a and M15a, waiting to be identified.

16.1.2 Floristic composition

Described by Rodwell (1991b) as including "mildly calcicolous *Schoenus* vegetation of South-West lowland Britain which cannot readily be integrated into the *Schoenetum*" [M13]. Thus, the vegetation is usually dominated by *Schoenus,* but the associated flora is typically less species-rich than M13. Some species frequently occur which are generally absent from M13 (such as *Eleocharis multicaulis, Pinguicula lusitanica, Rhynchospora alba*) and *Sphagna* are usually much more prominent than in M13. *Sphagnum subnitens* is particularly characteristic, but others also occur, including *S. auriculatum* and the more basiphilous *S. contortum*. One or more species of other basiphilous bryophytes (such as *Scorpidium scorpioides, Campylium stellatum*) also occur, but they may be sparsely developed and the species represented varies between stands. The community is moderately species-rich (five to 38 spp per sample) and supports more than 20 rare mire species (see Table 16.1).

Table 16.1 Number of species recorded from stands of M14

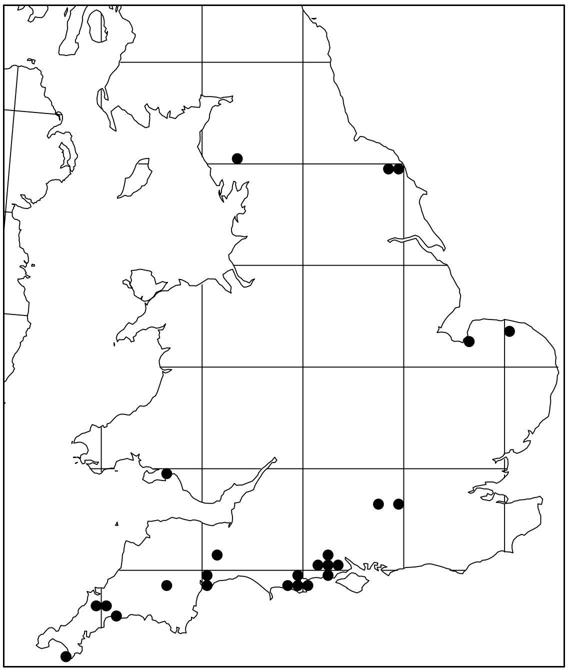
	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	154	18.5	0.20	5	38
Mire species (spp 4 m^{-2})	106	16.4	0.19	5	34
Rare mire species* (spp 4 m^{-2})	22	1.3	0.14	0	5

** These include: Calliergon giganteum, Cladium mariscus, Drosera intermedia, Drosera longifolia, Epipactis palustris, Erica ciliaris, Eriophorum gracile, Eriophorum latifolium, Hammarbya paludosa, Hypericum undulatum, Osmunda regalis, Philonotis calcarea, Pinguicula lusitanica, Rhizomnium pseudopunctatum, Selaginella selaginoides, Sphagnum contortum, Sphagnum molle, Sphagnum pulchrum, Sphagnum subsecundum, Thelypteris palustris, Utricularia intermedia, Utricularia minor*

16.1.3 Distribution

This is an uncommon community, usually only occupying small areas, which mainly occurs locally in Cornwall, Devon, Dorset and the New Forest (Figure 16.1; 89 sites). Although M14 vegetation as described by Rodwell (1991b) is largely confined to the South of England, a strikingly similar vegetation type can be found in Norfolk, Yorkshire and Cumbria, and associated with some of the flushed blanket mire and patterned fens of Northern Scotland. There are few known records for Wales, but similar vegetation (though generally without *Schoenus*) occurs in a few locations.

The constancy of certain components of the flora of M14, especially *Pinguicula lusitanica*, almost certainly reflects its phytogeographical location (*P. lusitanica* does not occur in the north easterly examples of the community). Rodwell (1991b) suggests, probably correctly, that the occurrence of *Schoenus nigricans* in less base-rich conditions than it usually occupies is a consequence of the more oceanic climate of the South-West (a ecogeographical trend which has long been known but which is little understood (Wheeler, 1999a)).



(data from FenBASE database)

Figure 16.1 Distribution of M14 in England and Wales

16.1.4 Landscape situation and topography

Typically found in sites where there is a strong soligenous input of telluric water. The majority of examples occur in valleyhead fens, where they may occupy (usually small) seepages and soakways or occur as small flushes within wet heath. In parts of Scotland, the community occupies soakways at the mineral edges of some blanket mires, but no examples in this context have been recorded in England and Wales.

16.1.5 Substratum

Sometimes water and liquid muds over more solid peat or mineral soil (especially in soakways), but also occurs on more consolidated peaty surfaces (especially in small seepages or flushes). In a very few cases (such as Hartland Moor, Dorset), the community occupies a buoyant vegetation raft. The peat is typically shallow (less than one metre), mostly monocot peat with *Sphagnum* where macro-remains are recognisable, but often humified and amorphous; it is sometimes mineral-enriched. Basal material ranges from sands and gravels to silts and clays.

The community is characteristic of locations irrigated by relatively base-rich water, but often as localised patches within more acidic conditions. The source of the localised base enrichment almost certainly reflects local hydrogeological variation. In the New Forest, some examples of M14 seem to be associated with a water supply that has in some way been associated with the Headon Beds (which are relatively base-rich), though in some cases the association may be quite remote. Thus at Holmsley Bog, a small, localised M14 soakway is fed (at least in part) by surface flow from a small side-valley which drains from Headon Beds near its head. At Cranesmoor, patterns of base enrichment from the mire appear to be associated with localised inflow of relatively base-rich water from the Headon Bed-capped ridge to the east of the mire (Newbould, 1960). Elsewhere the community appears to be fed by direct, but localised, groundwater outflow from (weakly) calcareous aquifers (such as Devonian Meadfoot and Ladock Beds in Cornwall; Upper Greensand and Budleigh Salterton Pebble Beds in Devon). In some locations (such as Purbeck), some valleyhead mires with M14 appear to be sourced from the same Poole Formation aquifer units as those with no evidence of M14. In these cases, the base enrichment associated with M14 may be a consequence of local lithochemical variation, and could relate as much to variation in the character of the associated clay aquitard units as to the character of the sandy aquifers *per se.*

16.1.6 Zonation and succession

Many examples of M14 typically occur as soakways and water tracks within valleyhead mires, and are most typically flanked by M21 vegetation. Such examples often occur as axial soakways along small valleys, and occasionally adjoin wetter and less base-rich M29 water tracks. In most cases the area of M14 is small relative to the area of flanking M21, but in the north-western arm of Hartland Moor M14 not only forms a large axial stand, but one that is proportionately large compared to the flanking M21. M14 soakways also occur on steeper gradients flowing down the valleyhead slopes. These examples are conceptually transitional to the examples of M14 that occupy sloping seepages or flushes. They may also be largely surrounded by more acidic mire vegetation (M21 or M25), but can also occur as isolated units embedded within heathland, wet grassland or, sometimes, dry grassland (such as Stoney Cross, New Forest).

Little information is available on successional trends in this community. Most examples are so small that they have not warranted consideration separate from their flanking mires, and the development of this community is probably inextricably bound with these (see 18.1.6). It is possible that many examples of M14 may be too wet for direct scrub encroachment, but their narrow width means that they could easily become overtopped by a canopy of woody plants growing on drier terrain alongside. Such overgrowth would probably result in loss of the M14, as most of its species are heliophiles.

M14 stands are not normally associated with topogenous terrestrialisation contexts, but an example in the north-western arm of Hartland Moor occupies a quaking surface over about 0.5 m depth of loose muds and water (possibly reflooded turbary). Here, there is evidence of small (possibly residual) pools (some with *Carex limosa*) and patches of *Sphagnum auriculatum* (M1). It is possible that the latter are progenitors of M21, and that a *Sphagnum*-dominated surface may spread over much of the present M14, restricting it to increasingly narrow soakways until a steady-state condition, maintained by water flow, is reached. At Great Candlestick Moss (Cumbria), a community which is probably best referred to M14 also occurs in an apparently flushed zone within a small basin.

16.2 Water supply mechanisms and conceptual model

M14 essentially occupies two situations in mires: soakways and soligenous slopes. The latter may be flushes or seepages, but appear always to be fed primarily by groundwater outflow. Many soakways are probably also primarily groundwater-sourced, including drainage from groundwater outflow on adjoining soligenous slopes, but in a few locations surface water may be significant. The proportionate contribution of groundwater and surface water to such locations is not known, but because of its dependence on relatively base-rich conditions, it is likely that base-rich water sources may sometimes have a hydrochemical importance disproportionate to their contribution to the water budget of the soakway.

M14 frequently occurs in (sometimes anomalous) locations where, as Rodwell (1991b) has pointed out, “flushing provides a local amelioration of prevailingly acidic soil conditions”. However, Rodwell (1991b) seems to consider that the base enrichment encountered within M14 is a function of a flow-induced increase in pH and calcium, but we are unable to support this proposition. Whilst higher rates of endotelmic water flow are usually associated with a slight elevation of pH relative to adjoining surfaces, and presumably with increased *loadings* of solutes, they do not necessarily lead to significantly increased *concentrations* of these. Moreover, in the New Forest mires, soakways with M14 appear always to be associated with base-enriched water sources. Lines of enhanced, but un-enriched, flow may be associated with trails of *Schoenus nigricans,* but not usually with the basiphilous bryophytes diagnostic of M14. For example, although *Schoenus* is widespread at Cranesmoor, where it invariably marks water flow lines through the mire, most of these appear to be *Schoenus*-rich versions of M21, with M14 being restricted to some particularly base-rich locations.

M14 is typically found in situations where there is a consistent throughflow of telluric water: 48 per cent of samples were identified as occurring within WETMEC 15 (Seepage Flow Tracks such as Fort Bog (New Forest), Roydon Common (Norfolk)), 24 per cent within WETMEC 10 (Permanent Seepage Slopes such as Stoney Cross (New Forest)) and 16 per cent with WETMEC 17 (Groundwater-Flushed Slopes such as Retire Common (Cornwall), Stoborough Heath (Dorset)). A few examples occurred within WETMECs 11, 13 and 19.

16.3 Regimes

16.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 16.2, together with mean recorded values for summer water table associated with stands of M14. Water conditions for M14 are difficult to specify quantitatively, partly due the lack of detailed time-series data, but more importantly because microtopography generates subtle but ecologically important differences in water regime within individual stands. Runnels and tussocks provide a complex of microhabitats that contributes greatly to the species diversity of high-grade stands. Consequently, **mean water table values have limited value, are potentially misleading and should be interpreted with caution**.

Table 16.2 Mean rainfall, potential evaporation and summer water table for M14

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	863	639	1,548
Potential evaporation (mm a^{-1})	597	534	620
Mean summer water table (cm agl or bgl)	1.4	–12	13.4

Specific time-series data for stands of M14 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Typically at or just above surface level in the runnels between tussocks, and generally found within a fairly narrow range.
- Water levels appear to be near the surface year round. Winter water levels are not well known. On soligenous slopes, they are probably little higher than summer levels. However, soakways can experience high winter water levels. In

some cases this may lead to inundation of the community, but in others this may be mitigated to some degree by the expansibility of the loose infill beneath the vegetation. [In a few cases (such as Hartland Moor, Dorset) the community occupies a buoyant surface]

- Requires continuous irrigation.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can therefore be speculated that this would lead to a loss of wetland species and increased representation by dryland species. Peat drying and degradation would lead to development of rank fen rapidly becoming wooded without management.

- Deep inundation associated with water stagnation, especially in the spring or summer months, is likely to be detrimental to this community.

16.3.2 Nutrients/hydrochemistry

This community is typically found in conditions of moderate base status but low fertility. Irrigating water can have a quite high pH (above seven) (Table 16.3) but fairly low concentrations of bicarbonate (FENBASE database) and is weakly buffered. Rodwell (1991b) quotes dissolved calcium concentrations of 5–35 mg l^{-1}. Shaw and Wheeler (1991) found a trend for an increase in species density and number of rare fen species with an *increase* in substratum fertility, but as the latter was also positively related to an increase in Ca concentration, the relationship with species density may have been mediated by an increase in base richness rather than an increase in levels of major nutrients. However, the community does occupy some substrata with elevated N concentrations, suggesting that availability of P may be the major limiting factor to plant growth.

The tussocky nature of *Schoenus* provides niches for different species, with calcifuges tending to occur in the more acidic conditions on the tussock tops (or on top of a mat of more basiphilous bryophytes), and the calcicolous element confined to areas of close contact with the base-rich irrigating waters.

Table 16.3 pH, conductivity and substratum fertility measured in stands of M14

Variable	Mean	SE	Min	Max
Water pH	5.5	0.04	4.6	6.5
Soil pH	5.6	0.01	4.4	6.8
Water conductivity (K_{corr} µS cm^{-1})	170	1.1	59	470
Substratum fertility[1] (mg phytometer)	4.8	0.08	4	7

16.3.3 Management

In most cases, management of examples of M14 is dependent on the management of the wider habitats within which the stands are embedded. Appears to require some grazing pressure to maintain species diversity: unmanaged stands tended to have lower species

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

densities and numbers of typical fen species than managed stands and heavily grazed stands had lower species numbers, and fewer rare species, than the more lightly grazed stands (Shaw and Wheeler, 1991). Nonetheless, some wet examples may be largely self-maintaining. Some stands are occasionally burnt.

Rodwell (1991b) speculates that succession in unmanaged situations may result in colonisation by *Salix cinerea, Betula pubescens* and perhaps *Alnus glutinosa* and the eventual development of some sort of wet woodland. However, seral processes may often be dominated by events on adjoining surfaces, and a woodland canopy may be able to extend across examples of M14 from shrubs growing near M14 more readily than scrub can directly colonise the community.

16.4 Implications for decision making

16.4.1 Vulnerability

M14 may be one of the most vulnerable of wetland communities, especially because of its association with relatively base-rich, but often weakly buffered, water supply.

The community is likely to be particularly vulnerable to a prolonged overall lowering of water tables, and some of the narrower examples could readily be completely destroyed by ditching. In addition, a reduction of base-rich water inflow is likely to be detrimental to the community, even in contexts where the overall water level within the vegetation remains appropriate. In some cases the occurrence of the community may hinge upon a single source of base-rich water, which may arise some considerable distance from the mire, making it potentially vulnerable to events that can affect both groundwater and surface water sources distant from the site.

The weakly buffered character of the community may mean that it is vulnerable to processes of acidification within the catchment, and its characteristics suggest that it may be amongst the most sensitive of all mire communities to acid deposition.

This low-fertility community is likely to be sensitive to eutrophication, and examples fed by surface water could be particularly vulnerable to this. It requires moderate grazing pressure to maintain species diversity.

Figure 16.2 outlines some of the possible floristic impacts of changes to the stand environment.

The possible effects of environmental change on stands of M14

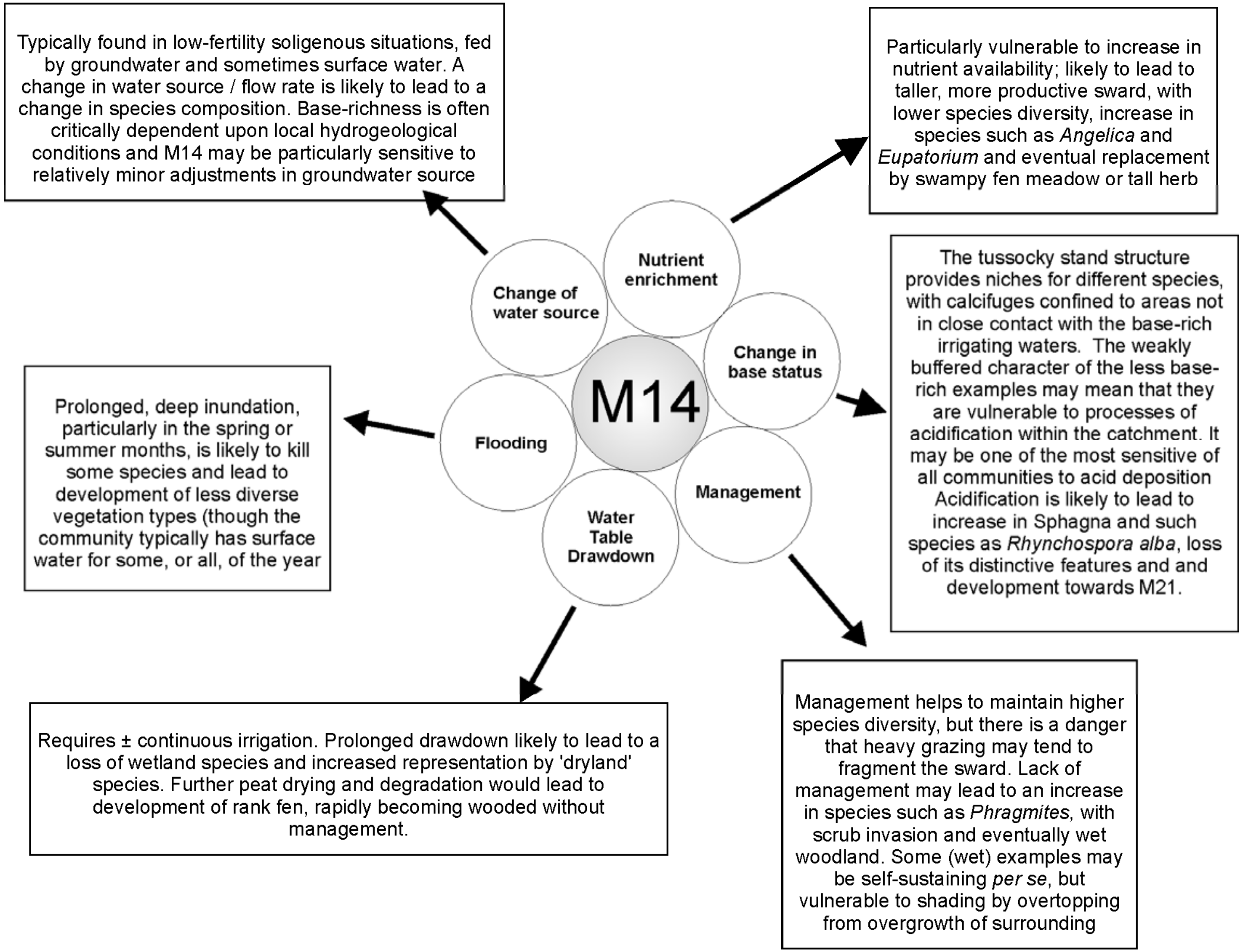


Figure 16.2 Possible effects of environmental change on stands of M14

16.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M14 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M14 in the short to medium term.
- Attempts to increase the wetness of M14 by blocking outflows could be detrimental to the vegetation if they result in the establishment of strongly stagnant and reducing conditions.
- The occurrence of one of the best and most extensive examples of M14 in a location which *may* be a former turbary (Hartland Moor), points to the possibility of (re)creating this community by turf removal in some dry valleyhead sites, providing the hydrogeological context is appropriate.

16.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- The information used is largely based on information held within the FenBASE database.
- The syntaxonomic status of M14 and its relationship to other community types (such as M9-1 (M9a), M15a) requires re-examination using data additional to those available to Rodwell (1991b).
- There are currently no data to better inform the temporal water table characteristics of M14 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M14 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- Data on the spatial extent of M14 are lacking.
- In some instances, sources of the base enrichment critical to the occurrence of M14 are not really known. A better understanding of this would help evaluate potential catchment threats, which could result in a reduction of bases, or increase in nutrients, entering examples of M14.
- The hydrochemistry of M14 has been little investigated. More information would be valuable, particularly with regard to critical loadings of acidic deposition.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

17 M18 (*Erica tetralix–Sphagnum papillosum*) raised and blanket mire

17.1 Context

Examples of the M18 community have been included in the “active raised bogs” SAC interest feature. [See Tables 3.1 and 3.3]

17.1.1 Concept and status

The conceptual basis for a syntaxon broadly with the compass of M18 was first established by Moore (1968) and then by Birse (1980). This concept was subsequently modified by Rodwell (1991b) to form the current M18 unit. In essence, it encompasses the *Sphagnum*-based communities of lowland raised bogs. Stands from other situations (such as gentle slopes in some valleyhead fens in higher rainfall regions) may also show strong affinities to M18, but these do not have *Andromeda* and are often better allocated to a related ombrogenous community such as M17. However, we do not have sufficient data for other ombrogenous communities to clarify their inter-relationships.

Stands of M2 (*Sphagnum cuspidatum/recurvum* bog pool community) often occur in pools embedded within M18 and thus have clear spatial relationships with this. Moreover, the ombrogenous surfaces of some wet basin mires of the West Midlands have affinities both with M2 and M18, and it is sometimes difficult to determine to which of these units they are best allocated (except in the trivial sense that the epithet ‘bog pool’, which Rodwell (1991b) attached to M2, is not appropriate for most of these surfaces). Rodwell considers that the *Sphagnum recurvum* surfaces of the West Midlands basin mires may be best allocated to M18a, but our data suggest that many of them are closer to M2 and would be better allocated there (even though they are not necessarily bog pools). In some cases, these extensive M2 surfaces occupy mires which formerly supported a more diverse range of *Sphagna* – including *S. papillosum* – and they may represent a degradation product of former M18 (Tallis, 1973). A DCA ordination of M18 and M2 (Figure 17.1) shows some intergradation between the two communities, with some stands allocated to M2 (by MATCH) occupying essentially the same ordination space as M18, but an interesting feature of this diagram is that, for the most part, the two syntaxa occupy surprisingly discrete sectors of the ordination.

Rodwell (1991b) suggests that M18a “can also come very close in its floristics to the *Narthecio-Sphagnetum* [M21], the typical Sphagnetalia mire of lowland valley bogs”. However, whilst there are clear affinities between the two communities, our own data indicate that M21 and M18a are discrete entities which do not overlap in ordination space (Figure 17.1). M21 does show considerable overlap with M2, that is, the wet ombrogenous surfaces of some of the West Midlands basin bogs.

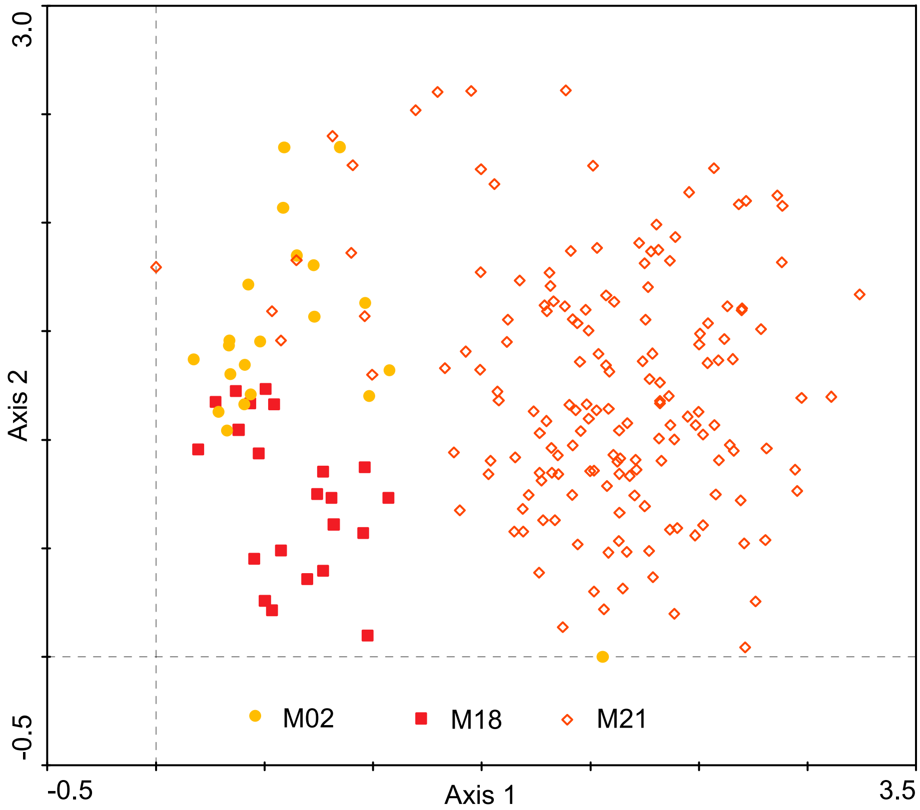


Figure 17.1 Plots of samples of *Sphagnum cuspidatum/recurvum* bog pool community (M2), *Erica tetralix–Sphagnum papillosum* raised and blanket mire (M18) and *Narthecium ossifragum–Sphagnum papillosum* valley mire (M21) on Axes 1~2 of a DCA ordination

17.1.2 Floristic composition

The wet, acidic conditions and limited nutrient availability mean that the environment of raised bogs is not well suited to the growth of many plant species, and M18 is typically rather species-poor: Rodwell (1991b) gives the mean number of species per sample as 17, but with a wide range of 8–30 spp. This corresponds quite well with the data from FENBASE (Table 17.1). The vegetation is generally dominated by Sphagna with a few ericaceous sub-shrubs (such as *Calluna vulgaris*), monocotyledons (such as *Eriophorum* spp) and herbs. However, it does support a few rare species (Table 17.1). Of these, *Andromeda polifolia* is particularly notable as it is especially characteristic of M18 (and raised bogs), though it is not present in all examples and, like all so-called 'bog species', occurs in weakly minerotrophic mires as well as truly ombrotrophic examples. The rare species *Drosera anglica* and *Dicranum undulatum* have also been reported from some examples of M18, but do not occur in any samples on FENBASE.

Rodwell (1991b) recognises two sub-communities of M18: *Sphagnum magellanicum–Andromeda polifolia* sub-community (M18a) and *Empetrum nigrum–Cladonia* sub-community (M18b). All of the stands sampled for the current project had highest MATCH coefficients with M18a or generically with M18 and no data are available for the drier stands referable to M18b.

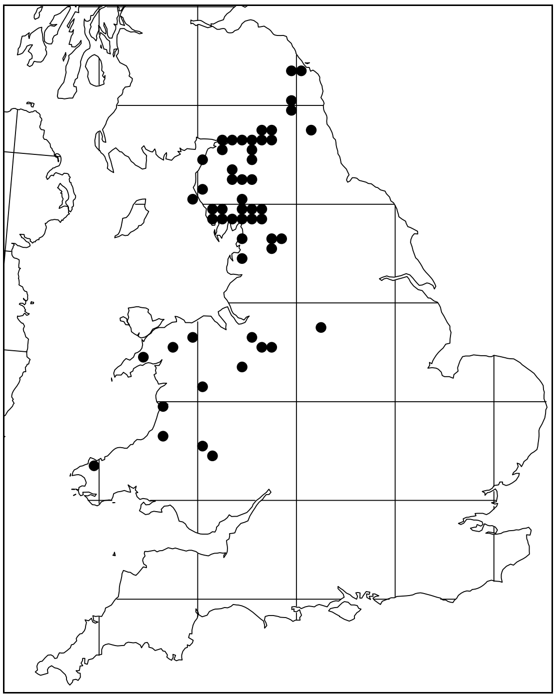
Table 17.1 Number of species in stands of M18a

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	111	19.3	0.14	10	30
Mire species (spp 4 m^{-2})	50	13.8	0.10	8	19
Rare mire species* (spp 4 m^{-2})	10	0.9	0.11	0	3

** These include: Andromeda polifolia, Carex limosa, Carex magellanica, Carex pauciflora, Cladopodiella fluitans, Dicranum undulatum, Drosera longifolia, Osmunda regalis, Sphagnum molle, Sphagnum pulchrum*

17.1.3 Distribution

This community is solely dependent on rainfall for water supply, and has a mainly western and northern distribution in Britain, being primarily found in North-West England, through the lowlands of Wales and in Scotland up to the Clyde–Moray line. The distribution of M18 in England and Wales (89 sites) is shown in Figure 17.2. Ombrotrophic bogs were also once widespread in Fenland and M18 almost certainly once occurred there and probably in other sites in Southern England (such as Somerset Levels, Amberley Wild Brooks (Sussex)) which once supported fairly wet raised bogs. Both sub-communities occur throughout the range.



(data from FenBASE database)

Figure 17.2 Distribution of M18a in England and Wales

17.1.4 Landscape situation and topography

M18 is considered to be the natural core community type of lowland raised bogs, where peat accumulation has raised the surface above the influence of minerotrophic water. Raised bogs are primarily (but not exclusively) lowland peatlands which, in Britain, mostly occupy the bottoms of broad, flat valleys, the heads of estuaries or shallow basins. M18 vegetation can also occur as a late-seral development in basin wetlands, where development of a floating raft (*schwingmoor*) prevents inundation of the surface by minerotrophic water.

The overall topography of little-damaged raised bogs varies considerably. Some (usually rather small) examples have a quite strongly domed appearance in which the profile of the bog peat deposit approximates to a half-ellipse. In others, the peat deposit is more like a plateau, dipping sharply around its margins, and with a surface profile that may reflect irregularities in the underlying mineral ground.

17.1.5 Substratum

The surface of a little-damaged raised bog is characterised by a spongy, actively growing layer (around 20–50 cm thick) of living plants (principally *Sphagnum* mosses), recently dead plant material and fresh peat, referred to as the acrotelm (Ingram and Bragg, 1984). The bulk of the peat beneath the acrotelm is the so-called 'inert layer'[1] (or *catotelm),* built up from former acrotelm peat which has become well consolidated and often strongly humified. The depth of peat in raised bogs is very variable and depends particularly upon the age of the deposit. Thicknesses of bog peat reported from Britain typically range between about one and five metres, although depths greater than 10 metres have been recorded.

In some basin mires, the quaking raft supporting M18 vegetation forms part of a classic *schwingmoor* with a considerable depth of open water beneath a spongy surface peat horizon (as at Wybunbury Moss, Cheshire). In others, the basin may be largely infilled with unconsolidated peats, and include water gaps within the profile.

17.1.6 Zonation and succession

The surface of a little-damaged raised bog often displays a distinctive microtopography: M18a vegetation (the *Sphagnum magellanicum–Andromeda polifolia* sub-community) generally occurs as wet *Sphagnum* lawns and as hummock–hollow complexes intermixed with pools typically occupied by bog pool vegetation such as *Sphagnum cuspidatum/recurvum* bog pool community (M2). The *Empetrum nigrum–Cladonia* sub-community (M18b) tends to occur in drier parts of the bog, and may be the only sub-community in some drier sites. In a wet bog, M18b may occur as taller hummocks in mosaic with M18a, or may form the main expression of M18 in a drier zone surrounding a more central M18a. In some sites, M18 communities stretch virtually to the peripheral minerotrophic lagg, where they may be juxtaposed with minerotrophic community types (such as M4, M5, M25, S27, W4). However, in the more strongly domed raised bogs, M18 is frequently separated from peripheral communities by a sloping rand which may be occupied by drier vegetation types on the better-drained ombrotrophic surface (such as M15, M17, M20). In many sites, disturbance has distorted any natural zonation that may once have occurred. Peripheral drainage and peat extraction have often removed the original lagg, and sometimes much of the rand, so that the remaining ombrotrophic surface is perched on a residual block of peat. This can produce various idiosyncratic, and usually unconformable, juxtapositions of plant communities. In some damaged sites, much of the surface has been affected by drainage, and in such cases examples of M18 may be confined to the wetter conditions of abandoned, recolonised peat pits.

Raised bogs, and the M18 communities they support, have developed both by terrestrialisation and paludification processes. M18 stands on undisturbed surfaces are

[1] The catotelm is not, strictly speaking, 'inert'.

sometimes the culmination of long-term seral processes that were initiated early in the post-glacial period (for example, Walker, 1970). Some sites show stratigraphical evidence of natural surface drying, in which M18a became replaced by M18b, or in which M18 became replaced by a different, drier vegetation dominated often by ericaceous plants. These phases, which may be a consequence of climatic change and, perhaps, the topographical development of the bog dome and adjoining parts of the complex (for example, see Casparie 1972), may be replaced once more by M18 if wetter conditions become re-established. Subject to these types of change, the surface of a raised bog is generally considered to represent a climax state and is, accordingly, self-maintaining. Little-disturbed raised bogs in Britain appear naturally to be treeless, except perhaps during drier developmental phases, though a few examples support patches of woodland for reasons that are not well understood. Partly drained bogs are often readily invaded by birch and pine.

In raised bogs developed by terrestrialisation, the ombrotrophic peat is frequently underlain by thick minerotrophic deposits, but is nonetheless often sufficiently deep for the surface to be elevated well above the influence of telluric water. This is also the case for some ombrotrophic surfaces in small basins, which can have a pronounced dome of fairly deep ombrogenous peat and appear to be indistinguishable hydrodynamically from the surfaces of sites more traditionally considered to be raised bogs. However, in some wet basin bogs the ombrotrophic surface (and hence the M18 communities) is often raised only slightly above the telluric water table, is often quaking or semi-floating, and in some instances may occupy elevated surfaces in mosaic with minerotrophic hollows and pools, supporting communities such as M1, M2, M3 or M4. In some instances, the M18 surface seems to have arisen within the last few hundred years by the terrestrialisation of wetter, perhaps weakly minerotrophic, precursor communities such as M2. However, in some of the Cheshire basin mires, Tallis (1973) has provided stratigraphic and hydrochemical evidence which suggest that former M18 surfaces may have lost many of their distinctive species and shown retrogressive succession towards communities such as M2. Although the resulting surfaces are certainly not bog pools, many examples are closer floristically to M2 than to M18. The cause of such change is not really known, but appears to be associated with a slight increase in the base and nutrient status of the basins, However, the cause of this is not clear: atmospheric deposition of solutes is one possibility; another is enrichment of the telluric water in the basins and/or an increase in the level of the telluric water table.

M18 surfaces in basin bogs are more prone to tree invasion than the surfaces of raised bogs. The reason for this is not known. Possibilities include a slightly more favourable hydrochemical environment for tree growth, created by solutes residual from a recent telluric condition, or that rafts colonised by trees have low hydraulic conductivity characteristics. When the raft is fairly thin and unstable, precocious establishment of trees can lead to a depression of the raft below the telluric water table, or even a localised breakdown of the integrity of the raft.

17.2 Water supply mechanisms and conceptual model

All M18 samples were found in ombrotrophic situations. Most (65 per cent) were in WETMEC 1 (Domed Ombrogenous Surfaces (‘raised bog’ *sensu stricto*) such as Wedholme Flow, Meathop Moss (Cumbria)), but 35 per cent occurred in WETMEC 2 (Buoyant Ombrogenous Surfaces (quag bog) such as Biglands Bog (Cumbria), Wybunbury Moss (Cheshire)).

M18 occurs on solid or semi-floating peat surfaces that are isolated from telluric water influences, and are (now) fed directly and exclusively by precipitation. Much of the surface of a little-damaged raised bog is very wet, even in summer, despite its elevation above the adjoining land; indeed, the highest, more central (least well-drained) parts of the bog are often the wettest and typically show the most pronounced development of surface patterning and pool systems, whereas the sloping margin (rand) is better drained.

In ombrotrophic peatlands hydrological processes, peat accumulation and vegetation are linked through a positive feed-back mechanism whereby plant growth and accumulation of dead plant remains as peat help to determine some of the hydrological processes. The acrotelm forms the main conduit of water discharge from the bog; water moves quite readily through the upper layers of the acrotelm, which contains and helps to regulate water-level fluctuations caused by variation in water inputs and outputs, thereby providing a degree of hydrological stability for the plants. The catotelm has a much lower permeability than the acrotelm and correspondingly slower rates of water movement within it.

17.3 Regimes

17.3.1 Water regime

In an ombrotrophic peatland, the only source of water to the surface is from precipitation (rainfall, snow, fog and so on). Some of this is returned to the atmosphere through potential evaporation, while the remainder gradually seeps laterally towards the edges of the bog, mainly through the surface layers (*acrotelm*) or vertically to become stored within the more highly decomposed peat of the lower layers (*catotelm*). Vertical loss of water downwards through the base of the bog *via* the catotelm is generally assumed to be negligible, although this may not always be the case. Although a raised bog develops because of an overall precipitation surplus, during some parts of the year, especially summer, evapotranspirative losses may temporarily exceed precipitation inputs. On such occasions, the perched water level will fall as water is removed from storage (the acrotelm forms an unsaturated layer). Subsequent precipitation replenishes the storage water, before seepage towards the margins is increased as the water table rises again.

With some exceptions, M18 vegetation is generally found in locations with an annual precipitation of between 800 and 1,200 mm, and 140–180 wet days annually (values from Rodwell, 1991b). Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 17.2, together with mean recorded values for summer water table associated with stands of M18.

Table 17.2 Mean rainfall, potential evaporation and summer water table for M18a

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	1,024	702	1,480
Potential evaporation (mm a^{-1})	533	462	614
Mean summer water table (cm agl or bgl)	–6.8	–22	3

Water levels have been monitored at different bog sites (such as Cors y Llyn: Gilman, 1998; Walton Moss: Labadz *et al.,* 2004; Wedholme Flow: Labadz *et al.*, 2002), although it is not always known to which plant community the records apply. The following general comments can be made:

Optimal water levels

- Typically just below surface level and generally found within a fairly narrow range between about –2 and –15 cm. However, the microtopographical variations in the surface of M18, which are to some extent associated with floristic differences, make it difficult to specify generic water tables for the community as a whole.
- Certain plant species, including Sphagna, often occupy distinct positions with respect to water level, either as part of the small-scale microtopographical

mosaic of a patterned bog surface (for example, Lindsay *et al.,* 1988), or as part of a wider change in water level from the wet centre to the drier margins of a bog.

- The *Empetrum nigrum–Cladonia* sub-community (M18b) is characteristic of drier peat, and may be favoured by minor surface or marginal drainage.
- The acrotelm can provide some vertical mobility of the bog surface, together with high rates of lateral seepage and some water storage capacity, thus helping to confer hydrological stability and maintain wet conditions for most of the year.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community.
- Partial drainage which results in seasonal, rather than permanent, waterlogging is likely to lead to a change in the composition of the *Sphagnum* carpet towards species more tolerant of drier conditions, and development of a wet heath community.
- Drying out of a bog remnant, cuttings or baulks typically results in an invasion of woody species, most commonly birch, but also species such as pine and *Rhododendron.* This is generally thought to be detrimental to the bog vegetation due to: shading (both from living leaves and smothering by litter); increasing water loss through potential evaporation; reduction of water input through interception of rainfall; nutrient enrichment through leaf fall; provision of roosting posts for birds and a positive feedback through the production of seeds. Even with adequate control of water levels on a site, the control of scrub is likely to remain a major management issue until the bog can be returned to a self-sustaining system in which birch colonisation is naturally kept in check.
- As well as directly increasing rates of water removal, drainage can damage the hydroregulatory functions of the acrotelm. Peat extraction removes the natural acrotelm so that former catotelm peat becomes exposed at the surface. This has a comparatively high bulk density and low water storage capacity and apparently lacks the water regulating properties of the acrotelm (see discussion in Money *et al.,* in press). Water table instability is thus a feature of many damaged bogs, and a drop in water table to 50–100 cm bgl is not uncommon during summer months, even in some sites where ditch blocking has taken place. This often generates adversely dry conditions for *Sphagnum* establishment (Wheeler, Money and Shaw, 2003).
- Drying makes the stands more prone to damage by burning, as well as permitting greater access to (and possible damage by) grazing animals.
- Prolonged, deep inundation, particularly in the spring or summer months, is likely to kill some species and lead to development of bog-pool vegetation.

17.3.2 Nutrients/hydrochemistry

The ombrotrophic waters of raised bogs are typically base-poor (pH values are often below four) and of low fertility (Table 17.3). The low pH is partly a product of acidification induced by the growth of species of *Sphagnum* (Clymo, 1963; Clymo and Hayward, 1982; Andrus, 1986), whilst the small concentrations of other solutes reflect the primarily rainfall water source.

Raised bogs are generally regarded as unproductive and infertile ecosystems, and low availability of nitrogen or phosphorus is likely to be a major constraint upon primary production. Estimates of above-ground net production of ombrotrophic vegetation are typically in the range of 300–700 g m^{-2} (Doyle, 1973, Clymo and Reddaway, 1974; Forrest and Smith, 1975). It is notable that, whilst quite small, such rates are comparable with or even greater than those reported from various types of fen (Wheeler and Shaw, 1991).

The ionic composition of bog water shows quite strong geographical variation, reflecting variation in solute concentrations in rainfall. There is a gradient of chemical conditions in bogs across Britain and the European mainland (Bellamy, 1967; Proctor, 1992). In British bogs, concentrations of several ions, especially sodium, are greater than in more continental examples, reflecting maritime influences. M18 sites with highest water conductivities were all from oceanic, near-coastal locations (Bowness Common, Hollas Moss, Wedholme Flow (Cumbria)). In addition, regional variation in the chemical composition of precipitation, reflecting solutes and solids from agricultural and industrial sources, can be reflected in the composition of ombrotrophic mire waters (Proctor, 1992). In combination, this can make it difficult to specify a clear hydrochemical signature for ombrotrophy, and consequently to demonstrate this state. For example, the M18 site with the highest water EC values (Hollas Moss: K_{corr} = 129 µS cm^{-1}) is not only near the coast in a high rainfall area, but also occupies a tiny basin surrounded by agricultural land. In this context, it is not possible to be certain with available vegetation and hydrochemical data whether the M18 stand is truly ombrotrophic.

Mild enrichment of M18 may be responsible for the occurrence of extensive M2 surfaces in some West Midlands basins, which in some cases seem formerly to have supported M18. Details of the M2 community are not included in this report, but available data suggest that samples of M2 (which relate mainly to the M2 surfaces of the West Midlands basins) have a slightly higher mean water pH than M18 (3.9 *versus* 3.8) and a higher mean soil fertility (5.7 mg *versus* 4.1 mg). Although these differences are not great, they are compatible with the suggestion that the M2 surfaces represent slightly enriched examples of former M18.

Table 17.3 pH, conductivity and substratum fertility measured in stands of M18a

Parameter	Mean	SE	Minimum	Maximum
Water pH	3.6	0.02	3.5	3.9
Soil pH	3.6	0.02	3.2	4.0
Water conductivity (K_{corr} µS cm^{-1})	19	0.9	0	129
Substratum fertility[1] (mg phytometer)	4.1	0.21	2	8

17.3.3 Management

As a self-sustaining system, in an undamaged state a raised bog should require only minimal management. However, as all of the bogs in England and Wales have been damaged to some degree, management and restoration of raised bogs can be a key issue for conservationists. One of the main objectives is usually to maintain or restore a sufficient area of actively growing raised bog (M18-vegetation) to enable the site to return to a self-sustaining system. However, some form of ongoing, and usually long-term, management is often necessary to achieve this, in order to maintain or enhance the species composition and to reverse the adverse effects of damage.

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

The most common operations are scrub control and ditch blocking; bog vegetation is sometimes mown to control growth of *Calluna* and birch. Only a few raised bogs (such as Walton Moss, Cumbria) are grazed agriculturally, other than on the claimed bog margins or cut-over areas, although it is not clear to what extent this occurred in the past. Of course, many sites may be grazed to some degree by wild animals.

17.4 Implications for decision making

17.4.1 Vulnerability

Conservation management involves ensuring waterlogged, low fertility and base-poor conditions. As M18 vegetation is irrigated directly and more or less exclusively by precipitation, the community is particularly susceptible to drainage (either direct or indirect)[1] and to base and nutrient enrichment, and is likely to be slow to recover from damage. The component plant species may be well adapted to scavenge solutes from dilute solutions, and may also be particularly susceptible to atmospheric pollutants[2]. The elevation of the dome of many raised bogs means that they may be little affected by enrichment of proximate telluric water sources – enriched ditches sometimes flow through bog sites with little impact upon the adjoining peat surfaces – though these may seriously constrain some re-wetting options. However, where the peat surface has been lowered, or telluric water inflows are directed onto the peat surface, this may be much more vulnerable to chemical enrichment. In some cases, nutrients and bases have deliberately been introduced into the interior of bog sites such as Thorne Moors (Smart, Wheeler and Willis, 1986) though, interestingly, they are not necessarily prejudicial to development of M18-like vegetation in nearby peat workings. Indeed, mild base enrichment may facilitate *Sphagnum* recolonisation of peat workings in certain circumstances (Money and Wheeler, 1999).

Figure 17.3 outlines some of the possible floristic impacts of changes to the stand environment.

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[1] Indirect pressures from drainage around the bog margins and water abstraction from underlying aquifers may also cause damage in some circumstances, and may need to be addressed in restoration programmes in addition to direct drainage.

[2] Those most likely to affect plants growing on raised bogs are the main constituents of 'acid rain' [*i*sulphur dioxide and derivatives, especially bisulphite; nitrogen oxides (NO_x) and derivatives, especially nitrate; and ammonia].

The possible effects of environmental change on stands of M18

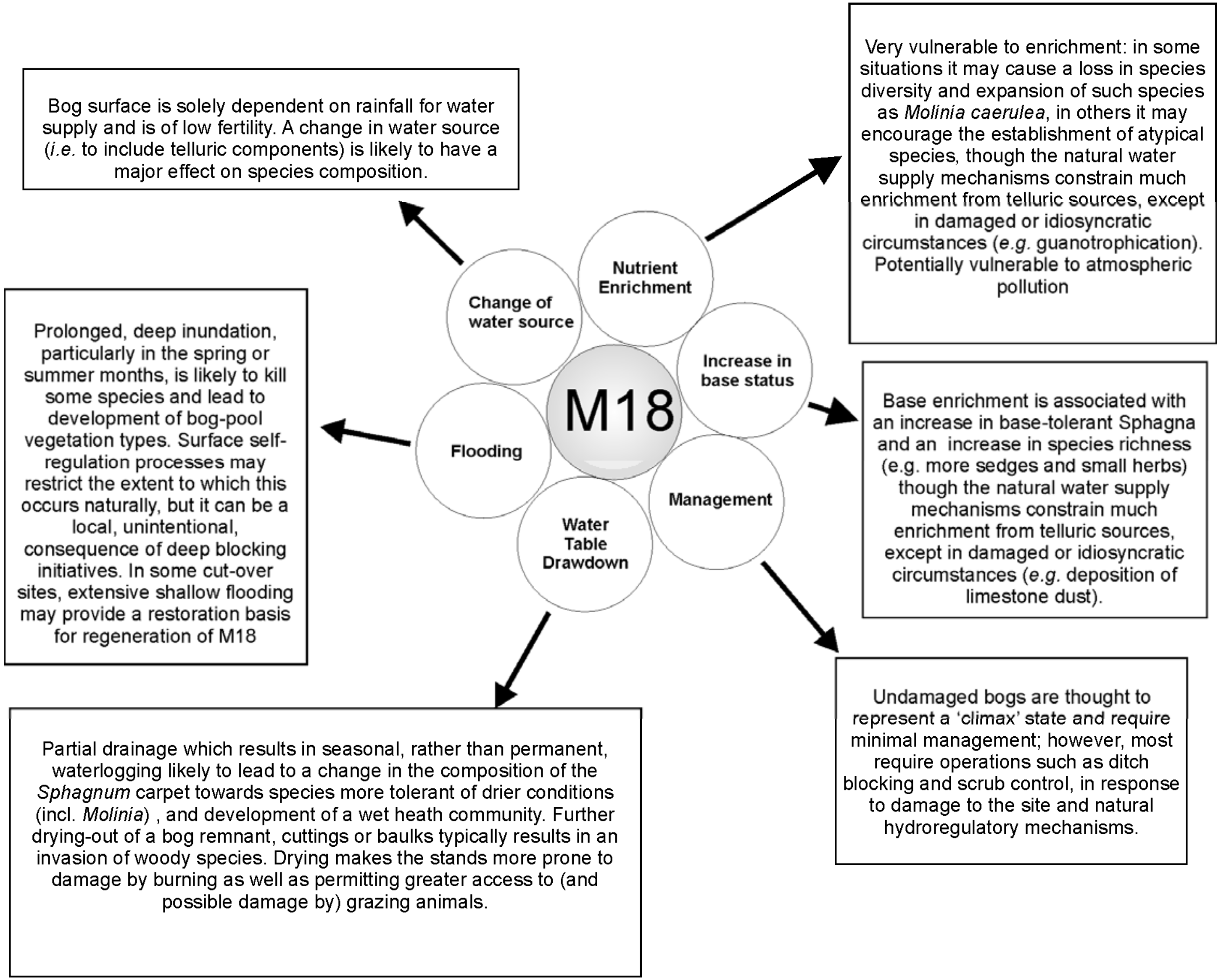


Figure 17.3 Possible effects of environmental change on stands of M18a

17.4.2 Restorability

Considered to be the natural core community type of many lowland raised bogs, the recreation of M18 vegetation usually forms the focus for the restoration of damaged raised bogs, and has received considerable attention (for example, Wheeler and Shaw, 1995d; Stoneman and Brooks, 1997; English Nature, 2003; Blankenburg and Tonnis, 2004). Restoration is being undertaken at many raised bog sites in the UK, involving key operations such as ditch blocking and scrub clearance. At the most extensively damaged sites more elaborate restoration initiatives may be required, such as reprofiling of the surface, bunding and creation of lagoons to help retain water.

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions deviate from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Starting conditions may vary in terms of the climatic, hydrochemical and hydrological features of the damaged sites. The ombrotrophic character of the surface means that variation in climate can have a large impact on the nature and feasibility of restoration options. For example, restoration initiatives in low rainfall regions may require the provision of acrotelm-surrogate structures, such as shallow lagoons to store winter rainfall excess, until an acrotelm layer with some hydroregulatory capacity can develop, whereas such engineering solutions may be needed less in cooler and wetter climates. BRIDGE (Blankenburg and Tonnis, 2004) has provided a review of starting conditions in cut-over mires and the restoration options they engender. Some generic summary points can be made:

- The primary objective of restoration of damaged bog surfaces must be to recreate an acrotelm with properties similar to those of the original. The primary problem of such initiatives is that some of the properties provided by the original bog acrotelm (most notably its capacity for hydrological self-regulation) are themselves required to regenerate a new surface with a comparable functional role. The trick of much bog restoration is therefore to mimic on the exposed peat surface some of the functional properties of the original acrotelm until a new acrotelm has developed.

- In addition to the lack of a functioning acrotelm, there may be other features in cut-over bogs inconducive to the maintenance of a high water table (such as active drains, sloping surfaces, marginal water drawdown, regional drainage), which need to be addressed.

- As raised bogs are essentially ombrogenous systems, there is an understandable view that their restoration requires the re-establishment of an ombrotrophic chemical environment, and this can dictate conservation and restoration policies (such as a requirement for the retention of a minimum thickness of ombrogenous peat, separating the restoration surface from any underlying telluric influences). However, it is far from certain that ombrotrophic conditions are essential or even optimal for the development of M18 vegetation, nor that they necessarily provide the best starting conditions for raised bog regeneration. Unfortunately, the exact nature of the relationship between M18 surfaces and hydrochemical conditions is neither clear nor consistent, but it has been suggested that in some circumstances, weakly minerotrophic conditions may promote bog regeneration. (Wheeler, Money, and Shaw, 2003). It is important to appreciate that no M18 species are confined to the ombrotrophic environment and that, for many of them, growth may be enhanced in weakly minerotrophic conditions. From this perspective, the species that occupy an ombrotrophic bog surface grow there because they are able to tolerate the difficult environmental conditions that prevail, not because such conditions are necessarily optimal for them.

- It is possible that in some regions atmospheric pollution may constrain bog restoration, and perhaps even threaten intact bogs (Wheeler and Shaw, 1995d; Wheeler, Money and Shaw, 2003).

- The BRIDGE study (Blankenburg and Tonnis, 2004) indicated that, in the North-West European lowlands, the key to successful establishment of a *Sphagnum* cover on cut-over surfaces is correct ground preparation (by creation of shallow lagoons, preferably with the ability to manipulate water levels), perhaps with inoculation by a macerate of *Sphagnum* material, coupled with encouragement of an open cover of emergent companion plants (particularly cotton-grasses). Lagoons can help to substitute for the water storage function of the acrotelm and also, if sufficiently wet, can provide an appropriate environment for terrestrialisation-based recolonisation, even in mires that were originally predominantly paludification systems. In other climatic regions, particularly those that are consistently cool and wet, or where much precipitation occurs in the growing season, it is possible – and in sufficiently wet contexts, even likely – that storage of winter water excess is not such a necessary requirement and that, given time, cut-over surfaces can recolonise without recourse to the construction of lagoons or other water storage structures (see Grosvernier *et al.,* 1995). However, the potential of this approach and, particularly, the climatic thresholds involved, remains uncertain (Wheeler, Money and Shaw, 2003).

- Even where appropriate hydrological conditions can be re-established, there remains some uncertainty over the subsequent development of M18 surfaces, perhaps because of constraining factors external to the peat deposit, including past and present atmospheric deposition and lack of propagules, but also because in some cases the cut-over surface conditions may be too base-impoverished for successful recolonisation by such species as *Sphagnum magellanicum* and *S. papillosum* (Wheeler, Money and Shaw, 2003).

- Good results can often be achieved with simple ditch blocking and scrub clearance initiatives on surfaces that are only partially damaged. There have also been encouraging responses to major management works on some highly damaged sites (for example, Fenns and Whixall Mosses (Shropshire/Clwyd), Wedholme Flow (Cumbria)). However, it is premature to comment on the long-term revegetation success of recent restoration initiatives, particularly those that have involved creation of lagoons.

- As ombrogenous surfaces, and M18-type communities, have developed spontaneously over large parts of Northern Europe, and appear to represent a climax state, attempts to restore ombrogenous surfaces are consistent with natural successional processes. It is thus likely that ombrotrophic surfaces can eventually be restored from a wide range of starting conditions, and the role of many restoration initiatives may be mainly to stimulate and accelerate the initial phase of this process.

17.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following.

- The information used is largely based on the *Sphagnum magellanicum–Andromeda polifolia* sub-community (M18a) community only.

- The long-term revegetation success of recent major restoration initiatives is unknown.

18 M21 (*Narthecium ossifragum–Sphagnum papillosum*) mire

18.1 Context

Some examples are included in the “depressions on peat substrates (*Rhynchosporion*)” SAC feature, though this community rarely occurs in such situations, nor is it referable to the *Rhynchosporion*. [See Tables 3.1 and 3.3]

18.1.1 Concept and status

The M21 syntaxon was introduced by Rodwell (1991b) who, following Ivimey-Cook, Proctor and Rowland (1975), recognised its affinities to the *Narthecio-Sphagnetum acutifolii euatlanticum* that had previously been described from Brittany. Rodwell points out that in his conspectus of bog and heath vegetation in Northern Europe, Moore (1968) had allocated this vegetation to a category of wet heath (Ericion tetralicis) but Rodwell (1991b) considered, correctly in our view, that the community was more appropriately referred to the acidic mires of the Erico-Sphagnion alliance.

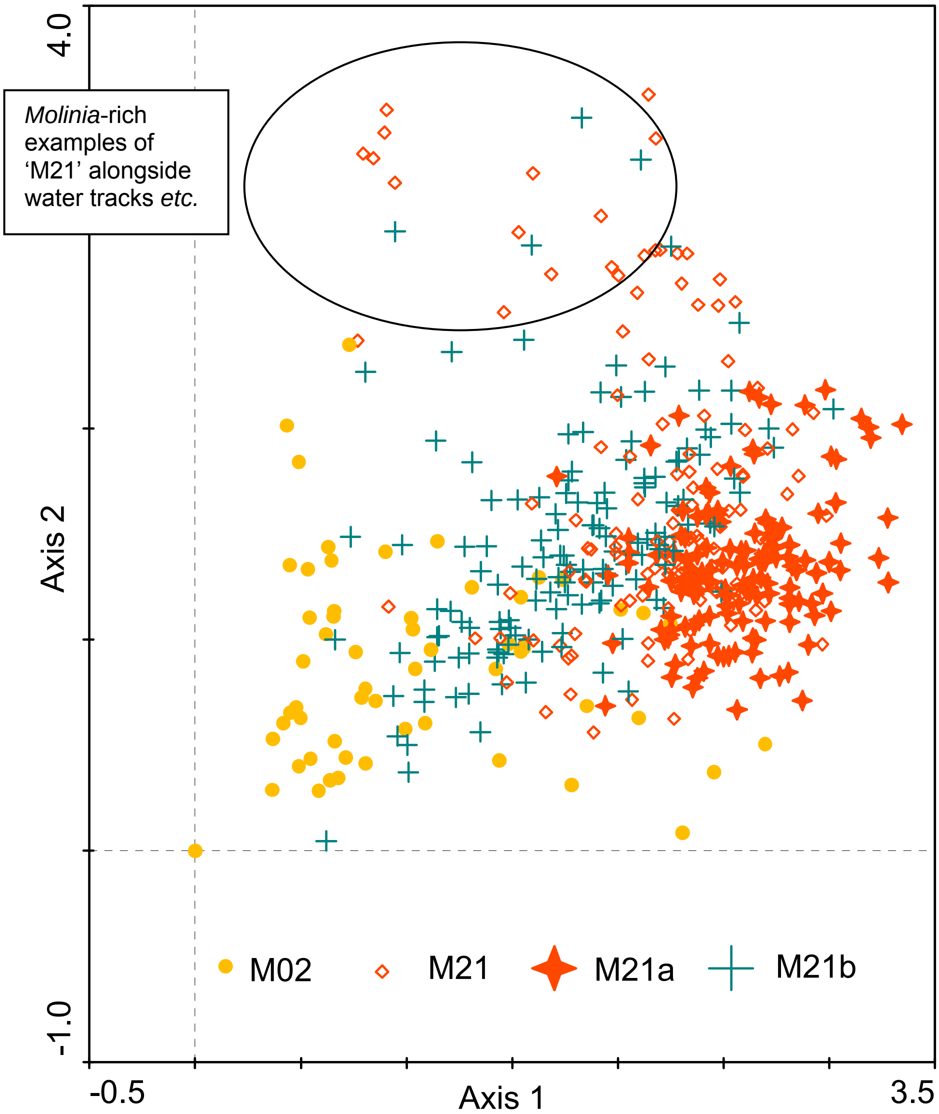
M21 is undoubtedly a useful floristic unit, but it does present some definitional difficulties. In particular, it shares some floristic similarities with certain types of ombrogenous mire – perhaps not surprisingly, in view of the difficulty Proctor (1992) found in identifying consistent hydrochemical differences between examples of weakly minerotrophic and ombrotrophic mires.

DCA ordinations suggest that whereas M21 samples form a unit that is discrete and separate from samples of M18, they show much overlap with M2 (Figure 18.1). A more detailed examination indicates that the overlap with M2 is largely found with samples of the *Vaccinium oxycoccos–Sphagnum recurvum* sub-community (M21b) and with samples that have highest MATCH coefficients with M21 generically (rather than with either sub-community). The *Rhynchospora alba–Sphagnum auriculatum* sub-community (M21a) shows little overlap with M2. It also forms a rather tight, coherent cluster, whereas samples of M21b and generic M21 form a rather nebulous cloud of points. Interestingly, M21b shows *less* overlap in the ordination with M21a than it does with M2. This suggests that M21a is a good floristic unit, but that the status of M21b and M2 may be more questionable. Although Rodwell (1991b) describes the two units M21a and M21b, he provides no indication of any different habitat or topographic preferences associated with them.

There is also some floristic variation within M21 which is not accommodated well within the two recognised sub-units. One of these is the occurrence, often in water flow-path trails within M21, of species that often occur in more base-rich conditions, such as *Anagallis tenella, Cirsium dissectum* and *Schoenus nigricans.* These species provide such stands with affinities to M14, and some surveyors have allocated them to this unit, but in our view they are better considered as versions of M21 (see account of M14). Nonetheless, there is no subdivision within M21 within which this distinctive version of the vegetation can be accommodated.

Another difficulty sometimes encountered with M21 is the occurrence of stands rich in *Molinia caerulea* and with a rather limited development of *Sphagnum.* These can occur in various contexts, but are particularly characteristic of some valley bottoms, distant from marginal groundwater outflows, or forming a distinct transitional zone separating more

Sphagnum-rich M21 from water tracks or watercourses. Such stands are often clearly distinct from more typical M21, both physiognomically and in terms of the habitat they occupy. As they are often easily mapped, some surveyors regard them as a separate mapping unit, but MATCH analyses of the present dataset show consistently that such stands have highest coefficients with M21 (generic) or M21b rather than with a community such as M25 (though sometimes the coefficients are low for all communities). Nonetheless, such stands mostly occupy peripheral locations on the DCA ordinations and a case could be made for their segregation into a separate unit, possibly into a third sub-community of M21. The alternative is just to consider M21 (generic) and M21b as a variable ‘dustbin group’ which contains a range of stands from acidic mires, varying in their species composition and habitat affinities, but characteristically species-poor. Such a unit is likely to be very difficult to characterise environmentally.



Samples have been segregated into those with highest coefficients of MATCH generically with M21 and to the *Rhynchospora alba–Sphagnum auriculatum* (M21a) and *Vaccinium oxycoccos–Sphagnum recurvum* sub-communities (M21b).

Figure 18.1 Plots of samples of *Sphagnum cuspidatum/recurvum* bog pool community (M2) and of *Narthecium ossifragum–Sphagnum papillosum* valley mire (M21) on Axes 1~2 of a DCA ordination

18.1.2 Floristic composition

A poor-fen community, typically dominated by carpets of Sphagna (especially *Sphagnum papillosum*), with a variety of leafy liverworts and scattered herbs and sub-shrubs (such as *Calluna vulgaris, Erica tetralix*), but infrequent small sedges and rushes. *Narthecium ossifragum* is constant and often abundant. *Molinia caerulea* is of high frequency throughout, but of variable abundance (probably often restricted by the poor aeration and nutrient-poverty of the substratum), and often not forming robust tussocks. In some sites, *Myrica gale* provides a (mostly fairly open) small shrub layer. The community mostly lacks calcicolous species, but some stands support species like *Anagallis tenella, Cirsium dissectum* and *Schoenus nigricans.* The community can form extensive lawns, or occupy drier areas within low-amplitude hummock–hollow systems or, where *Molinia* is prominent, form a tussock–hollow mosaic. The community is fairly species-poor (mean of 17, range of 5–39 spp per sample), although overall it supports over 20 rare mire species (Table 18.1).

Rodwell (1991b) recognises two sub-communities of M21: *Rhynchospora alba–Sphagnum auriculatum sub-community* (M21a) and *Vaccinium oxycoccos–Sphagnum recurvum* sub-community (M21b).

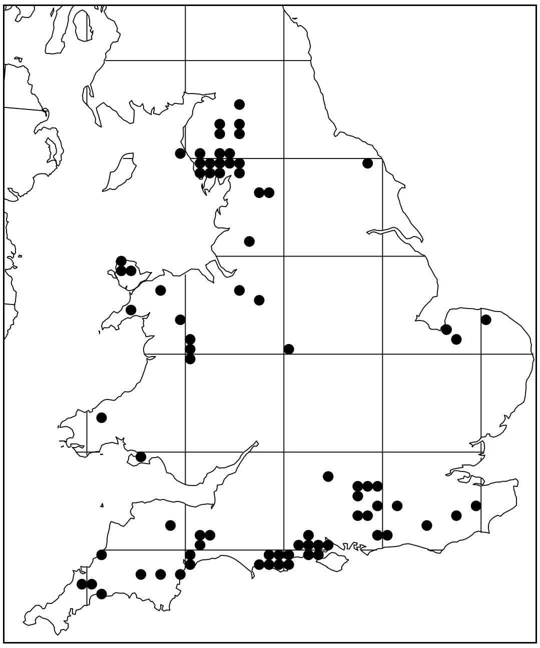
Table 18.1 Number of species recorded in stands of M21

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	244	16.9	0.08	5	39
Mire species (spp 4 m^{-2})	125	13.7	0.07	5	29
Rare mire species (spp 4 m^{-2})	24	1.2	0.06	0	6

* These include: *Andromeda polifolia, Carex lasiocarpa, C. limosa, C. magellanica, C. pauciflora, Cephalozia loitlesbergeri, C. macrostachya, Cladium mariscus, Cladopodiella fluitans, Dactylorhiza praetermissa, Drosera intermedia, Drosera longifolia, Erica ciliaris, Eriophorum gracile, Hammarbya paludosa, Osmunda regalis, Pinguicula lusitanica, Sphagnum contortum, Sphagnum molle, Sphagnum pulchrum, Sphagnum subsecundum, Sphagnum teres, Sphagnum warnstorfii, Utricularia intermedia, Utricularia minor.*

18.1.3 Distribution

A local community, particularly characteristic of the acidic valley mire of Southern and South-Western England, but also widespread in Cumbria and scattered in Wales (recorded from 189 sites:Figure 18.2). Largely restricted to the southern lowlands of Britain, but extending as far north as Cumbria and North Yorkshire. Particularly characteristic of mires in the New Forest (Hampshire) and Dorset; towards the north and west, stands tend to be less well characterised floristically. Rodwell (1991b) maps no records for Scotland, but FENBASE shows stands in some Scottish mires as this community (mainly in the Borders and the Hebrides).



(data from FenBASE database)

Figure 18.2 Distribution of M21 in England and Wales

18.1.4 Landscape situation and topography

Characteristic of permanently waterlogged, soligenous situations, especially in valleyheads and troughs. Often on quite strongly sloping ground, but large examples also occur in the rheo-topogenous context of gently sloping bottoms.

18.1.5 Substratum

Occurs on acid and oligotrophic peats, which may be quite shallow (20–150 cm). Predominantly found in catchments of prevailingly acidic substrata. In Southern England it is particularly associated with Eocene clays, sands and gravels and Lower Greensand deposits where, over sometimes gently undulating topography, base-poor groundwaters emerge. Examples in Cumbria and Wales are associated with a variety of bedrocks, but a number are associated with Silurian deposits (such as Penstrowed Grits Formation, Yewbank Formation). These deposits may have little primary porosity, but may support local minor aquifers, with fracture flow within superficial fracturing. However, little is known about groundwater sources for most of these sites.

18.1.6 Zonation and succession

Examples of M21 in the valleyhead mires of Southern England often form part of a distinctive zonation of communities, forming an intermediate zone between the wet central axis of the mire (which may support woodland or a water track, often M29 but sometimes M14), and wet heath (such as M16, M25) on the margins. This is seen, for example, in the New Forest mires (see Rose, 1953; Newbould, 1960). Broadly similar zonations occur quite widely elsewhere, as in the Subberthwaite Common area of Cumbria (here with M9a in the water tracks). In other cases, the community occupies the wet edge of mire systems, grading into types of topogenous mire in the valley bottom or basin, or sometimes into drier mire with increasing distance from the groundwater outflow. Elsewhere M21 can occur in a variety of situations, embedded within other habitats or other types of mire, depending on the vagaries of topography and hydrology. Rodwell (1991b) suggests that towards the north and west there is a tendency for "stands to survive in fragmentary form within much-altered landscape". Whilst this is doubtless correct for some locations, some examples of M21 in the north and west are far from fragmentary, and in some cases existing fragments may represent the natural extent of hydrotopographical conditions appropriate for this vegetation.

Little is known about the successional relationships of this community, possibly partly because in many sites it occurs over very thin accumulations of peat. The view has been expressed (see Rose, 1953; Newbould, 1960) that some of the mires that support M21 could be relatively recent in origin, a product of increased groundwater levels, possibly associated with forest clearance. An alternative explanation is that in some sites (such as Thursley Common, Surrey) peat excavation has stripped most of the peat over large areas, and the surfaces now occupied by M21 are the result of relatively recent recolonisation of turbaries (Rose, 1953).

Some examples of M21 occur on deep peat, though in some instances (such as Cranes Moor, New Forest) these may also have cut-over, at least in part (Barber and Clarke, 1987). In some instances, *Sphagnum* peat has replaced former woodland (such as Holmsley Bog, Wilverley Bog (New Forest)) (Rose, 1953; Clarke, 1988). However, in some of the New Forest mires palaeoecological investigations point to the long-term stability of the *Sphagnum* (mostly M21) surfaces. At Church Moor, where a *Sphagnum* surface flanks a soakway dominated by alder carr, Clarke and Barber (1987) suggest that the present vegetation pattern may have been in existence for some 5,000 years. At Stephill Bottom, Clarke (1988) considered that the hydrological environment and vegetation character has shown "very little change over the last 3,000 years", and he considered the loose upper layer of peat present to be a persistent natural feature of the location (rather than a consequence of former turbary).

It has sometimes been suggested that small raised bogs once occurred in some of the larger, flatter, cut-over sites of the New Forest, in locations now largely occupied by M21. At Cranes Moor, where peat digging appears to have truncated the original profile at about 4000 BP (Barber and Clarke, 1987), Clarke (1988) has speculated that about 2.8 m of peat may have been removed and that ombrogenous peat may once have occurred, a possibility previously raised by Newbould (1960). Rose (1953) has pointed to the ombrogenous affinities of the current (M21) vegetation of Ockley Bog, and although in neither of these cases is there any direct evidence for former raised bogs, this possibility cannot be dismissed.

Very few detailed stratigraphical data exist for examples of M21 in the valleyhead troughs of Southern Cumbria, but in some cases the occurrence of lake muds at depth suggests that the present surface is a product of long-term terrestrialisation. At Stable Harvey Moss (Cumbria) some M21 surfaces occur over a former lake basin: Hodgkinson *et al.* (2000) describe a stratigraphical sequence over late-Devensian clays (surface at 4.7 m depth bgl). This appears to have gone through a fairly classic post-glacial hydroseral sequence of lake muds (gyttja), *Phragmites* swamp, monocot and sedge fen and alder woodland, all of which is overlain by about one metre of *Sphagnum* peat. In some lowland contexts, this sequence is not dissimilar to that which could lead to the formation of a raised bog over a former lake, but Stable Harvey, although rich in *Sphagnum*, is not a raised bog but rather an irregular, gently sloping mire trough, in which gentle M21-supporting slopes trailing down from the adjoining hills have developed over, and largely obliterated surface evidence for, a former lake basin.

18.2 Water supply mechanisms and conceptual model

In the lowlands of Britain, *Sphagnum*-rich vegetation is only found in areas where there is a consistent water supply or where topography maintains a locally high water table, as precipitation falls below the 1,200 mm a^{-1} or 160 wet days a^{-1} threshold needed to maintain blanket-bog vegetation (Rodwell, 1991b). In the valleyhead mires of Southern England, M21 appears to be largely associated with groundwater-fed areas, though it may also occur in an intermediate zone on shallow marginal peats which are kept consistently wet, but where throughput is not so strong. In the wetter regions of Cumbria and Wales, groundwater outflow may be less important to the maintenance of this vegetation, and a proportionately greater contribution from rainfall and surface run-off seems likely. Nonetheless, in many of the sites examined some groundwater contribution, if only from minor fractured aquifers, appears likely, though available information about this is sparse.

Twenty-four per cent of M21 samples were identified as occurring within WETMEC 10 (Permanent Seepage Slopes, such as Holmhill Bog (New Forest), Roydon Common (Norfolk)), 22 per cent in WETMEC 14 (Seepage Percolation Troughs, such as Cranes Moor (New Forest), Dersingham Bog (Norfolk)), 19 per cent in WETMEC 15 (Seepage Flow Tracks, such as Thursley Common (Surrey), Wilverley Bog (New Forest)), 13 per cent in WETMEC 16 (Groundwater-Flushed Bottoms, such as Thursley Common, Dersingham Bog), and 11 per cent in WETMEC 17 (Groundwater-Flushed Slopes, such as Landford Bog (Wiltshire), Cors Llyn Coethlyn (Montgomery)). A few examples occurred within WETMECs 2, 11, 13 and 19. The examples from WETMECs 2 and 13 are all rheo-topogenous, representing basins supplied with a throughflow of weakly minerotrophic water (WETMEC 2c) or small, wet sumps embedded within examples of WETMECs 14 or 16.

18.3 Regimes

18.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 18.2 together with mean recorded values for summer water table associated with stands of M21.

Table 18.2 Mean rainfall, potential evaporation and summer water table for M21

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	883	627	2,101
Potential evaporation (mm a^{-1})	593	474	620
Mean summer water table (cm agl or bgl)	–0.6	–23	15

Specific time-series data for stands of M21 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Summer water level typically at or just below surface level.
- The water table is maintained at or very close to the ground surface throughout the year, favouring the growth of peat-building Sphagna (Rodwell, 1991b) such as *Sphagnum papillosum*.

- In some (mostly larger) valleyhead sites M21 vegetation at the upland margin, at the point of much groundwater discharge, is particularly rich in *Sphagnum* whereas examples further from the margin, or where seepages are weaker, may have much more *Molinia*, often in a more strongly tussocked form. This may be a consequence of lower, or more strongly fluctuating, water tables associated with a less consistent supply of groundwater. However, existing data are sparse and this possibility cannot readily be disentangled from other potential influences, such as slightly increased nutrient availability in some valley-bottom locations.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside the normal range of this community. It can therefore be speculated that these would lead to a loss of wetland species and increased representation by dryland species. Prolonged peat drying and degradation would lead to development of rank fen or wet then dry heath, becoming wooded if not managed.
- Partial drainage which results in seasonal, rather than permanent, waterlogging is likely to lead to a change in the composition of the *Sphagnum* carpet towards species more tolerant of drier conditions, and growth of a wet heath or *Molinia*-dominated community.
- It is possible that a small reduction of groundwater outflow may help increase the abundance of *Molinia* within this vegetation, though without necessarily changing it beyond the limits of M21.
- Drying may also make the stands more prone to damage by burning, as well as permitting greater access to (and possible damage by) grazing animals. In some sites, poaching could be a contributory cause of tussocky *Molinia* in the less consistently wet examples of M21.
- Prolonged, deep inundation, particularly in the spring or summer months, is likely to kill some species and lead to development of bog-pool vegetation types. However, in some instances attempts to rewet drained sites may necessarily require local elevation of the water level above the limits normally associated with M21.

18.3.2 Nutrients/hydrochemistry

Typically found in base-poor, mostly oligotrophic conditions (

Table 18.3), and typically the least fertile of all of the examined weakly minerotrophic mire communities. An increase in base status has been found to increase species richness (Shaw and Wheeler, 1991), and may be associated with the occurrence of such species as *Anagallis tenella* and *Cirsium dissectum.* In some sites, trails of *Schoenus nigricans* are evident within this community. These appear to occupy locations with higher surface water flow, but the water is not necessarily more base-rich than that of the flanking M21, and this circumstance should be distinguished from that in which stands of M21 flank more base-rich soakways with *Schoenus* that are referable to M14.

Some stands of M21 show evidence of nutrient enrichment, especially those alongside streams and soakways and which may receive some water supply from these. No significant relationship has been found between soil fertility and the number of mire species present in the vegetation, but there is evidence for a significant ($P < 0.005$) decrease in the number of rare species with an increase in soil fertility.

Table 18.3 pH, conductivity and substratum fertility measured in stands of M21

Variable	Mean	SE	Minimum	Maximum
Water pH	4.7	0.02	3.4	6.8
Soil pH	4.9	0.04	3.3	6.6
Water conductivity (K_{corr} µS cm^{-1})	133	0.6	31	536
Substratum fertility[1] (mg phytometer)	5.6	0.13	1	12

18.3.3 Management

The community mostly occurs in grazed sites. Some of these are within the open grazing land of the New Forest or Dorset Heaths and can be heavily grazed. Management may help to maintain higher species diversity, and retard successional processes, but there is a danger that heavy grazing may fragment the *Sphagnum* carpets (though without necessarily being detrimental to species richness). Shaw and Wheeler (1991) found evidence that managed stands were generally more species-rich and supported more rare species than unmanaged stands. The wetness of the substratum may give some protection against burning and grazing. It is not clear to what extent M21 vegetation is able to persist in the absence of grazing, but it is possible that the community may be partly self-maintaining, at least in some of the wetter locations. Conversely, drainage may encourage scrub encroachment.

18.4 Implications for decision making

18.4.1 Vulnerability

Conservation management involves ensuring low fertility and relatively base-poor conditions. M21 is particularly vulnerable to lowered water tables and eutrophication. Figure 18.3 outlines some of the possible floristic impacts of changes to the stand environment.

Drainage poses an obvious threat, particularly through the loss of *Sphagnum*, although the general low fertility of the substrata may help to prevent the fast establishment of coarse species, especially where grazed. High water tables may also help to protect the community against the detrimental effects of burning and grazing. Base enrichment is associated with an increase in species richness (and the community can grade into M14 where there is some base enrichment). In some situations, nutrient enrichment may cause a loss in species diversity and expansion of such species as *Molinia caerulea*; in others, it may encourage the establishment of atypical species.

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[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

The possible effects of environmental change on stands of M21

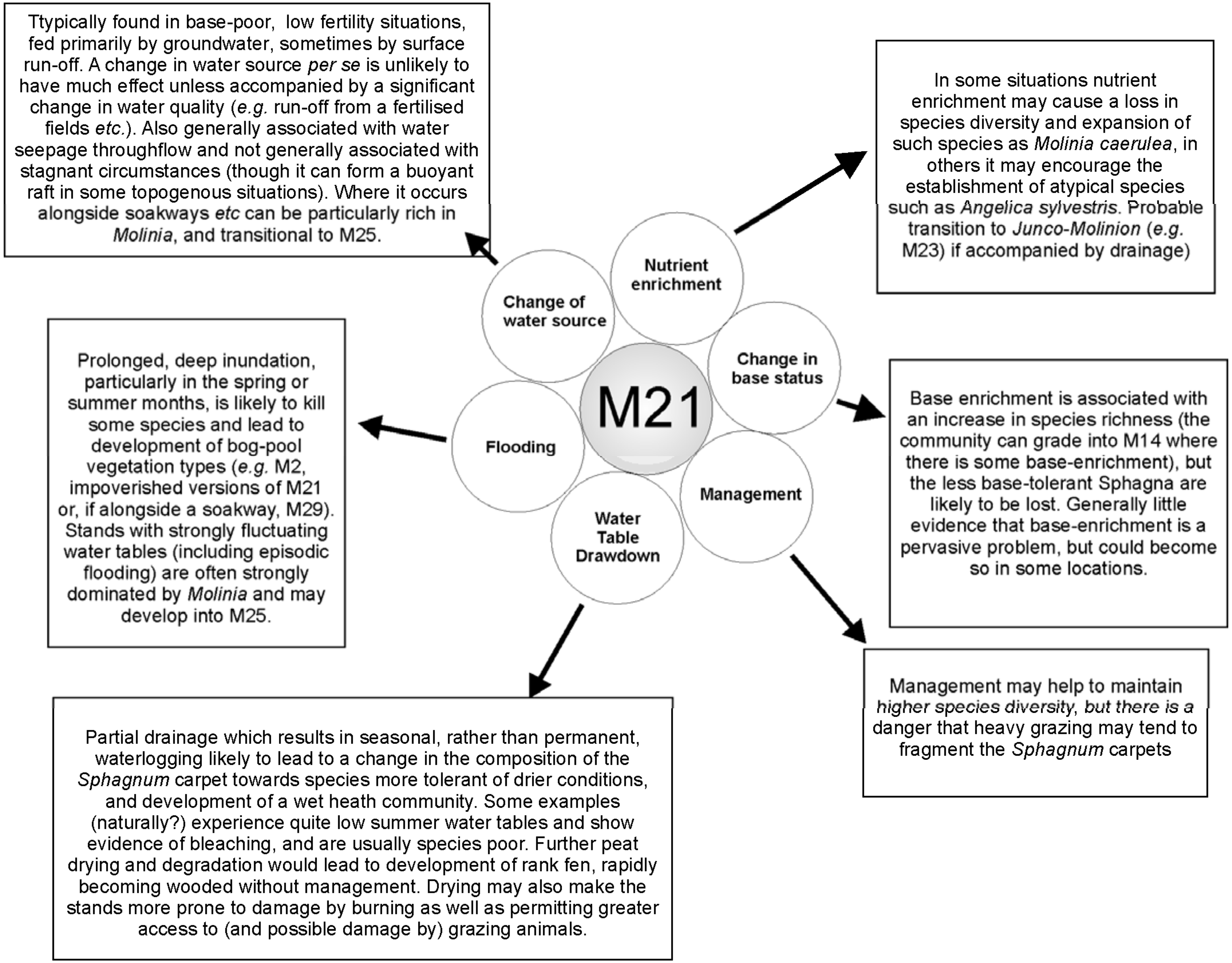


Figure 18.3 Possible effects of environmental change on stands of M21

18.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M21 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M21 in the short to medium term.
- Some mires have been damaged by peat-cutting (and associated drainage). However, in some circumstances this can diversify the surface patterning within the mire, and produce new areas for regeneration in mires that are becoming dry. There is sometimes no visible surface evidence for past turbary in sites where documentary or stratigraphical data suggest that it once occurred, and spontaneous regeneration of M21 seems to have occurred readily.
- Recent restoration initiatives in the New Forest have attempted to reverse the impacts of drainage and erosion at some M21 sites, for example by the use of heather bales and gabions.

18.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently no data to better inform the temporal water table characteristics of M21 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M21 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- Data on the spatial extent of M21 are lacking.
- Possible differences in environmental conditions influencing the two sub-communities have not been explored here.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

19 M22 (*Juncus subnodulosus–Cirsium palustre*) fen meadow

19.1 Context

M22 is present in a number of SSSIs, but is not usually the main designation feature. In some regions where fens are scarce, such as the South Midlands, most sites with M22 have not been designated as SSSIs, though it sometimes occurs in SSSIs designated for other features (such as Pilch Fields, Buckinghamshire). The community has apparently been used as a basis for SAC habitat designation under the category 'calcareous fens with *Cladium mariscus* and species of the CARICION DAVALLIANAE' (*see* Table 3.1and Table 3.3), but this is exceptional and has dubious legitimacy.

19.1.1 Concept and status

The vegetation encompassed by M22 was recognised and described first by Wheeler (1980c) as 'rich-fen meadow', and subsequently became incorporated into the *National Vegetation Classification* as M22 (Rodwell, 1991b). One reason why Wheeler referred to it as 'rich-fen meadow' rather than as a formal syntaxon was because it was a particularly variable unit which was difficult to define and characterise. It was also difficult to identify clear subdivisions within the community, and repeat analyses indicated several alternative subdivision solutions, none of which was entirely satisfactory. The variability of the unit doubtless reflects the range of edaphic and topographical circumstances in which this type of vegetation occurs, as well as the vagaries of individual management regimes, both past and present. This is coupled with effects of fragmentation and the identity of adjoining vegetation types, and is doubtless enhanced by the large number of examples of the community.

Despite these caveats, the unit forms, as Rodwell (1991b) recognised, a broadly coherent unit referable to the Calthion alliance. Nonetheless, the variability of the unit means that specification of environmental thresholds is particularly difficult. This is manifest in the WETMEC analyses which show that the community can be equally at home on consistently wet spring mounds and in intermittent seepages. Moreover, its relationship to water regimes appears to be partly conditional on the nutrient status of the substratum: examples of M22 can be found in intermittent seepages across much of the observed fertility range, but it usually occurs in permanent seepages only in mesotrophic or eutrophic conditions. Whereas versions that occur in drier conditions are often floristically distinct from those in permanent seepages, these differences do not necessarily correspond to the sub-communities of M22 recognised by Rodwell (1991b). A more exact assessment of environmental thresholds may therefore require a more precise intra-community classification, though experience suggests it may be difficult to arrive at a universally acceptable solution.

Stands of M22 can be transitional to those of other communities, both in concept and in the field, in time as well as in space. Spatial relationships between tall herb derivatives from M22 often appear abrupt and clear in the field, because of management boundaries, but this can mask a more gradual temporal change in species composition with plenty of overlap between M22 and tall herb communities, especially S25.

M22 also shows some overlap with M13, and the status of the transitional *Juncus–Carex lepidocarpa* nodum identified by Wheeler (1980c) is discussed under M13 (see 15.1.1). However, in general the overlap is not great. A much bigger problem, as recognised by

Rodwell (1991b), is the relationship between M22 and M24, as many transitional examples occur (Figure 15.2).

19.1.2 Floristic composition

M22 fen meadow is typically dominated by sedges and rushes of medium height. *Juncus subnodulosus* is the most characteristic rush, but it is not always present, and in some sites *Juncus acutiflorus* and, occasionally, *J. inflexus* may predominate. *Carex acutiformis* and *C. disticha* are particularly characteristic sedges and on occasion can be strongly dominant. Although distinctive physiognomically, this vegetation type is not easy to define because of its floristic variety and lack of good positive characterisation. The species that are particularly distinctive are essentially (wet) meadow plants; these not only occur in wet meadows but many, such as *Juncus subnodulosus, Cirsium palustre*, *Filipendula ulmaria, Lotus uliginosus, Calliergon cuspidatum,* can also be found in examples of M13 (though usually with lower frequency and constancy than in M22) and other communities. *Juncus subnodulosus*, a frequent dominant of M22, can also be dominant in M13, but whilst other M22 dominants such as *Carex acutiformis* and *C. disticha* can occur in M13, they are not usually as dominants.

The community is variable, but can be very species-rich (mean of 26, range 3–66 spp per sample) (Table 19.1). A total of 31 rare species were recorded from M22 stands, but the mean number of rare species per sample is less than one.

Rodwell (1991b) recognises four sub-communities of M22: typical sub-community (M22a), *Briza media–Trifolium* spp. sub-community (M22b), *Carex elata* sub-community (M22c), *Iris pseudacorus* sub-community (M22d).

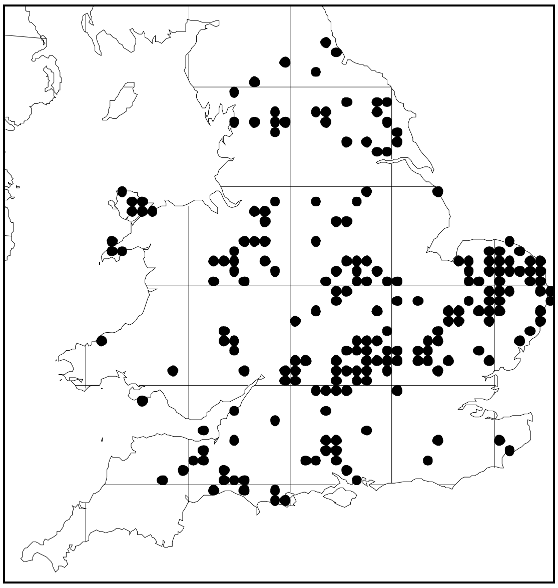
Table 19.1 Number of species recorded in stands of M22

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	403	25.8	0.07	3	66
Mire species (spp 4 m^{-2})	152	14.9	0.06	2	46
Rare mire species (spp 4 m^{-2})	31	0.7	0.04	0	10

* These include: *Blysmus compressus, Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Carex acuta, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Carex viridula ssp viridula, Cladium mariscus, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Eleocharis uniglumis, Epipactis palustris, Erica ciliaris, Eriophorum latifolium, Hypericum undulatum, Juncus alpinoarticulatus, Lathyrus palustris, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Philonotis calcarea, Plagiomnium elatum, Potamogeton coloratus, Ranunculus lingua, Sphagnum teres, Stellaria palustris, Thalictrum flavum, Thelypteris palustris.*

19.1.3 Distribution

The distribution of the community in England and Wales is shown in Figure 19.1. M22 has been recorded from 331 sites and is the most widespread plant community of base-rich fens in England and Wales. In some regions (such as much of the South Midlands) it provides the only real representative of herbaceous fen, but it is also widespread in East Anglia, often as a derivative of other, more distinctive, vegetation types. Its main distribution is in Central and Eastern England, but this is probably due to the presence of suitable substratum conditions (wet, base-rich, mesotrophic soils) rather than a direct influence of climate (Rodwell, 1991b). Similar vegetation occurs in some base-rich fen meadows in parts of Scotland (such as Ardblair and Myreside SSSI (Perth and Kinross)), but usually with neither *Juncus subnodulosus* nor *Carex acutiformis* and, because of the sparsity of data for comparable vegetation in Scotland, it is not clear if this is best considered a northern variant of M22, or another community (perhaps M26).



(data from FenBASE database)

Figure 19.1 Distribution of M22 in England and Wales

19.1.4 Landscape situation and topography

M22 stands are particularly a feature of lowland valleyhead fens, although this has less to do with the hydrological characteristics of these systems than the fact that many of them are (or, until recently, were) grazed, whereas this is less true of many topogenous systems. When grazed, base-rich floodplain sites can support M22 vegetation (such as Burgh Common (Norfolk), Woodwalton Fen (Cambridgeshire)); if grazed (or annually mown litter) fens were more widespread in floodplain systems, M22 would be more widespread within them. The community also occurs in some partly drained grazing levels.

The majority of stands occupy more or less flat situations or hollows, but a large number occur on seepage slopes (of varying grades of steepness) and in certain (base-rich mesotrophic-eutrophic) circumstances, they can cover spring mounds.

19.1.5 Substratum

M22 stands can occur on very shallow peaty soils, sometimes organic gleys, but also on deep (more than 1.5 m) peats in floodplains or basins. About 75 per cent of the stands were recorded in valleyheads, and these typically have very shallow peat (less than 0.5 m). Some 20 per cent of samples were recorded from floodplains, with a mean peat depth of 1.47 m. Only eight per cent occupied peat deposits deeper than 1.5 m, all in basins or floodplains. The substratum and irrigating water are typically of high (circumneutral) pH, though there are examples of lower pH in some floodplain peats, especially where these have been partly drained or are near the upland margins of some sites (values between 4.5 and 5.0 were recorded along part of the margin of Catfield Fen, Norfolk). Lower pH values are also found in the few sites associated with less base-rich bedrocks (5.5 on Lower Greensand, such as

Nares Gladley Marsh, Bedfordshire). There is considerable variation in the fertility of the deposits, but the majority are clearly mesotrophic.

M22 stands can be associated with a wide variety of bedrocks. Many of these are obviously strongly calcareous (Chalk, Jurassic and Carboniferous Limestone), but the community is also sometimes associated with other types, such as Old Red Sandstone (Pont y Spig Monmouth), Upper Greensand (such as Stowell Meadow, Somerset) and Lower Greensand. Examples on the Lower Greensand tend to be more acidic than others, are often dominated by *Juncus acutiflorus* and represent the base-poor extreme of M22 (which is perhaps transitional to M23). Many examples of M22 are located upon various superficial deposits, particularly glacial sand and gravel (such as Cors Hirdre, Caernarfon), sometimes expressed as sandy lenses within Boulder Clay (such as Clack Fen, Buckinghamshire) and may have little interaction with the bedrock. A few are located over non-sedimentary bedrocks.

19.1.6 Zonation and succession

Numerous examples of M22 do not display clear zonations with other mire communities. In some cases they occur as small fragments, in others they occupy entire (usually valleyhead) sites and their limits are bounded by transitions into drier ground or watercourses. In some instances (such as where M22 covers seepage slopes), their transition into drier habitats is often abrupt and determined by the topographical disposition of the site and controls upon the emergence of groundwater. In some floodplain locations, M22 can occupy large areas and in some instances entire compartments, bounded by dykes, are covered by the community. Such expanses of M22 are not necessarily uniform, but floristic variation within them is expressed in terms of different versions of M22 rather than different communities (often because of the strong selective pressures imposed by grazing management).

In many instances M22 occurs in juxtaposition with other mire communities. M22 is essentially maintained by grazing or regular mowing and where these occur differentially, the community may adjoin dereliction derivatives such as S24 or S25. The boundary between M22 and other communities may be abrupt (for example, along the line of a fence). The community also occurs in more natural zonations. In some seepage systems it forms a zone flanking the main seepage communities (such as M13), in conditions that may or may not be drier but which are often more fertile (when the main seepage is also quite fertile, the whole system tends to be blanketed by forms of M22). Some stands of M22 contain a number of typical *Molinion* species, and these may grade out into examples of M24 in drier conditions. However, other examples of M22 can be as dry as examples of M24, and the consistent difference between these two communities is that M22 is more fertile than M24.

M22 frequently forms a zone in wet hollows, surrounding wetter forms of fen or swamp and grading out into wet or dry grassland, as is seen clearly in some of the West Norfolk pingo fields. In many instances, M22 is not obviously part of the terrestrialisation sequence of the hollows, but occurs on shallow peat or mineral ground around them. Nonetheless, examples of M22 do occur on surfaces which have originated by terrestrialisation, but the community mainly occurs as a grazing-maintained secondary feature (plagioclimax), derived by scrub clearance and encouraged by partial drainage. This seems to be the status of M22 in the topogenous basin at Great Cressingham Fen, where the natural herbaceous vegetation appears to have been a form of M9. Likewise, examples on floodplains may be a product of scrub clearance or of grazing of tall herb fen (S24, S25), again often – but not always – enhanced by drainage. A corollary is that M22 can disappear as a result of dereliction, though the process can be slow and is not always complete: in a number of locations in Broadland, patches of strong *Juncus subnodulosus*-dominance within S24 are probably the relicts of former M22 litter fens, where mowing seems to have been abandoned well over fifty years ago. Lambert (1948) observed in the Yare valley that replacement of former litter fen by tall herb fen as a consequence of dereliction occurred most rapidly alongside the dykes and least rapidly in the centres of compartments. M22 has now virtually disappeared from unmanaged examples of these mires, but at Wheatfen small patches of *Juncus subnodulosus* dominance still persist in locations distant from the dykes.

19.2 Water supply mechanisms and conceptual model

Samples of M22 vegetation were recorded from a wide range of WETMECs: from 5 through to 17. Most are from areas with permanent or intermittent seepages or where groundwater tables are shallowly sub-surface year round, sometimes peripheral to permanent seepages: 30 per cent were from WETMEC 11 (Intermittent and Part-Drained Seepages, such as Booton Common (Norfolk), Cors Hirdre (Caernarfon)) and 22 per cent from WETMEC 10 (Permanent Seepage Slopes, such as Cors Hirdre, Buxton Heath (Norfolk)).

M22 stands can be irrigated by surface water and groundwater, depending on their situation. It is estimated that groundwater provides the main component of water supply to the rooting zone of about 70 per cent of sites and surface water, about 10 per cent. The remaining 20 per cent are either mixtures of groundwater and surface water (around five per cent), or sites with low summer water tables (where the surface is mostly exclusively rain-fed). Examples on river floodplains and in other valley bottoms mostly appear to be dependent upon surface water inputs, whereas those in valleyhead situations are mostly groundwater-fed. However, in some topogenous situations the surface water may be largely derived from proximate groundwater sources, whilst in some valleyhead systems, where the community occupies intermittent seepages, rain-generated run-off may have greater importance in contributing to the summer water supply than is the case with permanent seepage faces. Wheeler and Shaw (2000a) found that there appears to be an interaction between soil nutrient status and water conditions occupied by M22 in spring-fed fens. For example, oligotrophic spring mounds fed by Chalk water rarely support M22: M13 is usually the main vegetation type, with M22 occurring only in peripheral locations (Boyer and Wheeler, 1989). However, mesotrophic spring mounds fed by water from glacial sands and gravels may have the entire surface and surroundings covered by M22 (Wheeler, 1983). Wheeler and Shaw (2000a) provide further discussion on water sources and supply to stands of M22.

19.3 Regimes

19.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 19.2, together with mean recorded values for summer water table associated with stands of M22.

Table 19.2 Mean rainfall and potential evaporation for M22 stands

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	651	539	1,050
Potential evaporation (mm a^{-1})	601	435	638
Mean summer water table (cm)	–10.8	–175	12

Water conditions associated with M22 are variable (Table 19.2). Consequently, **mean water table values have limited value, are potentially misleading and should be interpreted with caution**. A very low value of 175 cm bgl has been measured at Cornard Mere in a drought period, but this is exceptional. Typically, water conditions range from being rather dry to just above the surface, the latter being associated with permanent seepages.

Much of the variation in species composition can be attributed to differences in the kind and degree of waterlogging (Rodwell, 1991b). For example, species such as *Carex acutiformis, Carex paniculata* and *Carex disticha* tend to be associated with wetter conditions, whilst species such as *Carex hirta* and *Deschampsia cespitosa* are more typical of summer-dry conditions.

Specific time-series data for stands of M22 are not available for the majority of sites. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal water levels

- Most examples of M22 are characterised by summer water tables that are below the surface (–5 to –18 cm).
- The M22 stands with the highest summer water tables are mostly those with the strongest groundwater inputs.
- The most species-rich stands are found at water levels of between about –5 and –20 cm.

Sub-optimal or damaging water levels

- Very wet sites (summer water table usually above-surface between tussocks) tend to be less species-rich. Prolonged, deep inundation, particularly in the summer, is likely to be damaging.
- Moderate reduction in water levels may actually increase species richness (Shaw and Wheeler, 1991), but a long-term reduction of the summer water table beneath high quality stands of M22 can be expected to result in some loss of botanical interest.

More discussion of the relationships between hydrological conditions and floristic variation within M22 stands (and comparison with M13 stands) can be found in Wheeler and Shaw (2000a).

19.3.2 Nutrients/hydrochemistry

Typically found in base-rich conditions and of moderate fertility, although M22 can span a wide range (Table 19.3). The community tends to occupy more fertile situations than M24 or M13 (Shaw and Wheeler, 1991). In general, some of the least fertile examples were the most species-rich, although Shaw and Wheeler (1991) found no relationship between substratum fertility and species richness, indicating that other variables may be more important in regulating this. Low fertility conditions may help to retard invasion by tall herb fen and scrub into unmanaged stands.

Shaw and Wheeler (1991) reported a decrease in species richness associated with an increase in base status, suggesting an avoidance of some species of particularly base-rich conditions.

Wheeler and Shaw (1991a) report a mean increment (April to September) in dry weight of above-ground standing crop of 547 g dry wt m^{-2}, which is significantly higher than that of M13.

Table 19.3 pH, conductivity and substratum fertility measured in stands of M22

Variable	Mean	SE	Min	Max
Water pH	6.6	0.02	4.5	8.1
Soil pH	6.9	0.03	4.9	7.6
Water conductivity (Kcorr, µS cm^{-1})	612	1.2	113	1,780
Substratum fertility[1] (mg phytometer)	13.9	0.25	2	49

19.3.3 Management

This community owes its origin to management (mowing or grazing) and depends on this for its maintenance. It once formed extensive areas in the mowing and grazing marshes of Broadland and some other floodplain systems. As far as is known this vegetation has no natural analogues, but is a product of the clearance of wet woodland followed by management. A corollary of this is that many of the plant species typically found in this vegetation are shade-tolerant and grow readily in wet woodland. Variations in management regime (including timing, frequency and intensity) and their histories are reflected in the variations in species composition.

19.4 Implications for decision making

19.4.1 Vulnerability

Conservation management typically involves ensuring relatively wet, mesotrophic and base-rich conditions. The main threats are from dereliction and drainage (or interception of supply). As the community does not normally define a SAC habitat, and because it is widespread, it is often not assigned a high priority for protection. However, in some districts it represents the only form of base-rich mire vegetation and repository for mire species, and can therefore have considerable local or regional significance.

Perhaps the biggest threat to M22 vegetation is dereliction. This is likely to lead first to the development of tall herb vegetation (and associated species loss, particularly of small herbs) and then to development of some form of wet woodland (such as *Salix cinerea–Betula pubescens–Phragmites australis* woodland (W2)). The wet woodland may continue to support the majority of plant species that originally occurred in the M22 community, though in reduced numbers and probably without *Juncus subnodulosus*. A change in management regime (such as from mowing to grazing, or in timing or frequency) is also likely to result in a change in species composition. Management regimes can considerably affect the flowering performance of some of the less common species (such as *Dactylorhiza* spp.). Overgrazing can also be detrimental and may result in species loss, as well as poaching of the ground.

The wide range of water table conditions under which stands of M22 occur make it difficult to make simple comments on vulnerability to drainage. Drying of M22 stands is likely to result in some changes in species composition, but the floristic impact of this does not depend just upon the magnitude of change, but also upon the wetness of the pre-drying starting point. In other cases, drying can lead to a change from one sub-community of M22 to another. The absence of a clear and consistent relationship between water levels and species richness of M22 vegetation, coupled with the fact that many of the species that distinguish M22 from other community types are essentially wet meadow species, means that some drying of M22

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

stands may have little impact on species diversity *per se,* and in some cases could lead to a net increase in species richness.

M22 can accommodate considerable eutrophication without change to its basic composition provided that active management continues, although there is likely to be some floristic change, and low-fertility stands may lose their distinctive features. Conversely, low-fertility conditions may help to retard invasion by tall herb fen and scrub if left unmanaged.

Figure 19.2 shows the possible floristic impacts of changes to the stand environment. However, the concept of 'vulnerability' is complex and depends upon the starting conditions (including floristic composition), sensitivity of the stand and sensitivity of the site to the pressure of change. In such a context, the stand could be regarded as *sensitive* to change but not necessarily *vulnerable.* For this reason, **accurate assessment of vulnerability is likely to require careful site-specific investigations**.

The possible effects of environmental change on stands of M22

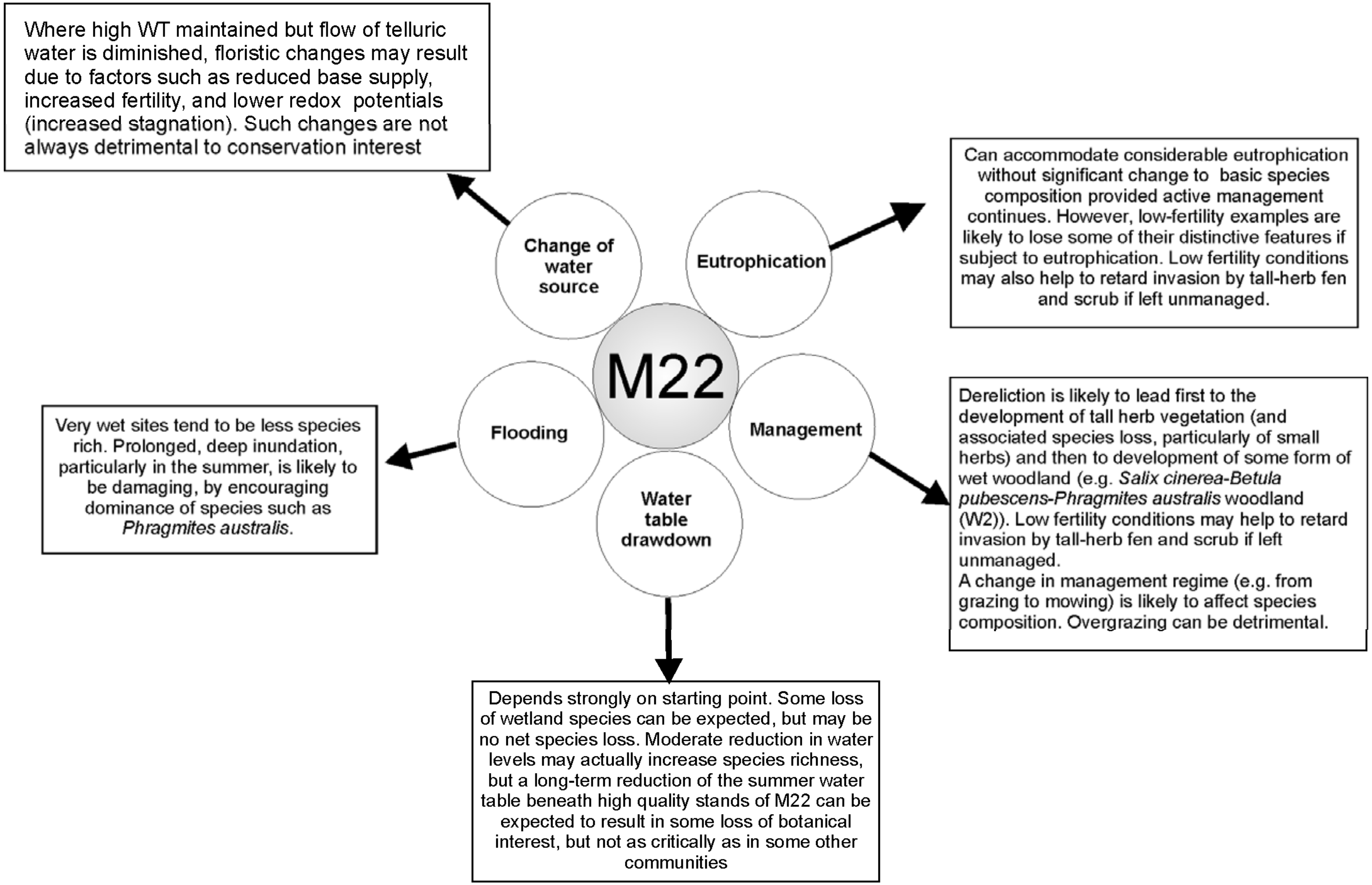


Figure 19.2 Possible effects of environmental change on stands of M22

19.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M22 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M22 in the short to medium term.
- Scrub removal and re-instatement of vegetation management may help to restore M22 vegetation that has been left unmanaged for a while, provided that other conditions have not changed irreversibly.
- Attempts to increase the wetness of examples of M22 by blocking outflows could be detrimental to the vegetation if they result in the establishment of prolonged periods with stagnant surface water and strongly reducing conditions.

19.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently no data to better inform the temporal water table characteristics of M22 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M22 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at representative sites.
- Data on the spatial extent of M22 are lacking.
- Possible differences in environmental conditions influencing the four sub-communities have not been explored here.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

20 M24 (*Molinia caerulea–Cirsium dissectum*) fen meadow

20.1 Context

Examples of the M24 community have been included within the SAC category 'chalk-rich fen dominated by saw sedge' and (probably) '*Molinia* meadows on calcareous, peaty or clayey silt-laden soils' (*see* Table 3.1and Table 3.3). The community can be found in fens and wet grasslands. However, whilst stands of M24 may be semi-natural features of the margins of mires, their occurrence within mires is often indicative of drying or drainage and may therefore be degenerative rather than desirable.

20.1.1 Concept and status

The *Cirsio-Molinietum* was identified for fens in England and Wales by Wheeler (1980c), as a unit equivalent to a community of the same name recognised from the Netherlands (Westhoff and den Held, 1969). It was subsequently modified and expanded by Rodwell (1991b) to include similar vegetation from wet grasslands as well as fen. The community as recognised by Rodwell shows strong links to various other communities, in particular to some types of fen dominated by *Phragmites* or *Cladium mariscus*, to Caricion davallianae types (such as M13) and to various wet grassland types, and it is rather difficult to identify a clear core to M24. The observed floristic variation and links reflect not only gradually varying environmental gradients, but also "*the direct effects of mowing and grazing, and of neglect, and their influence on the vegetation through soil changes, result in a frustrating degree of floristic convergence amongst many of the smaller elements of these different kinds of vegetation and a confusing medley of apparently interchangeable dominants through contiguous stands*" (Rodwell, 1991b).

The close floristic (and often spatial) relationships and intergradations between M24, M22 and especially M13 (Figure 15.2) have been discussed under the accounts for M13 and M22, and illustrate the difficulties of identifying clear floristic limits and environmental thresholds. One of the main problems is that, under certain environmental or developmental circumstances, elements of M24 occur, or form small embedded M24-like surfaces, within these communities and increase their affinities to M24. Surveyors, depending on the circumstance and their inclination, may allocate such stands either to one or other of the parent communities, or as a transition or mosaic between them. Such an approach may provide a realistic solution to vegetation mapping but does not resolve, and may often complicate, the tricky matter of identifying a water regime appropriate for the community.

Some of the problems of M24 arise because Rodwell extended its compass to form a broad, and hence rather nebulous, syntaxon. Rodwell (1991b) points out, for example, that some stands (of the *Eupatorium cannabinum* sub-community) are "very close to Phragmitetalia fen", but this is partly an artefact of his scheme: Wheeler (1980a) allocated such vegetation to a separate *Cladio-Molinietum* community, which Rodwell appears to have encompassed within M24. It is not difficult to see a rationale for this, because the *Cladio-Molinietum* undoubtedly intergrades fairly seamlessly into M24. Nonetheless, if it had been retained as an independent segregate it would have reduced the floristic affinities of a (truncated) M24 to Phragmitetalia fen and would have improved its environmental definition, by removing from the compass of M24 examples which have quite high summer water tables. This illustrates a difficulty at the heart of vegetation classification: which is most desirable, a small number of broad units which are variable, or a greater number of segregates of narrower compass which admit more precise floristic and environmental definition?

20.1.2 Floristic composition

The M24 community typically comprises much *Molinia caerulea* and *Cirsium dissectum* with a range of other forbs. Rushes such as *Juncus subnodulosus* often occur, but are generally less abundant than in many mire communities. *Cirsium dissectum* is not always present, and is notably absent from all examples in North-West Wales, which are outwith the range of this species. The vegetation can be fairly species-rich and support some rare species. However, the species complement varies considerably (mean of 23, range of 5–56 spp per sample (Table 20.1)), and the community is not particularly distinctive in terms of species composition. With the exception of the rare *Selinum carvifolia,* which is primarily associated with this community, all of the typical M24 species also occur in allied communities such as M13. A number of M13 characteristic species (Table 15.2) also occur in M24. Wetter stands of M24 contain the most mire species and M13 characteristic species, though there is no comparable increase in the number of rare species with increased wetness.

Rodwell (1991b) recognises three sub-communities of M24: *Eupatorium cannabinum* sub-community (M24a); typical sub-community (M24b); *Juncus acutiflorus–Erica tetralix* sub-community (M24c).

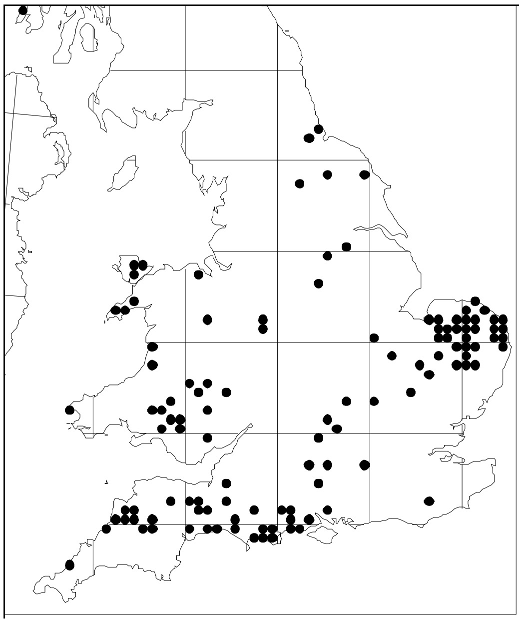
Table 20.1 Number of species recorded in stands of M24

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	318	22.8	0.09	5	56
Mire species (spp 4 m^{-2})	130	13.7	0.07	2	32
Rare mire species* (spp 4 m^{-2})	23	0.9	0.07	0	9

* These include: *Calamagrostis canescens, Calliergon giganteum, Carex appropinquata, Carex elata, Carex lasiocarpa, Cladium mariscus, Dactylorhiza praetermissa, Dactylorhiza traunsteineri, Epipactis palustris, Erica ciliaris, Eriophorum latifolium, Hypericum undulatum, Lathyrus palustris, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Plagiomnium elatum, Primula farinosa, Pyrola rotundifolia, Selinum carvifolia, Stellaria palustris, Thalictrum flavum, Thelypteris palustris*

20.1.3 Distribution

The community primarily occurs in the warmer parts of Britain and has been recorded from 181 sites in England and Wales (Figure 20.1). It is widespread in Eastern England, where it occurs in scattered and infrequent locations, and the dataset analysed here is dominated by samples from this region (around 80 per cent). The community is much more widespread in parts of South-West England and Wales, but here it occurs widely in habitats that would often have been regarded as wet grassland rather than mire. Non-mire examples of M24 in Western Britain tend to have a different species composition to examples from the East, and none has been included in the present analyses.



(data *from FenBASE database*)

Figure 20.1 Distribution of M24 in England and Wales

20.1.4 Landscape situation and topography

Stands of M24 occur in a variety of wetland contexts, usually peripheral to the main areas of wetter mire. The majority of recorded stands are associated with valleyhead wetlands, where they typically occupy a zone between wetter fen communities and drier grassland and heath. However, examples also occur in some floodplains and occasionally, in basins. In undrained floodplain fens, M24 may occupy a narrow, marginal zone alongside the main stands of fen vegetation, but in part-drained floodplains or those that naturally experience low summer water tables, M24 can occur over large areas of the floodplain proper. Likewise, the community can be extensive in some summer-dry, rather flat, valleyhead fens. In part-drained situations the community has usually replaced a wetter fen vegetation type, sometimes M13. In parts of South-Western England and Wales, stands of M24 are widespread in valleyheads and hillslopes that are perhaps better considered as wet grassland than fen meadow, though every intergradation between these two habitat categories seems to occur.

20.1.5 Substratum

M24 is most often found over organic or strongly humic soils (Rodwell, 1991b). Where M24 is located at the margins of fens, the community is usually underlain by a relatively shallow (less than 50 cm) depth of organic soil and peat. However, the community can be found on deep peat in some partly drained locations, for example, in groundwater-fed basins (such as Banham Great Fen, Norfolk) or on floodplains (such as Woodwalton Fen, Cambridgeshire).

20.2 Water supply mechanisms and conceptual model

A number of water supply mechanisms can support the M24 community. The main source of telluric water to the substratum supporting this vegetation is usually groundwater in valleyhead sites (notably through intermittent seepages) and surface water in the floodplains, though some floodplain examples may also receive groundwater seepage inputs, either directly or distributed through the surface water system. In some, perhaps many, cases M24 *surfaces* may currently receive little if any telluric water and be largely rain-fed, with base-rich conditions a product of a base-rich substratum and, in some drained examples, a legacy of former telluric water supply. The occurrence of narrow zones of M24 along the rising margins of floodplain fens is sometimes attributed to groundwater seepage, but this is not necessarily the case.

Forty-two per cent of M24 samples were identified as occurring within WETMEC 11 (Intermittent and Part-Drained Seepages such as Roydon Fen (Norfolk), Foulden Common (Norfolk), Bryn Mwcog (Anglesey)), with 19 per cent in WETMEC 9 (Groundwater-Fed Bottoms such as Roydon Fen (Norfolk), Hopton Fen (Suffolk)), 10 per cent in WETMEC 7 (Groundwater Floodplains such as Bransbury Common (Hants), Chippenham Fen (Cambridgeshire)) and nine per cent in WETMEC 8 (such as Cors Erddreiniog, Anglesey). A few examples were found within WETMECs 4, 5, 10, 16 and 17.

20.3 Regimes

20.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 20.2.

Table 20.2 Mean rainfall and potential evaporation for M24 stands

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	674	546	1,202
Potential evaporation (mm a^{-1})	612	590	646

Mean recorded values for summer water table associated with stands of M24 in mire systems, and segregated into data from Eastern England and for the rest of England and Wales, are presented in Table 20.3. These data refer only to examples of M24 from mire systems, and may be biased towards wetter conditions than those associated with examples of M24 from other habitats.

M24 characteristically occurs on sites with sub-surface water tables, at least during summer. Some stands occupy intermittent seepages, with winter water levels at or near the surface, but in others the water table is permanently sub-surface. Sites with relatively high summer water tables tend to show the greatest affinity towards M13. Examples from mires in Eastern England have significantly lower summer water tables than stands in mires elsewhere in England and Wales, but are not obviously less good examples of M24 (there is only a slight difference in the spread of samples from Eastern England *versus* those from elsewhere along Axis 3 of a DCA ordination, and no differences along Axes 1 and 2 (Figure 20.2)).

Table 20.3 Mean summer water table for M24 stands in England and Wales

Variable	Mean	Minimum	Maximum

Mean summer water table (cm bgl)			
Eastern England	–21.4	–48.4	–10.0
England and Wales except EE	–9.2	–31.6	–2.0
All England and Wales	–15.1	–48.4	–2.0

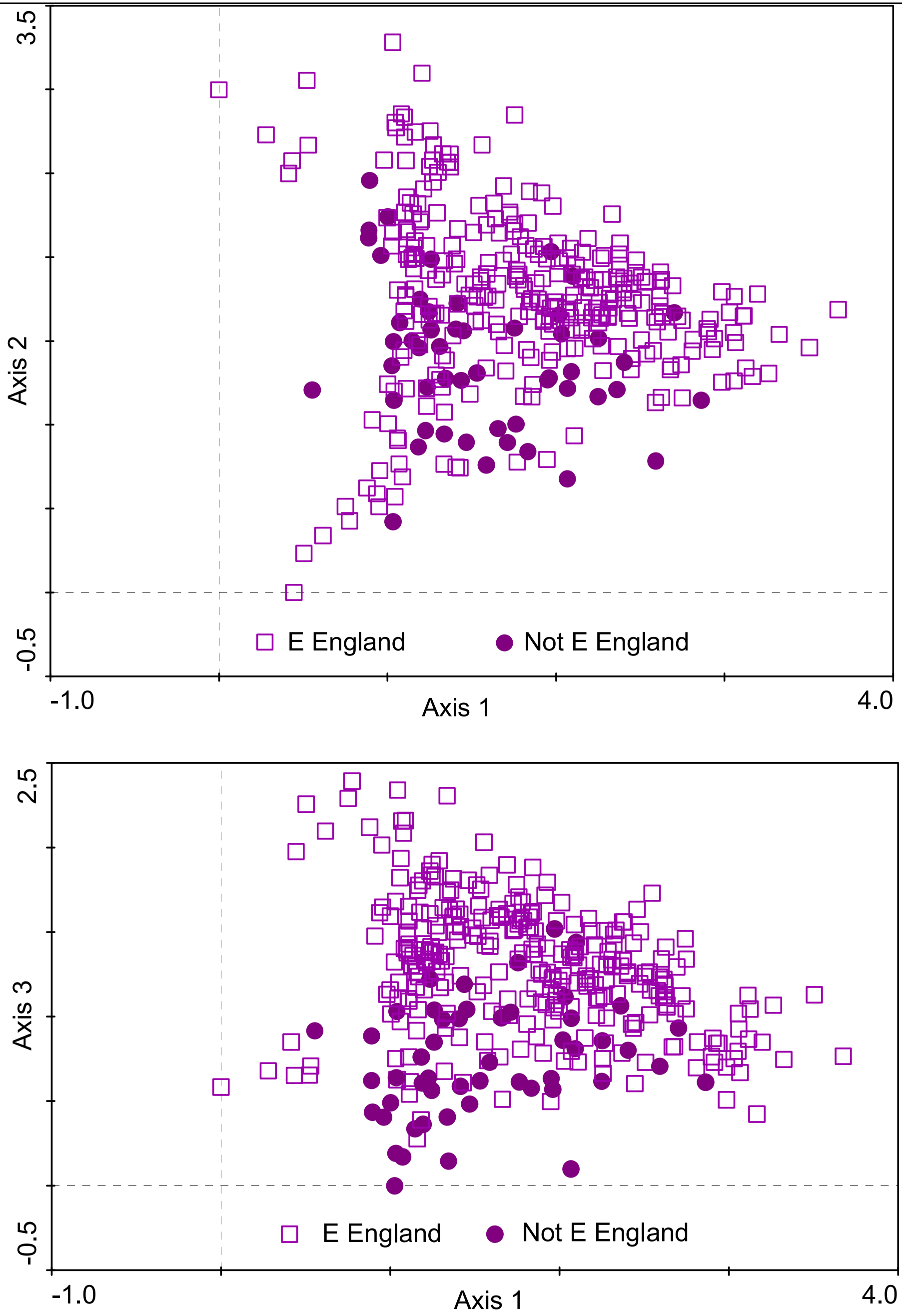


Figure 20.2 Axes 1~2 and 1~3 of a DCA ordination of samples of M24, categorised by regional location

Specific time-series data for stands of M24 are not available for the majority of sites. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal water levels

- M24 occupies a broad band of sub-surface summer water tables. Sites with relatively high summer water tables tend to show the greatest affinity towards M13. Winter water tables may be more or less at the surface in some sites.
- A relatively deep sub-surface summer water table may be a natural feature of some sites. It is often difficult to know to what extent relatively dry stands are natural or represent remnants of formerly wetter M24 or another mire community.
- M24 is not normally associated with inundation, except to a minor degree in the winter at particularly wet sites.

Sub-optimal or damaging water levels

- A summer water table at or near the surface is likely to generate vegetation closer to other fen types than M24 (M24 is one of the few mire communities in which persistently high, but still sub-surface, summer water tables may be damaging).
- Prolonged inundation in winter or summer is likely to lead to species losses.
- Strongly sub-surface winter and summer water tables are probably outside of the normal range of this community. Precise tolerances are not known, but it can be speculated that this will lead to a loss of wetland interest and increased representation by dryland species
- The potential for restoring M24 through rewetting of strongly dehydrated sites is largely untested.

20.3.2 Nutrients/hydrochemistry

The pH values of soils supporting M24 are rather variable, ranging from mildly acidic to base-rich (Table 20.4). The most acidic ones refer to examples of the community associated with less base-rich bedrocks, including the Eocene deposits of the Hampshire Basin, and these are often transitional to M25. The fertility of the soils is also variable: most examples are oligotrophic or mesotrophic, but some eutrophic examples have been recorded, mostly on deep peats of partly drained floodplain sites (such as Barnby Broad (Suffolk), Upton Fen (Norfolk)), and these tend to be transitional to M22. Deeper peats of drained floodplains may also provide a slightly more acidic substratum than shallower peats at the fen margins.

Table 20.4 pH, conductivity and substratum fertility measured in stands of M24

Variable	Mean	SE	Minimum	Maximum
Water pH	6.6	0.03	5.3	7.6
Soil pH	6.7	0.02	5.4	7.7
Water conductivity (Kcorr, µS cm^{-1})	581	2.0	60	1,034
Substratum fertility[1] (mg phytometer)	8.9	0.31	3	26

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

20.3.3 Management

M24 appears to be mostly a secondary vegetation type, with no natural analogues. In all sites, maintenance of this vegetation type depends upon some form of management, either mowing or grazing. The community can establish following woodland clearance and/or fen drainage on sites with a tradition of annual grazing and/or mowing for litter.

20.4 Implications for decision making

20.4.1 Vulnerability

M24 is particularly vulnerable to a reduction in water table, flooding and dereliction. The probable impacts of changes to the stand environment related to these three factors are identified in Figure 20.3. However, M24 can often be a product of drying of a former wetter fen community (such as M13).

The possible effects of environmental change on stands of M24

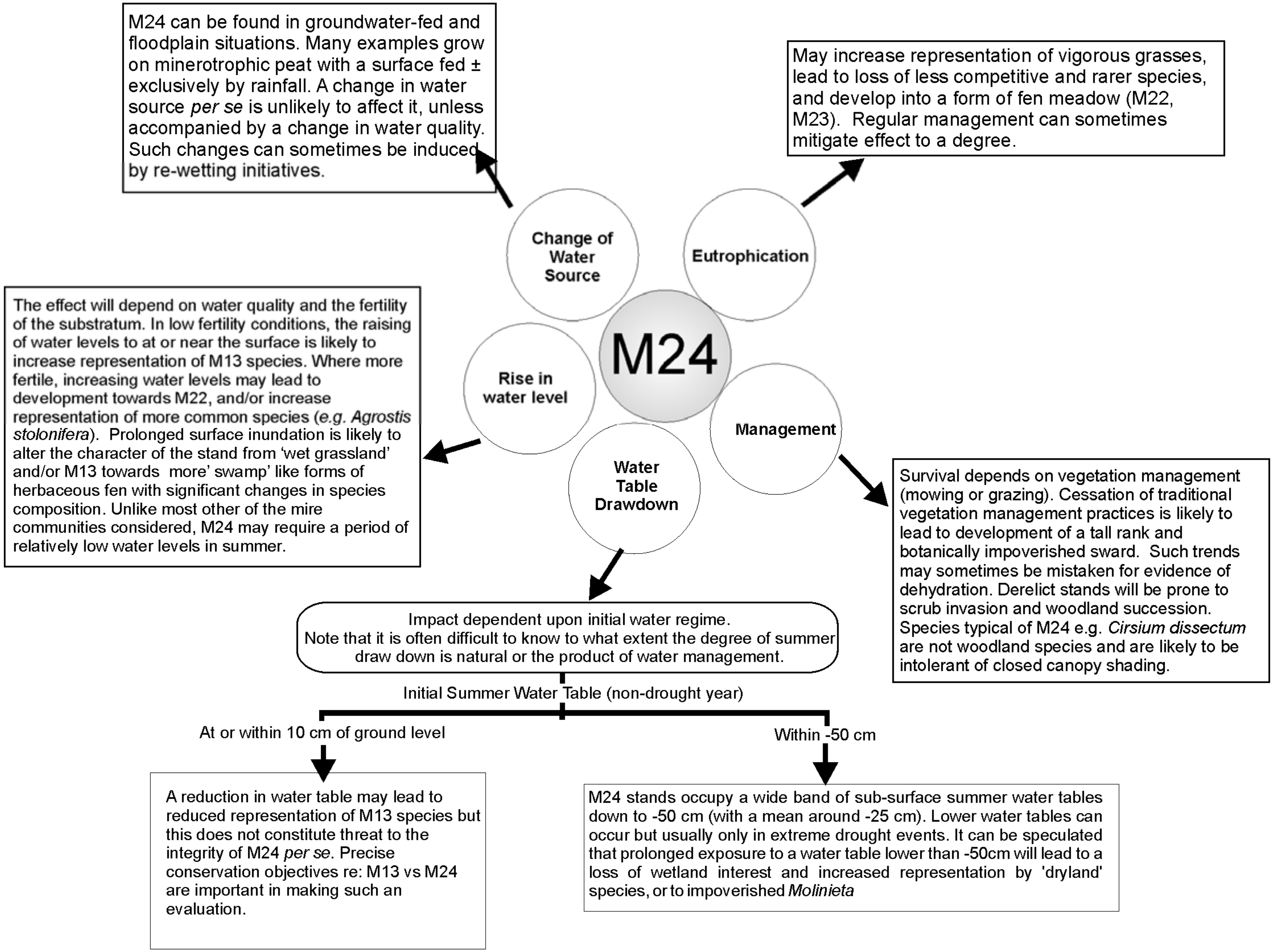


Figure 20.3 Possible effects of environmental change on stands of M24

For relatively wet examples of M24, a reduction in water table will result in the loss of some mire species and M13 characteristic species. If the conservation objective is preservation of characteristic M13 species, this may be considered undesirable. However, if the objective is the protection of the M24 community, such losses are arguably less important. Conservation objectives for M24 are important in this context and the assessment of their relative importance needs to be made on a site-by-site basis.

M24 stands are generally associated with relatively low summer water tables, and attempts to make them wetter may have unexpected and undesired effects. For example, there is some evidence that high dyke water levels at Chippenham Fen (Cambridgeshire) have resulted in an increase in *Agrostis stolonifera* in the vicinity of some dykes. Likewise, it seems probable that a speciality of that site, *Selinum carvifolia,* which is also found in M24 analogues in continental Europe, may be adversely affected by a sustained water table increase.

Dereliction of traditional vegetation management practices is likely to lead to development of a tall, rank and botanically impoverished sward. Such trends may sometimes be mistaken for evidence of dehydration (and/or enrichment). Derelict stands will be prone to scrub invasion and woodland succession. Species typical of M24, such as *Cirsium dissectum,* are not woodland species and are likely to be intolerant of closed canopy shading.

20.4.2 Restorability

Reinstatement of a regular vegetation management regime can be expected to improve stand quality. Whilst vegetation management is likely to be the most critical factor, a degree of rewetting may be required in severely drained situations in order to generate appropriate water conditions (though such measures are generally untested with respect to M24 restoration).

As with all restoration measures, the likely success depends on the cause of the damage and how far the starting conditions are from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment).

20.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here are as follows:

- The information presented here is primarily based on information from fen sites supporting M24, in which this community is frequently peripheral. No attempt has been made to collate/examine environmental information relating to this vegetation type from drained sites that are more wet grassland than fen, or from western examples (such as culm grasslands in the South-West and Rhôs pastures in Wales);
- There are currently no data to better inform the temporal water table characteristics of M24 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M24 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- A better understanding is needed of the water regime tolerances of M24. As it is often associated with sub-surface water tables, soil properties and precipitation inputs may be more critical than the position of the groundwater table.
- Data on the spatial extent of M24 are lacking.

- Possible differences in environmental conditions influencing the three sub-communities have not been explored.

21 M29 (*Hypericum elodes–Potamogeton polygonifolius*) soakway

21.1 Context

Examples of the M29 community have been included in the “transition mire and quaking bog” SAC interest feature. [See Tables 3.1 and 3.3]

21.1.1 Concept and status

The M29 syntaxon was recognised and described by Rodwell (1991b), with rather few published antecedent descriptions. It is generally a distinctive and readily identified community, both by the conspicuousness of the two nominative species (especially *Hypericum elodes*) and by the soakway habitat. *Hypericum elodes* can be prominent in some contexts different to normal M29 and it is possible that on occasion, vegetation referred to M29 is really a *H. elodes*-dominated form of another community. This may be the case, for example, with some flushed slopes rich in *H. elodes* in mosaic with tussocks *Molinia caerulea* and may perhaps explain some of the outliers observed for M29 on a DCA ordination (Figure 21.1). Nonetheless, in general the ordination confirms M29 as a discrete, fairly tight community type. Samples of M14 mire can occupy an ostensibly similar soakway habit to M29, and sometimes occur in the same sites, but their distribution in ordination space (Figure 21.1) suggests that M14 is a discrete community from M29. There is a small amount of overlap which occurs, for example, where M29-like stands contain calcicolous species such as *Campylium stellatum*, and in a few sites (such as Stoney Moors, New Forest) it is debatable whether individual stands are best referred to M29 or M14, but these are exceptional and overall M14 and M29 are more distinct than is often the case for community types of similar habitats. Thus, there can be little doubt of the floristic distinctiveness of M29, though there remains considerable doubt about the causative reasons for it.

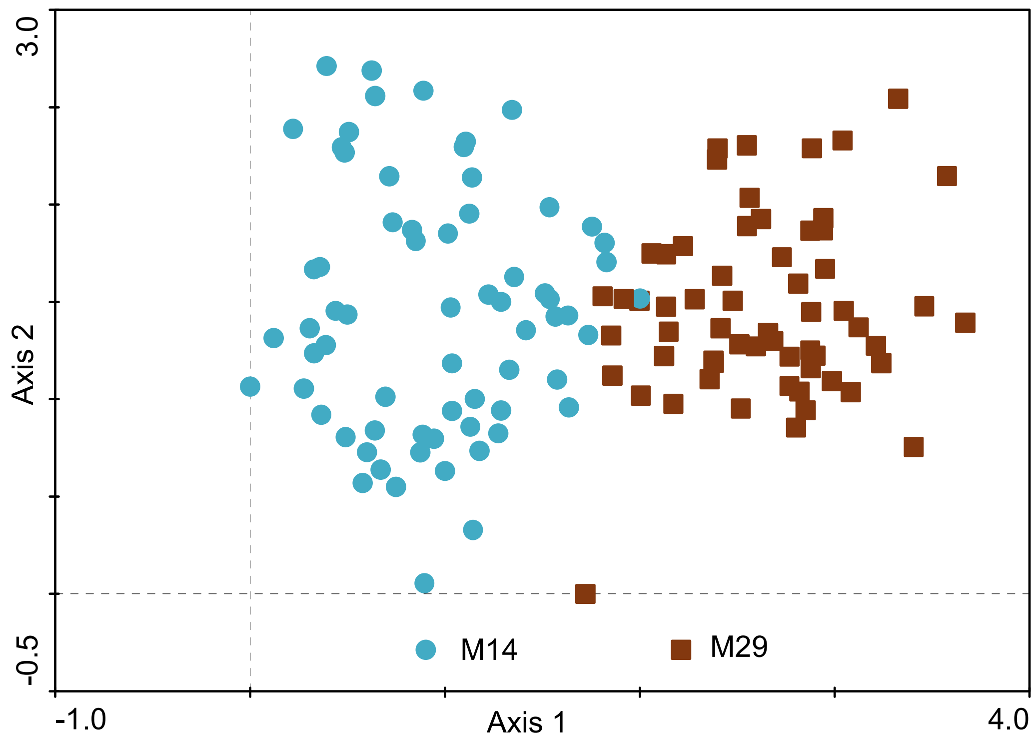


Figure 21.1 Plot of samples of *Schoenus nigricans–Narthecium ossifragum* mire (M14) and *Hypericum elodes–Potamogeton polygonifolius* soakway (M29) on Axes 1~2 of a DCA ordination

21.1.2 Floristic composition

The community typically consists of mats of *Hypericum elodes* and *Potamogeton polygonifolius,* often within a submerged carpet of *Sphagnum auriculatum*, but with a limited range of vascular associates (such as *Ranunculus flammula, Juncus bulbosus*). The community is characteristically low-growing and, in some close-grazed situations, can be very short. In others it may be associated with *Phragmites*, with the core community persisting even in quite dense reedbeds (such as Wilverley Bog, New Forest). On some flushed slopes the community can occupy a series of runnels anastomosing within a drier vegetation type, or in some cases forming a mosaic with tussocks of *Molinia caerulea.* M29 can be variable in species composition, but often moderately species-rich: mean species richness for examples recorded here was 19.3 spp per sample (Table 21.1).

Fourteen rare species have been recorded from samples allocated to M29 (Table 21.1), of which perhaps the most distinguished is *Eriophorum gracile.* This occurs in water tracks that are clearly M29 at Fort Bog (New Forest) and in soakways which are less clearly this community at Crymlyn Bog (West Glamorgan). The Crymlyn examples also account for all of the known localities for *Carex elata* in this community.

Table 21.1 Number of species recorded from stands of M29

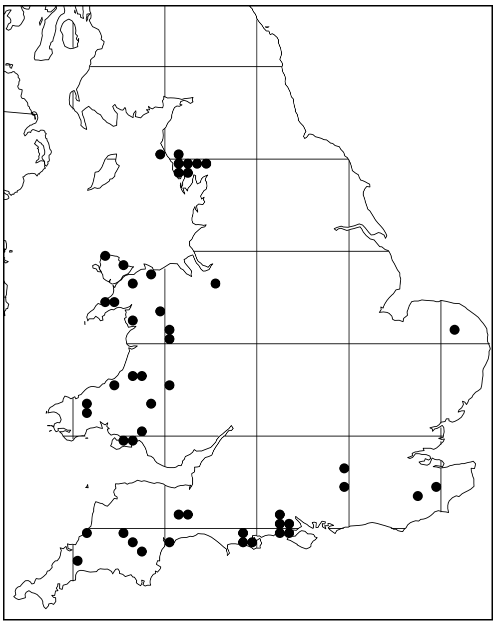
	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	139	19.3	0.18	7	32
Mire species (spp 4 m^{-2})	101	17.5	0.17	6	28
Rare mire species (spp 4 m^{-2})	14	0.9	0.14	0	5

* These include: *Calliergon giganteum, Carex elata, Carex lasiocarpa, Carex limosa, Drosera intermedia, Eleocharis uniglumis, Eriophorum gracile, Osmunda regalis, Parentucellia viscosa, Philonotis calcarea, Sphagnum contortum, Sphagnum subsecundum, Utricularia intermedia, Utricularia minor*

21.1.3 Distribution

M29 has an exclusively western distribution in Britain, mainly occurring in the South-West, New Forest, Surrey, and throughout Wales, extending north into Southern Cumbria (recorded from 75 sites: Figure 21.2). It is characteristic of the warm, oceanic parts of the country where February minima are usually at least a degree above freezing (Rodwell, 1991b). Rodwell states that samples of M29 were available from Galloway, but does not include them on his distribution map. FENBASE has a number of samples allocated to this community from the west coast of Scotland (Argyll and the Hebrides). The distribution maps do not do justice to the prevalence of this community in the New Forest, where it occurs widely, frequently to a degree not normally encountered in other locations.

The strongly oceanic distribution of this community, which reflects the oceanic distribution of *Hypericum elodes*, is suggestive of a climatic control on its distribution, but does not provide a reason for its distinctiveness from other soakway communities (such as M14, M9-1) which sometimes occur in close proximity to M29.



(data from FenBASE database)

Figure 21.2 Distribution of M29 in England and Wales

21.1.4 Landscape situation and topography

Particularly characteristic of shallow soakways, pools and water tracks within valleyhead wetlands but can also occur in hillslope, basin and floodplain wetlands. In some topogenous basins it can form a narrow trail through the main topogenous vegetation, probably representing a zone of greater lateral water flow. Sometimes found in isolated, shallow seasonal pools on heathlands.

21.1.5 Substratum

M29 soakways and water tracks occur both embedded within the (mostly shallow) peat of mires and as channels crossing sticky, clay-rich soils. The shallow soakways and pools usually have a substratum consisting of a mix of very loose peat, water and liquid muds over a more solid peat, although sometimes with a more consolidated surface, but some examples are quite strongly mineral (silt or clay) based. Basal material ranges from sands and gravels to silts and clays.

21.1.6 Zonation and succession

Some stands of M29 occupy channels within wet grassland or wet heath rather than mire, and can form the only representative of mire, often with a fairly sharp transition to adjoining drier ground. However, most of the examples examined were embedded within mire, typically as axial soakways and water channels flanked by mire slopes in valleyhead systems, but sometimes as soakways and runnels running transversely down the slopes of a valleyhead. The community also occurs in channels (in some cases occluded drains) flowing along the top of the mire slope and collecting water from springs and seepages. M29 is most often confined to discrete soakways and water tracks, but on occasion large areas of flushed slopes may support the community, as a series of runnels and soakways in mosaic with tussocks of *Molinia* and shallow tumps of elevated peat. The most frequent flanking community is M21, but in drier circumstances it may be M25 and unusually, but where there is greater base enrichment, M10.

In certain circumstances M29 forms discrete trails within topogenous hollows, often apparently marking zones of greater lateral water flow. For example, in the north-western arm of Cors Gyfelog (Caernarvonshire) rather nebulous trails of M29 occur within a community of uncertain and variable affinities, but which is probably mainly a form of M9-1. At Llyn y Fawnog (Denbighshire), M29 occupies what may be a broad inflow track into the basin, flanked partly by carr and by M5 and extending into the central swamp of *Carex rostrata* and *Equisetum fluviatile.*

At sites such as Llyn y Fawnog and Cors Gyfelog, M29 appears to form part of the hydroseral process, albeit one that is sometimes disruptive of the broader hydroseral pattern. Both sites seem likely to be reflooded turbaries and the M29 trails may perhaps be best seen as units that are emerging within the hydroseral succession, in locations where gradual consolidation of the flanking peat infill constrains water flow into increasingly discrete water tracks. At Llyn y Fawnog, *Hypericum elodes* and *Potamogeton polygonifolius* patches are locally prominent components of the central swamp, particularly in some of the most tremulous locations of the floating mat, and may represent the progenitors of future hydroseral spread of M29 across the basin. Both *H. elodes* and *P. polygonifolius* are known from hydroseral situations elsewhere, such as Louisa Lake (Kent) (Rose, 1953; Bellamy, 1967), where they form a vegetation which may be considered a species-poor, hydroseral variant of M29. However, the syntaxonomic status of some such topogenous stands is not clear: MATCH analyses reveal that their highest affinities are with M29, but the coefficients are small and their allocation to M29 may just reflect the absence of a better alternative.

Some linear, flushed peat pits support M29, with an abrupt transition to a drier community on the uncut, or less cut, surface. This may support heath, wet heath or wet grassland vegetation, sometimes on a degraded ombrogenous surface.

M29 vegetation occurs in some seasonally flooded pools (Rodwell, 1991b), but no such habitats were considered here.

21.2 Water supply mechanisms and conceptual model

The M29 stands sampled were confined to situations with at least gently flowing water conditions: the majority were in soakways and water tracks, and examples in more topogenous locations (including peat cuttings) almost certainly received throughflow of water. Fifty-six per cent of M29 samples were identified as occurring within WETMEC 15 (Seepage Flow Tracks such as Cors Graianog (Caernarfon), Fort Bog (New Forest)), and 25 per cent within WETMEC 19 (Flow Tracks such as Cors Gyfelog (Caernarfon), Stable Harvey Moss (Cumbria)). A few examples occurred within WETMECs 10, 17 and 20.

21.3 Regimes

21.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 21.2, together with mean recorded values for summer water table associated with stands of M29.

Table 21.2 Mean rainfall and potential evaporation for M29 stands

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	1,253	627	2,101
Potential evaporation (mm a^{-1})	572	524	614
Mean summer water table (cm)	2.5	–10	15

Specific time-series data for stands of M29 are not available, and in general few detailed data are available for this distinctive, but little-investigated, community. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- The vegetation is usually shallowly flooded for much of the time. Summer water levels are variable, and dependent on the context. In some sites they are generally at or just below the surface during the summer, but some soakways and hollows may have a summer water table well below the surface, though generally the mud bottom remains moist. [Note that the FENBASE data mostly relate to stands within mires and may therefore be biased towards wetter conditions than is characteristic of examples of M29 in those channels across mineral soils which tend to dry out during the summer period]

- Often forms a narrow, distinct zone within other vegetation types, picking out areas of increased lateral water movement or vertical fluctuation in water level.

- Above-ground water with at least some water movement through the stand during part of the year is a characteristic of this community, and may well be essential.

Sub-optimal or damaging water levels

- Strongly sub-surface water levels, particularly in winter, are outside of the normal range of this community, although some examples appear to tolerate drawdown in summer. Prolonged summer drawdown is likely to lead to a loss of wetland species and increased representation by dryland species; it is also likely to improve accessibility to stock.
- Prolonged deep flooding may lead to loss of species diversity, though examples of the M29 frequently experience above-surface water levels.

21.3.2 Nutrients/hydrochemistry

M29 is typically found in base-poor conditions with low fertility (Table 23.3). Mean soil fertility (6.9 mg) is slightly, but significantly ($P < 0.05$), higher than another soakway community, M14 (5.4 mg), and may be a discriminating variable. However, phytometric determinations of fertility are particularly difficult on the loose infill of many M29 stands, and may not be as reliable as for some other communities. Species richness has been found to increase with increases in calcium and bicarbonate concentrations, and more rare species were found in sites with higher conductivity and magnesium than average for the community (Shaw and Wheeler, 1991).

Rodwell (1991b) supposes that calcium concentrations are probably low in most cases and the character of the vegetation suggests that low availability of phosphorus and relatively slow turnover of nitrogen limit growth. However, his comment that "*the situations occupied by this vegetation are very distinctive but little understood*" may provide a safer assessment.

Table 21.3 pH, conductivity and substratum fertility measured in stands of M29

Variable	Mean	SE	Minimum	Maximum
Water pH	5.2	0.03	4.5	6.4
Soil pH	5.3	0.04	4.5	6.4
Water conductivity (Kcorr, $\mu S\ cm^{-1}$)	131	1.5	40	691
Substratum fertility[1] (mg phytometer)	6.9	0.2	2	13

21.3.3 Management

Stands usually occur within grazed sites. Shaw and Wheeler (1991) found no evidence that lack of management was necessarily detrimental to species richness, although this may depend on the wetness of the substratum – in sites that dry out in summer, grazing may help to prevent scrub invasion. However, heavy grazing may lead to poaching, in particular damage to the *Sphagnum* carpet. Heavily grazed sites tend to have lower species densities, and fewer fen and rare fen species than lightly grazed sites (Shaw and Wheeler, 1991). However, the nominative, and often dominant, species of the community (*Hypericum elodes* and *Potamogeton polygonifolius*) appear to be resistant to close grazing, and in some

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility = <8mg, high fertility>18mg.

circumstances it is possible that such grazing may help account for the abundance and prominence of this community.

21.4 Implications for decision making

21.4.1 Vulnerability

Conservation management involves ensuring low fertility and relatively base-poor conditions, possibly coupled with some grazing. A substantial increase in fertility, which may occur as a result of substratum mineralisation following prolonged lowering of the water table, as well as direct nutrient inputs, may be detrimental to this community, and promote the establishment of more rank vegetation.

Figure 21.3 outlines some of the possible floristic impacts of changes to the stand environment.

The possible effects of environmental change on stands of M29

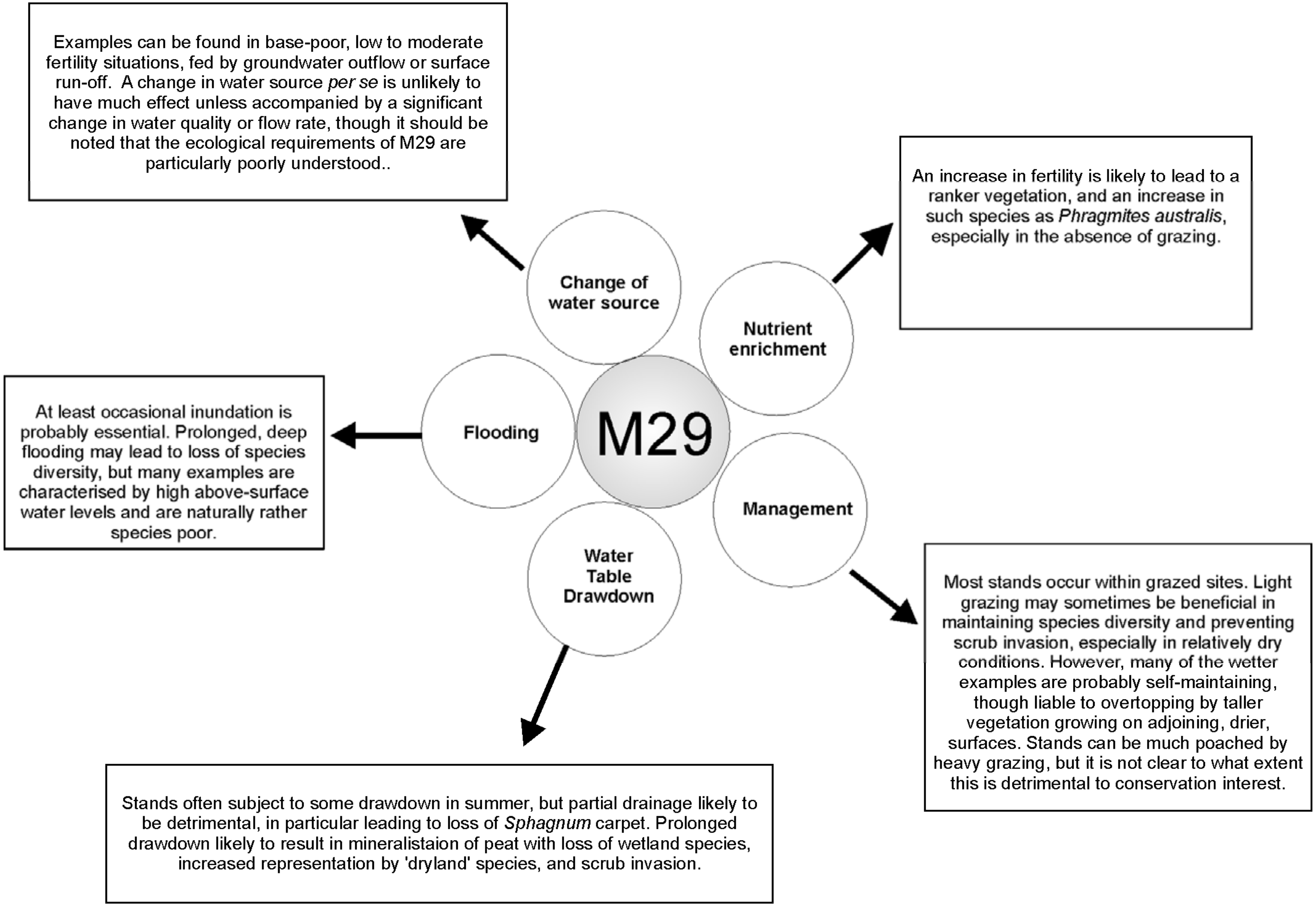


Figure 21.3 Possible effects of environmental change on stands of M29

21.4.2 Restorability

As with all restoration measures, likely success depends on the cause of the damage and how far the starting conditions deviate from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of M29 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate M29 in the short to medium term.
- In some circumstances, attempts to increase the wetness of examples of M29 by blocking outflows could be detrimental to the vegetation, but in general the response of this community to impeded drainage is to colonise the shallow pools thus created. In some circumstances, M29 may expand at the expense of flanking communities (such as M21).

21.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently no data to better inform the temporal water table characteristics of M29 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of M29 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- Data on the spatial extent of M29 are lacking.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

22 S1 (*Carex elata*) swamp and S2 (*Cladium mariscus*) swamp

These two community types are considered together here because: (a) they often occur together and in the same type of habitat; (b) they show much intergradation, both between the abstract units and amongst real stands, so that examples of *Cladium* swamp can also support much *Carex elata*; and (c) particular interest attaches to the conditions that favour these two community types in relation to M9-2 and M9-3.

22.1 Context

Examples of the S2 community have been included within the 'chalk-rich fen dominated by saw sedge' SAC feature. [See Tables 3.1 and 3.3]

22.1.1 Concept and status

Both S1 and S2 are essentially species-poor dominance types (defined by the dominance of an individual species), and as such they have been recognised by various workers in Britain (Rodwell, 1995). However, Wheeler (1980a), who provided a formal description of the units, restricted the compass of the communities to stands developed in swamp environments. This was in contrast to other workers, both in Britain and mainland Europe, who used terms such as *Cladietum* to refer to a wide spectrum of vegetation with *Cladium mariscus*, of which *Cladium* (or *Carex elata*) swamp is just one extreme. Rodwell (1995) essentially followed Wheeler's approach so that more species-rich stands with much *C. elata* or *Cladium* were considered to be facies of other, better-defined, floristic units such as M22, S24 or S25 rather than members of S1 and S2.

However, even with this restricted definition for S1 and S2, a potential problem with both units is that species-poor vegetation dominated by both species, but especially by *Cladium*, occurs over a wide water table range, with summer water level values ranging between about 50 cm agl to 100 cm bgl. Examples at either end of this range may have little in common floristically, other than the overwhelming dominance of *Cladium.* Thus, swamp examples may contain various aquatic plant species (such as *Potamogeton coloratus* or *Utricularia intermedia*) which are completely absent from the drier stands. However, whereas a floristic distinction can sometimes be made between the wetter and drier examples of S2, a frequent difficulty is that some unmanaged stands are so strongly dominated by *Cladium* that they are near-monocultures of *Cladium* and essentially 'the same' floristically whether they are very dry or very wet. Recognising this problem, Wheeler (1980a) specifically restricted his *Cladietum* to refer to species-poor *Cladium* vegetation developed in swamp or wet fen conditions and recognised a separate '*Cladium* sociation' to accommodate species-poor stands of dry locations. He commented that "*there is no floristic distinction between monotypic stands of the Cladium sociation and monotypic stands of Cladietum marisci. However, the former is developed where the water level is usually below the surface whereas the latter is found in swamp conditions, so it is considered that the units have ecological validity*" (the two categories are habitat classes).

In general, Rodwell (1995) appears to have followed Wheeler's 'swamp/wet fen' concept in the scope of S2, but he does not give his views on the status of the drier examples of *Cladium* near-monocultures, so their status in NVC is not defined and, in the absence of any other category in which to place them, surveyors encountering species-poor patches of *Cladium* dominance in fens have tended to allocate them to S2 whether or not they qualify as swamp. The practical significance of this is that stands often allocated to S2 span a very wide water table range, and the specification of thresholds based on this is both difficult and likely to be inappropriate for the maintenance of any species dependent on wet conditions, such as some of the aquatic plant species mentioned above. A similar problem arises with S1, but not to the same degree as S2.

Because of this, in this account 'S1' and 'S2' are adopted in the strict swamp sense as originally proposed by Wheeler (1980a), and apparently followed by Rodwell (1995). Thus, the water table data presented are not necessarily appropriate for the dry patches of dense *Cladium* found in a number of fen sites (such as Great Cressingham Fen). This is because such stands of *Cladium* do not require particularly high water tables for the perpetuation of their current character, even though in some instances they may once have been examples of wet S2 swamp.

Although, and perhaps partly because, they are species-poor dominance units, samples allocated to S1 and S2 on the basis of their highest MATCH coefficients occupy fairly discrete portions of a DCA ordination (Figure 22.1), with only a small degree of overlap (but note that examples with co-dominance of *Cladium* and *C. elata* were mostly assigned by MATCH to S1). Within S2, the two sub-communities recognised by Rodwell (1995) show a clear tendency to occupy rather different portions of the ordination, but only along Axis 3. Samples with their highest coefficient allocated generically to S2 are scattered across the range of both sub-communities, even when all three axes are considered.

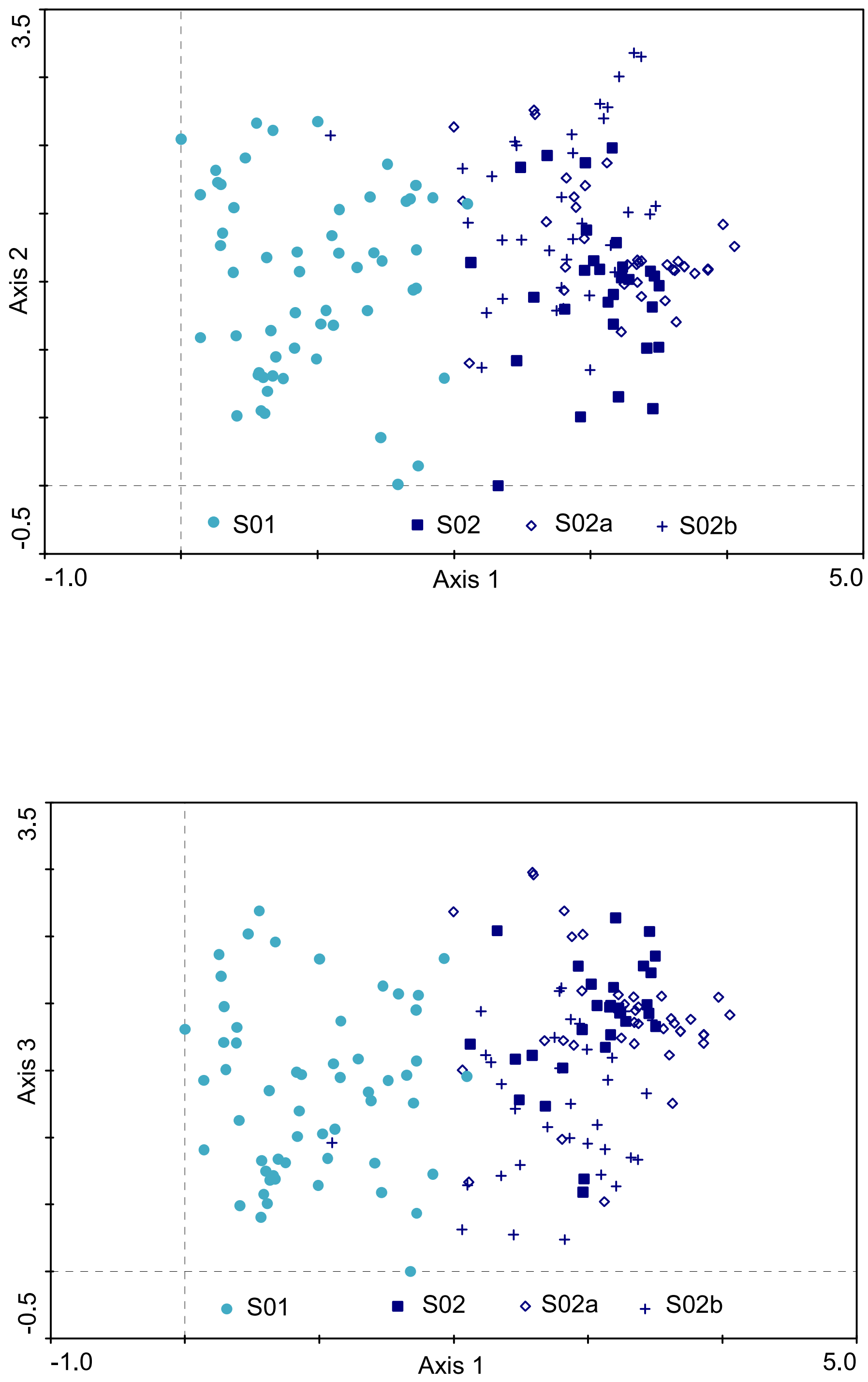


Figure 22.1 Plots of samples of *Carex elata* sedge swamp (S1) and sub-communities of *Cladium mariscus* swamp and sedge beds (S2, S2a, S2b) on Axes 1~2 and 1~3 of a DCA ordination

22.1.2 Floristic composition

These species-poor communities of wet fens and swamps are essentially defined by their dominant species and by the absence of species typical of less wet fen habitats. The occurrence of species of shallow water and swamp (such as *Menyanthes trifoliata, Sparganium minimum*) can provide some positive characterisation, but such species are absent from many examples. There can be considerable intergradation of dominance of the two defining species in the field.

S1 is typically dominated by tussocks of *Carex elata*, whilst S2 is a tall sedge community of wet fens and swamps characterised by the dominance of *Cladium mariscus.* Both communities are generally species-poor and support rather few uncommon species (Table 22.1, Table 22.2), though some stands of S1 are important in supporting populations of the rare grass *Calamagrostis stricta* (which often grows on the tops of the *C. elata* tussocks). The absence of species found in drier fens and the occasional occurrence of some tall herbs and species of shallow water/swamp help to provide positive characterisation.

Rodwell (1995) recognises no sub-communities within S1 but two sub-communities of S2: *Cladium mariscus* sub-community (S2a); *Menyanthes trifoliata* sub-community (S2b).

Table 22.1 Number of species recorded in samples of S1

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	115	10.4	0.23	1	26
Mire species (spp 4 m^{-2})	69	7.8	0.22	1	20
Rare mire species* (spp 4 m^{-2})	10	1.4	0.10	0	5

* These include: *Calamagrostis stricta, Carex appropinquata, Carex elata, Cladium mariscus, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Ranunculus lingua, Stellaria palustris, Utricularia minor.*

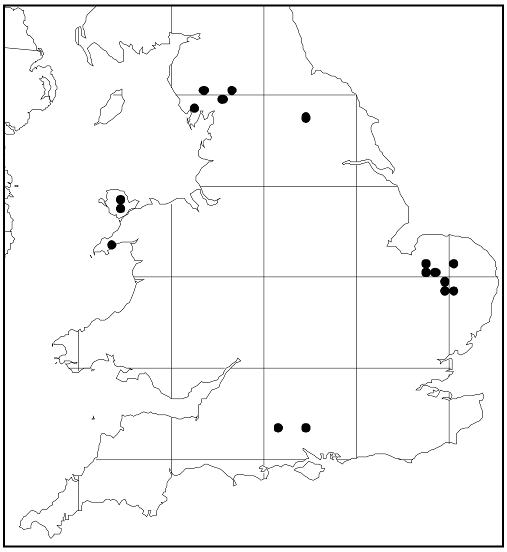
Table 22.2 Number of species recorded in samples of S2

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	106	6.1	0.13	1	16
Mire species (spp 4 m^{-2})	72	5.3	0.13	1	15
Rare mire species (spp 4 m^{-2})	15	1.8	0.06	0	4

* These include: *Calamagrostis canescens, Carex diandra, Carex elata, Carex lasiocarpa, Cicuta virosa, Cladium mariscus, Eleocharis uniglumis, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Potamogeton coloratus, Ranunculus lingua, Sium latifolium, Stellaria palustris, Thelypteris palustris, Utricularia intermedia*

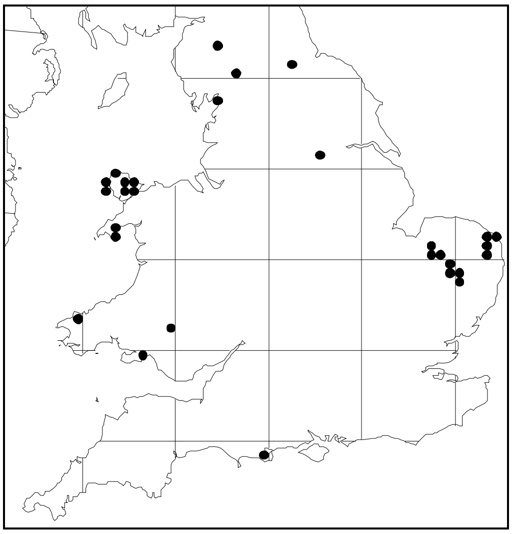
22.1.3 Distribution

The two main centres of both communities are East Anglia and Ynys Môn (Figure 22.2and Figure 22.3). Both are especially characteristic of many of the wet ground hollows (pingos) in central and Western Norfolk. Elsewhere they grow around the margins of lakes and pools, in overgrown ditches and reflooded peat pits. S2 in particular is an important recolonist of some reflooded turf ponds in Broadland. S2 is the more widely distributed of the two communities (recorded from 48 sites), occurring also around pools in the West Midlands, NW England, Yorkshire and parts of Scotland (particularly in the west), whilst S1 is more localised and recorded from only 21 sites. Both communities are considerably less widespread than their nominative species, which both occur widely in some less wet fen vegetation types.



(from FenBASE database)

Figure 22.2 Distribution of S1 in England and Wales



Data from FenBASE database

Figure 22.3 Distribution of S2 in England and Wales

22.1.4 Landscape situation and topography

The communities are associated with shallow depressions and occur in small basins or around the margins of lakes and pools. They occur in a number of valleyhead locations, but within these mostly occupy shallow ground hollows, some of which may be pingos or other ground ice depressions, or occluded ditches. Examples recorded from floodplains were all in reflooded peat workings and occluded ditches.

22.1.5 Substratum

The communities occasionally form semi-floating root-mats, but most examples are rooted in fen peat or in muddy basin and dyke sediments. Thickness of peat infill ranges from skeletal in examples around the margins of shallow ground hollows, to deep (more than four metres) in some examples in turf ponds and ditches on floodplains. Some examples around lakes and in basins have developed hydroserally over lake muds and marls.

22.1.6 Zonation and succession

Examples of both communities occur peripheral to open water and can form part of terrestrialisation sequences. Particularly clear zonations occur around some of the shallow ground hollows in West Norfolk. Both S1 and S2 can directly adjoin open water, or they may occur in the sequence: open water > S2 > S1. However, frequently such neat sequences do not occur and the distribution of S2 in particular can be idiosyncratic, neither forming clear zones nor occupying discrete ranges of water table. *Carex elata* and *Cladium* quite frequently form mixed swamps, which are not referable clearly to either community. In some cases, entire basins can be occupied by one or both of the communities. Both communities can be truncated on the landward margin and are adjoined by dry ground, but frequently they grade outward into another community, most often M22. In some sites (such as Cors Goch (Anglesey), Cors y Farl (Anglesey), Sunbiggin Tarn (Cumbria)), S2 may grade outwards into M9-2 and at Newton Reigny (Cumbria), a patch of *Cladium (*which might perhaps be considered to be M2) is embedded within M9-2 (*Carex diandra–Calliergon* mire) in a turf pond. In Broadland, S2 sometimes occupies the wettest locations in turf ponds, and can grade out into various other communities, including M9-3 (*Carex diandra–Peucedanum palustre* mire) and various, mostly *Cladium*-dominated, forms of *Phragmites australis–Peucedanum palustre* tall herb fen (S24).

Whilst S1 and S2 sometimes occur in close proximity, or intermingled, in some locations they occupy separate ground hollows for reasons that are not entirely apparent. In certain ground depressions in West Norfolk, S1 can be particularly associated with hollows surrounded by a more acidic drift, and with a lower water pH than S2, suggesting an association with slightly less base-rich conditions than S2 (and also raising questions about the precise groundwater source to the hollows). Another difference between the communities is that *Carex elata* is much more shade-tolerant than *Cladium*, raising the possibility that the differential distribution of the communities may sometimes relate to past habitat conditions (shaded *versus* unshaded).

The occurrence of clear community zonations around pools is not necessarily indicative of terrestrialisation sequences, but stratigraphical studies suggest that both S1 and S2 can form pioneer swamp communities which become replaced serally by a less wet form of fen. S1 is also particularly prone to direct precocious colonisation by woody plants, which sometimes readily gain a foothold on the tussock tops, and entire basins of swamp carr based on *Carex elata* tussocks sometimes occur. By contrast, scrub invasion of S2 is often very slow, first because of the wet conditions and then because of the strong dominance by *Cladium*, expressed in terms of the thick leaf canopy and, particularly, the accumulation of dense mattresses of dead, decay-resistant leaves.

In one site (Pilmoor, Yorks) there is clear stratigraphical and visual evidence of the development of a *Sphagnum*-dominated vegetation (M5) over former S1 swamp. Such acidification has no known counterparts, and may be a response to a lowering of the telluric water level within the basin, so that the surface is now largely, if not exclusively, rain-water fed.

22.2 Water supply mechanism and conceptual model

S1 and S2 communities are invariably associated with wet, swampy conditions in fens. Many of the samples included in this study occur in hollows that show considerable vertical water level fluctuation (WETMEC 12, Fluctuating Seepage Basins such as Foulden Common, East Walton Common (both in Norfolk)) and may episodically dry out. Others are associated with more constant inputs of groundwater (WETMEC 13, Seepage Percolation Basins such as Cors Erddreiniog (Anglesey), Cors Goch (Anglesey), Great Cressingham Fen (Norfolk), Newton Reigny (Cumbria)) or surface water (WETMEC 6, Surface Water Percolation Floodplains such as Catfield Fen (Norfolk)). Examples in this context occur not only in peat cuttings, but can form the main vegetation of some occluded dykes.

In valleyhead fens, stands of both communities are generally mainly groundwater-fed. Examples of S2 forming part of the swamp fringe around Barnby, Martham and Upton Broads also appear to receive groundwater inputs, at least in part, but some turf pond examples in Broadland appear to be primarily fed by surface water.

Most groundwater-fed examples of the two communities are associated with base-rich bedrocks (Chalk or Carboniferous Limestone), but the majority are not obviously associated with strong springs, and their wetness seems to be determined by the intersection of the topography with the water table. However, the precise source of the groundwater supply is not always clear. For example, in some ground depressions in the valleyhead sites of West Norfolk, the relative role of water from Chalk and Drift is not well understood and may vary within individual sites.

22.3 Regimes

22.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 22.3, together with together with mean recorded values for summer water table associated with stands of S1 and S2.

Table 22.3 Mean rainfall, potential evaporation and summer water table for S1 and S2 stands

		Mean	Minimum	Maximum
Rainfall (mm a^{-1})	S1	710	622	994
	S2	827	604	1,348
Potential evaporation (mm a^{-1})	S1	608	601	613
	S2	596	467	646
Mean summer water table (cm)	S1	6.8	–5	20
	S2	12.9	–20	50

Water levels associated with both S1 and S2 are well above the surface for some, sometimes all, of the year (Table 22.3). In a few cases the vegetation is semi-floating, but most examples are rooted to (often soft) underlying muds and, in the case of some deeper hollows, the outer edge of the community appears to be depth-limited and grades into open water. S2 can extend into deeper water than S1, but generally the two communities occupy a similar water depth range.

In some East Anglian valleyhead fens, gauge board readings point to water level fluctuations in some pools (such as Foulden Common) of up to two metres, indicating periodic deep flooding or sub-surface water tables (or both). Although good comparative data do not exist, there is strong reason to suspect that the development of aquatic macrophytes (such as *Hydrocharis morsus-ranae*, *Sparganium minimum*) in association with S2 is related to the degree to which they dry out. The impact of water level fluctuation does, of course, depend upon the position of the water table relative to the surface. For example, whilst the water table remains above the surface, even quite substantial changes in level (such as 50 cm) may have only limited impact upon the vegetation, provided it remains within the depth tolerances of the main species. However, a comparable reduction of water level below the surface can have much greater repercussions, especially on the survival of aquatic species.

An association of *Carex elata* vegetation with a fluctuating water table has been noted by Haslam (1965). However, whilst the present dataset supports the observation that S2 can occur in deeper water than S1, it provides no evidence that water levels in *Cladium*-dominated depressions are necessarily less strongly fluctuating than those in *C. elata*-dominated examples.

Examples of the S1 and S2 community can occupy a wide range of conditions, from wet swamp to relatively dry sedge beds, though the actual range depends upon the perceived compass of the communities, particularly in the case of S2. In addition, specific time-series data for stands of S1 and S2 are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal conditions

- Water levels associated with S2 are typically well above the surface for some, sometimes all, of the year. *Cladium* apparently grows best when the water table remains between around 15 cm below ground and 40 cm above. Standing water in winter may help to protect the growing point from frost damage (Conway, 1942); this may explain why *Cladium* is more exclusively confined to the swamp habitat of S2 (as opposed to *Cladium*-rich fen) towards the northern end of its range. S1 vegetation does not grow in as deep water as some examples of S2, but otherwise it has a similar habitat range.

- S1 and S2 stands that are associated with water tables at or above the fen surface all year round can support greater numbers of aquatic macrophytes.

- Where the vegetation is semi-floating, there is greater accommodation of water level fluctuation than when it is rooted to a solid substratum, but semi-floating examples of both of these communities are infrequent.

- The tussocky nature of S1 swamp means that it can be prone to scrub colonisation (of the tussock tops) even when water tables are high. It is presumed that grazing management may be instrumental in preventing this process. The tussock tops also provide a niche for the rare grass *Calamagrostis stricta.*

Sub-optimal and damaging conditions

- *Cladium* seems to be limited by water depth. Protracted sub-surface water tables or inundation greater than around 40–50 cm may lead to a loss of *Cladium* vigour, but not necessarily a loss of the species.

- Where the vegetation is semi-floating, ongoing hydroseral processes may lead to development of communities such as M9-2 and M9-3, with an associated increase in species diversity. [This may not be considered damaging]

- Deep inundation will result in loss of sedge cover and generation of open water.

- Populations of aquatic macrophytes will be absent from stands that are summer-dry for protracted periods.

- Sub-surface winter water tables and strongly sub-surface summer water tables will lead to a loss of *Cladium* and increased representation by dryland species. At Pilmoor (Yorks) this process appears also to have led to acidification, and *Sphagnum* expansion, in former S1 swamp.

- Peat drying and degradation may lead to development of rank fen, becoming wooded without management.
- The tussock-top niche for *Calamagrostis stricta* provided by *Carex elata* is relatively dry and the reason for the association of the grass with this location is not certain. The swampy conditions associated with S1 may be largely irrelevant to its occurrence, or they may have an indirect relationship by helping to exclude other plant species and, possibly, grazing animals.

22.3.2 Nutrients/hydrochemistry

Table 22.4 pH, conductivity and substratum fertility measured in stands of S2

Variable	Mean	SE	Minimum	Maximum
Water pH	6.5	0.06	5.7	7.6
Soil pH	6.3	0.10	5.0	7.2
Water conductivity (µS cm^{-1})	1,616	14.4	157	7,530
Substratum fertility[1] (mg phytometer)	7.9	0.48	3	12

S2 is typically found in base-rich, oligotrophic to mesotrophic conditions (Table 22.4). Mean substratum fertility of 7.9 mg phytometer (± 0.5) for S2 stands is rather low and compares with a mean of 11.9 mg for its *Phragmites*-dominated swamp (S4) (maximum fertility of 41 mg). Whilst *Phragmites* can be a swamp dominant in low-fertility conditions, it is also widely found in eutrophic and hypertrophic circumstances, whereas *Cladium* and *Carex elata* swamp appear consistently to be a feature of low-fertility locations. S2 occurs over a wide range of electrical conductivity. Particularly high conductivities were recorded in association with *Cladium* in the Thurne valley of Broadland, especially at Brayden Marshes.

Wheeler and Shaw (1991a) report that *Cladium* dominated stands have a high April standing crop (above 250 g m^{-2}) compared with other tall herbaceous fen types, but a modest April to September standing crop increment (at around 600 g m^{-2}). This reflects the winter-green, long-lived character of *Cladium* foliage, and the relatively low fertility conditions.

Too few hydrochemical data are available from S1 to permit meaningful generalisations to be made. The community can occupy conditions as base-rich as those in which S2 occurs (for example, a water pH of 7.5 was measured in S1 at Llyn wyth yr Eidion (Cors Erddreiniog, Anglesey). However, in other circumstances *Carex elata* swamp has been recorded from relatively base-poor conditions, without *Cladium* (Table 22.5).

Table 22.5 Chemical characteristics of water samples collected from *Carex elata* vegetation at Pilmoor (North Yorkshire) (November, 2003) and Foulden Common (Norfolk) (December, 1999)

Locality	Vegetation	Water level (cm)	Water pH	K_{corr} (µS cm^{-1})	HCO3 (mg l^{-1})
Pilmoor, S side of sump	*Carex elata–C. rostrata–*	–18	5.4	322	87.8

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.): low fertility < 8 mg, high fertility > 18 mg.

	Sphagnum				
Pilmoor, near centre	*Carex elata* swamp in small glade	–24	5.3	430	63.0
Foulden Common, Pingo, E of road (Drift fed?)	*Carex elata* / *J. effusus* swamp	*c.* +20	6.4	237	68.3
Foulden Common, Pingo, W of road (Chalk fed?)	*Cladium mariscus* swamp with *Carex elata*	*c.* +15	7.5	835	555.7

Values are means of five replicate samples

22.3.3 Management

S2 tends not to receive any management, except where it occurs alongside or within other communities (M9-3 and S24) that are traditionally mown for sedge and reed. Timing of management, if it occurs, is critical – winter floods can significantly inhibit re-growth if *Cladium* is mown too late in the year and cut stems are subsequently submerged. Where relatively dry, repeated summer cutting may result in development towards mixed sedge/litter fen or fen meadow (such as S24, S25, M24).

Some stands of S1 and S2 are sometimes grazed by cattle or horses.

22.4 Implications for decision making

22.4.1 Vulnerability

Figure 22.4 outlines some of the possible impacts of changes to the stand environment. The principal vulnerabilities are probably to water level change – either drawdown or flooding – and eutrophication. Many stands are unmanaged, but the dereliction of wider vegetation management practices may result in some stands of S2 becoming rank with much accumulated litter. Eutrophication without drying may lead to invasion by *Typha* and *Phragmites*, whilst a fall in water levels leading to peat drying and degradation may lead to loss of certain wetter vegetation components such as aquatic macrophytes (where they occur), followed by development of rank fen. Examples of both communities can become wooded without some form of management, but this process can be slow in S2, because of the high water tables and constraints on scrub establishment caused by the dense vegetation and persistent litter.

The possible effects of environmental change on stands of S1

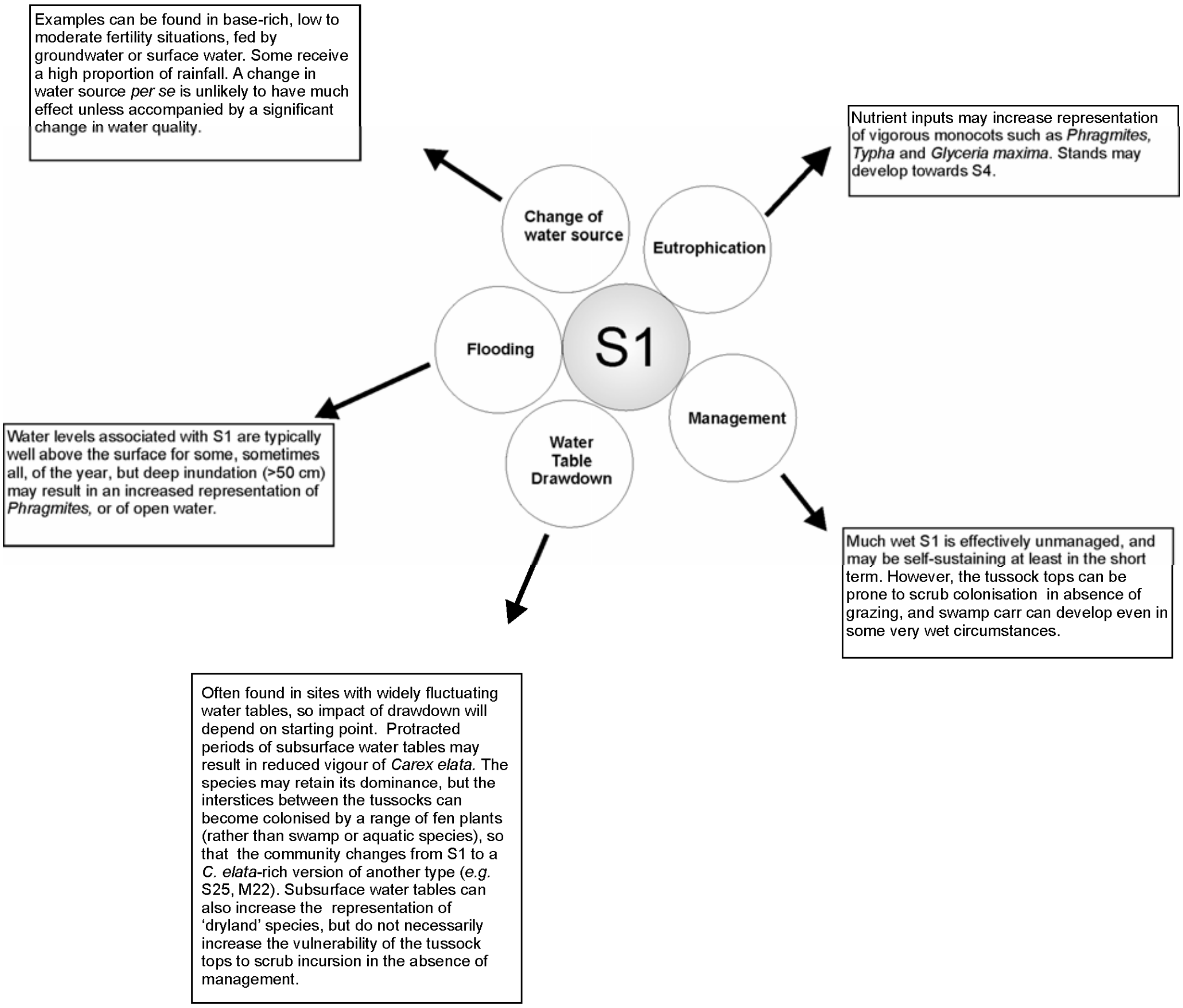


Figure 22.4 Possible effects of environmental change on stands of S1

The possible effects of environmental change on stands of S2

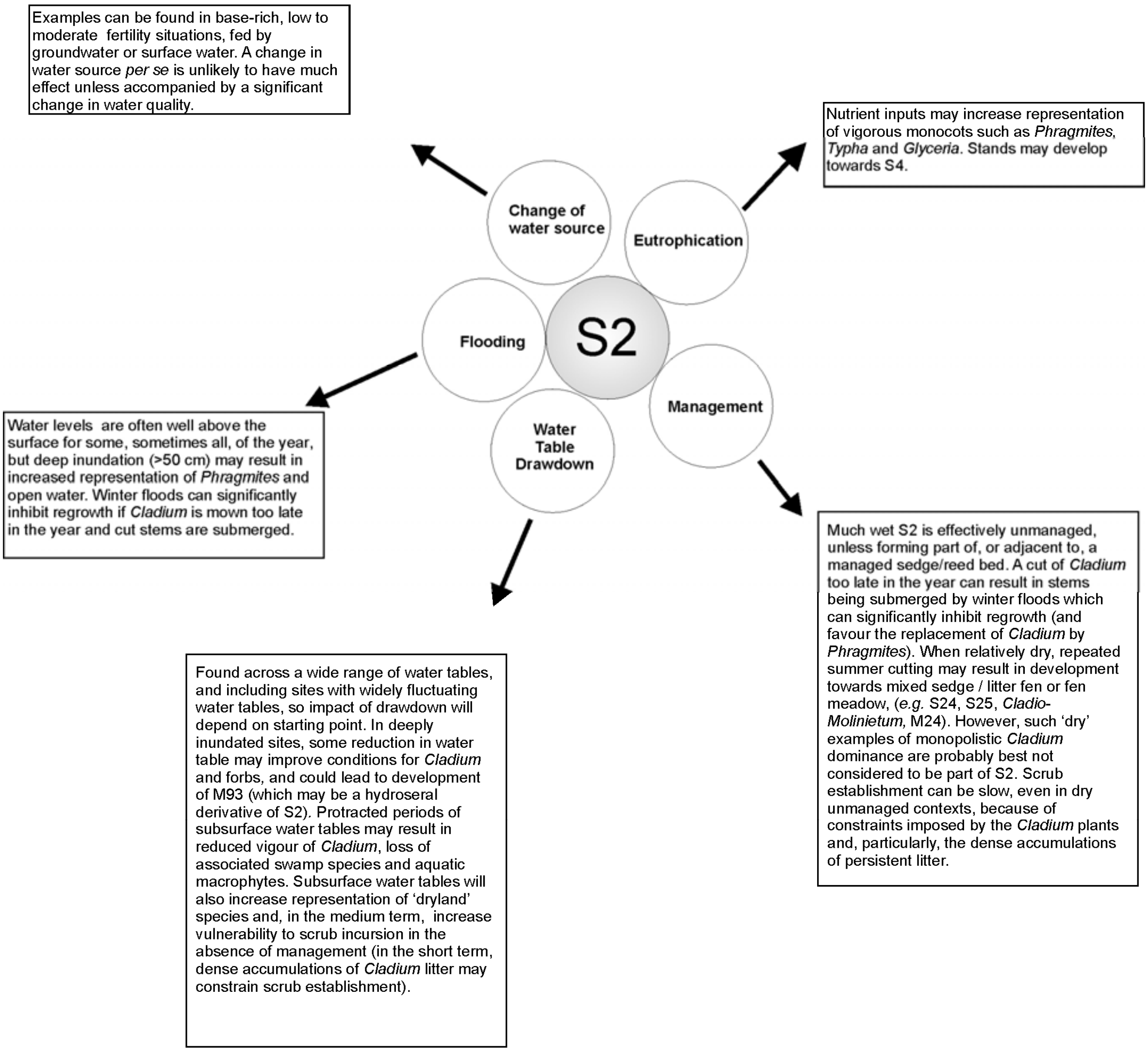


Figure 22.5 Possible effects of environmental change on stands of S2

22.4.2 Restorability

As with all restoration measures, likely success depends on the cause of the damage and how far the starting conditions deviate from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). The potential for restoring stands of S1 or S2 to dehydrated or derelict sites is largely untested (most pertinent fen restoration trials are at a relatively early phase), though the propensity for *Cladium* swamp to spontaneously colonise re-flooded turf ponds in the past is encouraging.

22.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- Rather few environmental data are available for S1 and S2, especially in the swamp form which is discussed here.
- There are currently virtually no data to better inform the temporal water table characteristics of S1 and S2 stands. Time series of dipwell (or gauge board) measurements are required to fill this gap.
- In order to make predictions on the vulnerability of S1 and S2 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at representative sites.
- The potential for restoring stands of S1 and S2 to dehydrated or derelict sites is largely untested.
- Data on the spatial extent of S1 and S2 are lacking.
- Possible differences in environmental conditions influencing the sub-communities have not been explored here.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

23 S24 (*Phragmites australis*–*Peucedanum palustre*) tall-herb fen

23.1 Context

Examples of the S24 community have been included within the ‘chalk-rich fen dominated by saw sedge’ SAC feature (although not all stands of S24 necessarily support *Cladium mariscus*). [See Tables 3.1 and 3.3]

23.1.1 Concept and status

S24 was first defined as a vegetation unit for Britain by Wheeler (1980a) as the *Peucedano-Phragmitetum*. This was a rather variable unit, with a number of distinct sub-associations, but it emerged from the multivariate data analysis as a distinct and coherent syntaxon, defined by a recurrent assemblage of characteristic species (including *Calamagrostis canescens, Carex elata, Peucedanum palustre* and *Thelypteris palustris*). Rodwell (1995) similarly recognised the “strong internal cohesion” of the unit and adopted it largely in its original form, though with some modification.

The classification solution adopted by Wheeler was at variance with some existing classification schemes of tall fen vegetation on the European mainland. There had been a tendency amongst many continental workers to recognise suites of tall fen communities based upon particular dominant species[1], but Wheeler’s *Peucedano-Phragmitetum* included vegetation dominated both various species (mainly *Phragmites australis* and *Cladium mariscus*, but also *Calamagrostis canescens, Glyceria maxima* and so on) within the one unit. The reason for this difference of solution may partly be because Wheeler’s classification was strictly based on floristic similarities (using multivariate procedures) and partly because of real differences in the character of the vegetation concerned. For example, *Cladium* is a good deal less widespread in fens on the European mainland than in parts of Britain and appears to have a more restricted vegetational and environmental range, whereas in Broadland *Cladium* and *Phragmites* are, in some environmental circumstances, interchangeable dominants determined by management. In this situation, the inclusion of reed- and sedge-dominated vegetation within a single unit made intuitive sense, as well as best reflecting the floristic inter-relationships. This perspective still holds good, and there is no known reason to rescind this approach, though there are other reasons why, as it stands, the *Peucedano-Phragmitetum* may not represent the optimal classification solution for the range of vegetation it encompasses.

One problem with the *Peucedano-Phragmitetum* is that it is variable, accommodating a wide range of floristic and environmental conditions, which makes the specification of usable environmental thresholds particularly difficult for the community as a whole. In a sense, the unit is hoisted on its own petard, in that the characteristic species which give it strong floristic cohesion and which make it a readily identifiable unit occur over a rather wide habitat range.

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[1] For example, in the scheme advanced for the Netherlands by Westhoff and den Held (1969) stands of *Peucedano-Phragmitetum* dominated by *Cladium* would probably have been placed in the *Cladietum marisci,* whereas many of those dominated by *Phragmites* would probably have been allocated to the *Thelypterido-Phragmitetum*. For yet others, their location in the Dutch scheme was far from obvious.

Rodwell (1991b, 1995) made a significant reduction in the range of Wheeler's *Peucedano-Phragmitetum* by removing the *P.-P. caricetosum* to his M9. Unfortunately, he did not provide a satisfactory syntaxonomic location for this vegetation within M9, but the validity of his approach has been recognised here by the allocation of this sub-association to M9-3 (see account for M9-3). However, it could be argued that further splits could be made within S24. For example, the *Schoenus nigricans* and *Myrica gale* sub-communities (S24f and S24g) have quite strong floristic and environmental links with *Molinia caerulea–Cirsium dissectum* fen meadow (M24) and a case could be made for considering them as sub-units of that community. This would, however, require considerable data re-analysis to explore the desirability of this approach, which would effectively run counter to the strongest floristic affinities of the units.

Another limitation of the *Peucedano-Phragmitetum* is that more detailed studies of the vegetation of Broadland have revealed the existence of distinctive varieties of vegetation which are not well accommodated within the floristic sub-structure of this community (or of any other). For example, the marginal fens in parts of Broadland support vegetation with strong affinities both to S24 and to *Carex rostrata–Potentilla palustris* tall herb fen (S27), but which in the current *schema* is not well accommodated within either unit.

A further difficulty with the unit, specifically as S24, is that samples with highest MATCH coefficients with S24 show much floristic overlap with those with highest MATCH affinities to *Phragmites australis–Eupatorium cannabinum* tall-herb fen (S25), as shown by a DCA ordination (Figure 23.1). To some extent this problem has been created, certainly exacerbated, by Rodwell (1995) who allocated some of the vegetation previously placed by Wheeler (1980a) within his *Angelico-Phragmitetum* (a progenitor unit of S25) into S24, thereby considerably reducing the floristic cohesion of the latter and enhancing the difficulty of separating it from S25.

The main conclusions that emerge from these considerations are that: (a) a re-consideration, and possible revision, of the status and compass of S24 in relation to similar units is required; (b) the ecological range of S24 as currently constituted is wide; and (c) it has limited value as a ecological unit for which meaningful environmental thresholds can be specified.

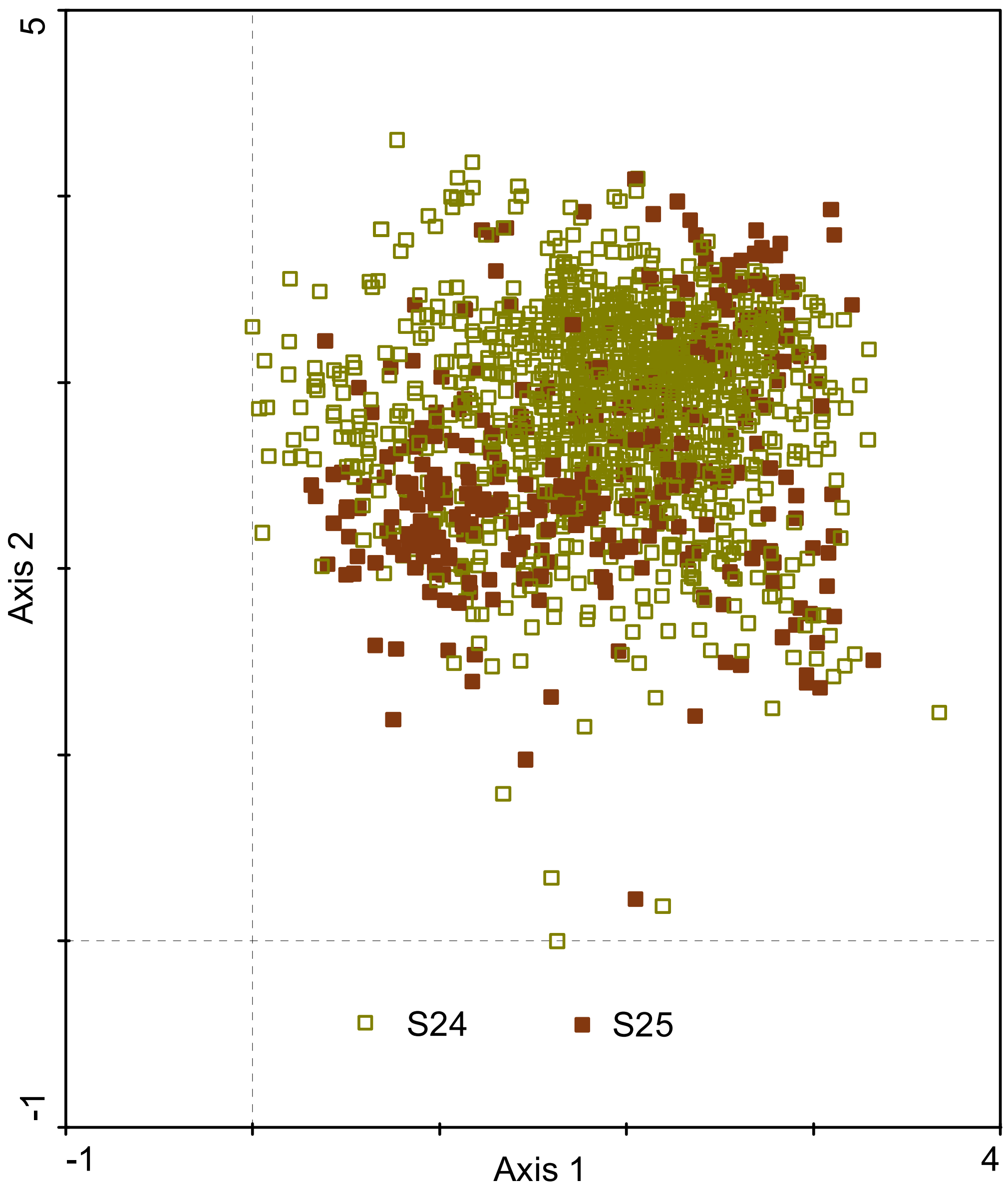


Figure 23.1 Plots of samples allocated to *Phragmites australis–Peucedanum palustre* tall herb fen (S24) and to *Phragmites australis–Eupatorium cannabinum* tall-herb fen (S25) on Axes 1~2 of a DCA ordination

23.1.2 Floristic composition

Tall herbaceous fen community with monocotyledons, notably *Phragmites australis* and *Cladium mariscus,* providing the major structural component. Variable in composition, with stands ranging from species-poor to species-rich (Table 23.1) and with a wide range of associated tall forbs such as *Lysimachia vulgaris, Eupatorium cannabinum* and *Filipendula ulmaria*. The community is given cohesiveness by the recurrence of such species as *Calamagrostis canescens, Carex elata, Peucedanum palustre* and *Thelypteris palustris.* It supports many rare or infrequent species (see Table 23.1) and is the main community for *Peucedanum palustre,* the food plant of the swallow-tail butterfly (*Papilio machaon*).

Rodwell (1995) recognises six sub-communities of S24: *Carex paniculata* sub-community (S24a); *Glyceria maxima* sub-community (S24b)*; Symphytum officinalis* (S24c); typical sub-community (S24d); *Cicuta virosa* sub-community (S24e); *Schoenus nigricans* sub-community (S24f).

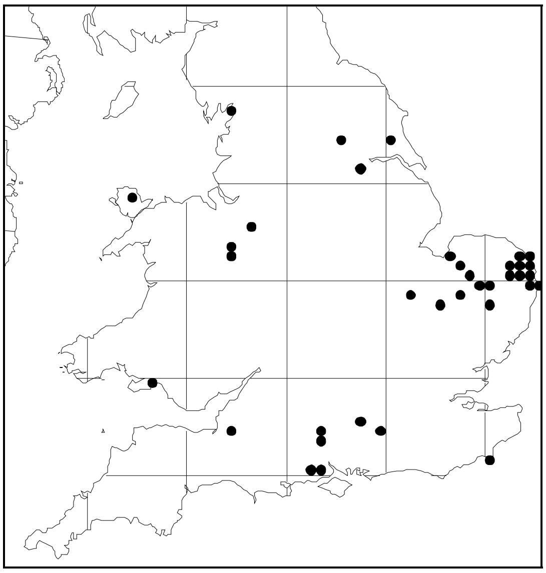
Table 23.1 Number of species recorded in samples of S24

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	384	17.4	0.05	2	46
Mire species (spp 4 m^{-2})	147	14.5	0.05	1	43
Rare mire species* (spp 4 m^{-2})	30	3.4	0.03	0	13

* These include: *Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Campylium polygamum, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Cicuta virosa, Cinclidium stygium, Cladium mariscus, Dactylorhiza praetermissa, Dryopteris cristata, Eleocharis uniglumis, Epipactis palustris, Lathyrus palustris, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Plagiomnium elatum, Plagiomnium ellipticum, Potamogeton coloratus, Pyrola rotundifolia, Ranunculus lingua, Rhizomnium pseudopunctatum, Sium latifolium, Sonchus palustris, Stellaria palustris, Thalictrum flavum, Thelypteris palustris*

23.1.3 Distribution

In England and Wales, the S24 community has been recorded from 115 wetland sites (FENBASE database) (Figure 23.2). It is very localised and primarily based in Broadland (where it is widespread and extensive), with outliers in a few other East Anglian sites (such as Cranberry Rough and Swangey Fen). It also occurs at Wicken Fen (Cambridgeshire), though in a form which is rather close to M24, and impoverished examples can be found at Woodwalton Fen (Cambridgeshire). The community occurs fragmentarily in the Somerset Levels and rather similar species assemblages occur in various other places (such as Crymlyn Bog (Glamorgan), Test valley (Hampshire), and in small patches associated with some of the West Midlands meres), but the syntaxonomic relationship of these stands to S24 remains to be clarified.



Data from FenBASE database

Figure 23.2 Distribution of S24 in England and Wales

23.1.4 Landscape situation and topography

The majority of examples occur in floodplain situations, where they form the main herbaceous vegetation over much of the Broadland fens and occupy some of the residual undrained surfaces in Fenland and the Somerset Levels. Some variants occur in basins and troughs.

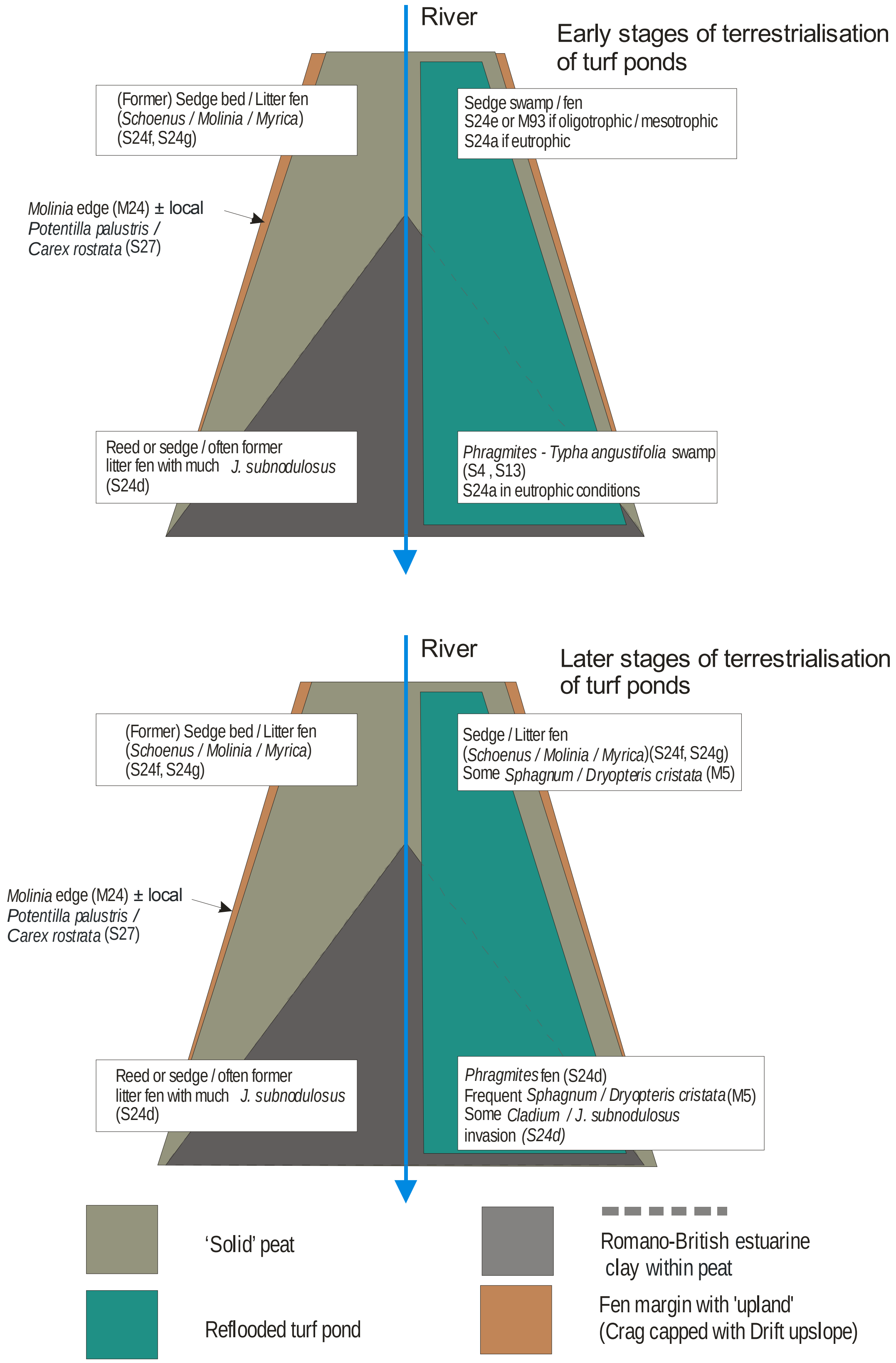
23.1.5 Substratum

S24 can occur on solid fen peat or as a quaking or semi-floating turf pond infill over fen peat. In many locations the peat is continuous and deep (more than four metres), and often has a lower layer of rather dense brushwood peat, but in Broadland the alluvial infill often contains a layer of estuarine clay some 50 to 100 cm bgl. Hydroseral examples, both natural and around deep peat workings, may occur over a considerable accumulation of lake muds and, occasionally, marl.

23.1.6 Zonation and succession

Some examples of S24 effectively occur as isolated blocks in residual wetland areas adjoined by, and sometimes elevated above, agricultural land on drained, former wetland surfaces, and are essentially unconformable with their surroundings. In some of these sites, such as Wicken Fen, the S24 vegetation is rather dry and impoverished. Elsewhere, and particularly in Broadland, S24 occurs widely over relatively intact floodplains. Even here, however, natural zonations are often difficult to detect, because the precise character of the vegetation has been much influenced by management past and present, and in places by past peat removal, producing a patchwork of stands of varying character. Nonetheless, there are some underlying environmental gradients, relating particularly to the proximity of rivers and presence or absence of estuarine clay, and it is possible to detect some broad vegetation patterns derived from either the development of different sub-communities of S24, or the juxtaposition of S24 with others. Figure 23.3 provides a much simplified illustration of broad zonation patterns in the River Ant valley (Broadland), and may be applicable to parts of the River Bure and River Thurne. However, in the Yare valley rather different communities and zonations occur. *Glyceria maxima* is prominent in parts of these fens, and some of the vegetation is referable to S24b. However, much of the vegetation is dominated by reed, to form stands variably referable to S24b, S24d, S25 and even S4. Reed is particularly prominent close to watercourses and at Wheatfen, there is a tendency for a gradual decline in reed dominance and productivity (and an inverse increase in species richness) with distance from the River Yare.

The preceding observations relate to zonations associated with solid peat and shallow turf ponds, but some of the best known zonations involving S24 occur in hydroseral contexts around some of the broads. These were elucidated from stratigraphical evidence by Lambert (1946, 1951) and have since been described by Rodwell (1995) in terms of NVC communities. In essence, S24 can form a hydroseral zone on the landward side of various swamp communities, including S2, S3, S4 and S5, with a different sub-community of S24 often being tied into a particular type of progenitor swamp: S2 > S24e or S24d; S3 > S24a; S4 > S24d; S5 > S24b. However, the occurrence of *any* significant extent of S24 in these hydroseral zonations is largely dependent on mowing management, which not only leads to an artificial prolongation of the herbaceous fen phase of the seral sequence, but also modifies its species composition. In the absence of such management, S24 is likely to be only fragmentarily developed in hydroseral sequences around the broads, and be more comparable with small fragments of fen found in the compressed zonations around some of the West Midland meres.



Fen woodland, dereliction communities and hydroseral sequences around broads have been omitted for clarity

Figure 23.3 Simplified scheme of herbaceous vegetation in the River Ant valley, Broadland, in relation to the presence of turf ponds and estuarine clay

23.2 Water supply mechanism and conceptual model

The majority of stands of S24 appear to be surface water-fed, primarily through periodic river flooding. However, the community also occurs in similar conditions created by groundwater inputs (such as East Ruston Common, Swangey Fen and Upton Fen (Norfolk)). In other cases (such as Sutton Broad) some groundwater contribution seems likely, but has not been demonstrated. Surfaces on solid peat that are distant from dykes and watercourses may naturally experience quite low water tables in summer, because of low rates of lateral recharge through the peat, and their hydrodynamics may be strongly influenced by rainfall events and evapotranspiration. In some sites on dysfunctional floodplains (such as Wicken Fen (Cambridgeshire)), the surface of the peat appears now to be fed just by precipitation, creating the paradox of an ombrotrophic fen in which the base-rich peat can be prone to surface acidification. Drying-induced acidification is a particular feature of some examples with sulphide-rich peat, which can occur particularly in locations where a shallow layer of peat is underlain by estuarine clay.

Examples of S24 on fairly recent turf pond infills tend to experience higher summer water tables than those on undug peat, apparently because of their lower surface level, higher rates of water recharge through the more transmissive sub-surface peat infill or, in some instances, buoyant mats of vegetation. The differences between examples on undug peat and turf-pond peat tend to be reflected in the sub-communities that occur, where sub-communities particularly associated with solid peat tend to have the lowest mean summer water tables. The mean summer water table associated with examples of S24 in reflooded peat workings was –9.1 cm, whilst that of examples on solid peat was –23.3 cm.

Forty-six per cent of S24 samples were identified as occurring within WETMEC 5 (Summer-Dry Floodplains such as Wheatfen, Strumpshaw, Catfield Fen (Norfolk)) and 41 per cent within WETMEC 6 (Surface Water Percolation Floodplains such as Sutton Broad, Catfield Fen, Cranberry Rough (Norfolk)). A few examples occurred within WETMECs 7, 8, 13, 15, 16 and 20.

23.3 Regimes

23.3.1 Water regime

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 8.2, together with together with mean recorded values for summer water table associated with stands of S24.

Table 23.2 Rainfall, potential evaporation and water table data for S24 stands

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	611	539	1,140
Potential evaporation (mm a^{-1})	622	562	627
Mean summer water table (cm)	–16.7	–78.4	+3.8

S24 is a highly variable vegetation type, and it can be difficult to disentangle the significance of water regime to vegetation composition from the influence of other factors such as management and substratum fertility.

The mean summer water table varies between sub-communities and with the character of the peat (solid *versus* turf pond infill). Moreover, although good time-series data are not available, it is known from both casual observations and some hydrometric data (Giller,

1982) that there can be considerable between-year variation in summer water tables. For example, some locations where summer water tables of 50 cm bgl have been recorded in dry summers can remain more or less permanently saturated in wet summers, and some river-connected sites can experience occasional summer flooding. Flooding is, however, much more a characteristic of winter conditions when water depths of 50 cm agl, or more, are not uncommon and can sometimes persist for quite long periods.

Optimal water levels

- The summer water level is typically around 15 cm bgl. However, relatively low sub-surface water tables in the summer may be a natural feature of some sites. It is sometimes difficult to know to what extent summer-dry stands are natural or represent remnants of formerly wetter S24.
- The sub-community (S24e) most often associated with a water table at or near the surface all year round on average supports the greatest number of rare species. These tend to occur on quaking or buoyant rafts in infilled turf ponds. However, stands of the drier sub-communities may still support a good number of rare species where soil fertility is relatively low and the vegetation is appropriately managed.
- Winter inundation is a natural feature of many S24 stands. The normal range of winter water tables is probably of little importance to the nature of the vegetation.

Suboptimal or damaging water levels

- Strongly sub-surface winter and summer water tables are outside of the normal range of this community. It can be speculated that this will lead to a loss of wetland species and increased representation by dryland species. Peat drying and degradation can lead to development of rank fen, rapidly becoming wooded without management, especially when it is associated with substantial nutrient release consequent upon mineralisation
- Very wet sites with prolonged summer inundation are likely to be less species-rich than those where the summer water table is sub-surface.
- Winter inundation is a natural feature of many S24 stands. However, deep, prolonged inundation in the spring or summer months is likely to kill some species and lead to development of less diverse swamp communities.

23.3.2 Nutrients/hydrochemistry

Typically base-rich and, particularly where subject to periodic river flooding, conditions generally range between mesotrophic and eutrophic. Figures for pH, conductivity and substratum fertility measured in stands of S24 are presented in Table 23.3.

Table 23.3 pH, conductivity and substratum fertility measured in stands of S24

Variable	Mean	SE	Minimum	Maximum
Soil pH	6.45	0.03	5.3	7.9
Water pH	6.45	0.01	3.7	7.9
Water conductivity (µS cm^{-1})	1,418	2.7	87	7,200
Soil fertility[1] (mg phytometer)	12.0	0.17	5.0	92.0

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.): low fertility < 8 mg, high fertility > 18 mg.

Some examples of S24 have soil and, particularly, water with low pH values. Acidic samples were recorded mostly from the Ant and Thurne valleys in Broadland, and in all cases were near or at the margins of the fens, where low pH values may be a product of characteristics of the adjoining mineral ground, or a consequence of drying-induced acidification. Heathland once formed an upland fringe to some of these fens and, although examples of this are now scarce, some calcifuge species such as *Calluna vulgaris* and *Erica tetralix* persist more widely in some places along the upland margins. Very high EC values have also been recorded in some Broadland sites, primarily in the Thurne valley fens. It is not known to what extent these are a product of brackish river surges or a legacy of the estuarine clays that underlie the peat surface at shallow depth. In most locations they seem unlikely to be a product of saline intrusions into the mineral aquifer underlying the fens.

In Broadland, the Yare valley fens tend to support the more fertile examples of the S24 community compared to the northern valleys, but eutrophic examples can occur anywhere where there is a supply of enriched water or soil, or where drying-induced mineralisation has occurred. The highest measured fertility (92 mg) from S24-like vegetation was recorded from Woodbastwick Fen, from a location which once received enriched mud pumped from the dykes onto the adjoining fen. At East Ruston Common, drying and burning of the peat surface below a former stand of S24 resulted in exceptionally high fertilities (155 mg), which were inconducive to the direct restoration of S24 in this damaged site (though they were still only some 10 per cent of the phytometric fertility value recorded from a commercial, peat-based horticultural compost).

Examples of S24 dominated by *Cladium* tend to occur in locations of relatively low fertility; those dominated by *Phragmites* can occupy a very wide fertility range; and examples with much *Glyceria maxima* are consistently associated with eutrophic soils. Wheeler and Shaw (1991) reported a mean increment (April to September) in dry weight of above-ground standing crop of 681 g dry wt m^{-2} (range: 381 to 1,097 g dry wt m^{-2}).

23.3.3 Management

S24 appears to be a completely artificial vegetation type, derived by the clearance of carr, the management of drained swamp or the recolonisation of reflooded, abandoned turbary. Where stratigraphical data are available, it is clear that present-day S24 locations have mostly been occupied by fen woodland for much of the post-glacial period. Management is essential to maintain the character of S24, and is principally by harvesting reed and sedge for thatching (annual mowing for marsh litter is no longer practised, except very locally and primarily for conservation rather than commercial purposes). The timing and frequency of management can profoundly influence vegetation composition (Wheeler and Giller, 1982a), and winter floods can significantly inhibit regrowth of *Cladium* if it is mown too late in the year and cut stems become submerged. Abandonment of traditional harvesting of marsh crops has led to problems of scrub encroachment across large areas of Broadland and reduction in area of S24. Abandoned sedge beds are generally more resistant to scrub encroachment than abandoned reedbeds with a similar water table, but when in an herbaceous unmanaged state, they are very rank and species-poor (Wheeler and Giller, 1982a). There is anecdotal evidence that scrub encroachment is particularly slow in some of the more brackish sedge beds of the Thurne valley, but little supporting information is available.

23.4 Implications for decision making

23.4.1 Vulnerability

The principal vulnerability of S24 is to scrub encroachment through dereliction of traditional vegetation management practices, although the degree to which this has a significant botanical effect depends upon the sub-community type. Most of the plant species that are particularly characteristic, and diagnostic, of S24 grow in shaded conditions as well as herbaceous fen (reflecting in some cases the origin of this community from former fen carr). Hence, the rationale for management of S24 is often primarily for a general enhancement of biodiversity and for uncommon species that are not especially characteristic of the community (such as *Schoenus nigricans*).

The wide range of habitat conditions associated with S24 makes it difficult to specify vulnerability to drying and eutrophication, but it is clear that in some locations proximity to eutrophic watercourses, deposition of enriched mud slubbed from adjoining dykes and drying-induced mineralisation can be detrimental to the community, and result in a rank, impoverished stand of S24, or conversion to another herbaceous vegetation type (such as S25 or S26).

Some examples of S24 in sites influenced by drainage of the adjoining land (such as Lakenheath Poor's Fen, Wicken Fen) have almost certainly been affected by lowering water tables, but this has not necessarily completely transcended the lower water table threshold of the community. In other locations, such as Broadland, drainage does not seem to be much of threat, though some examples may become summer-dry due to constraints on surface water recharge. In many locations, past peat extraction has apparently resulted in wetter surfaces (occupied by S24) than would naturally have occurred.

Figure 23.4 outlines some of the possible impacts of changes to the stand environment.

The possible effects of environmental change on stands of S24

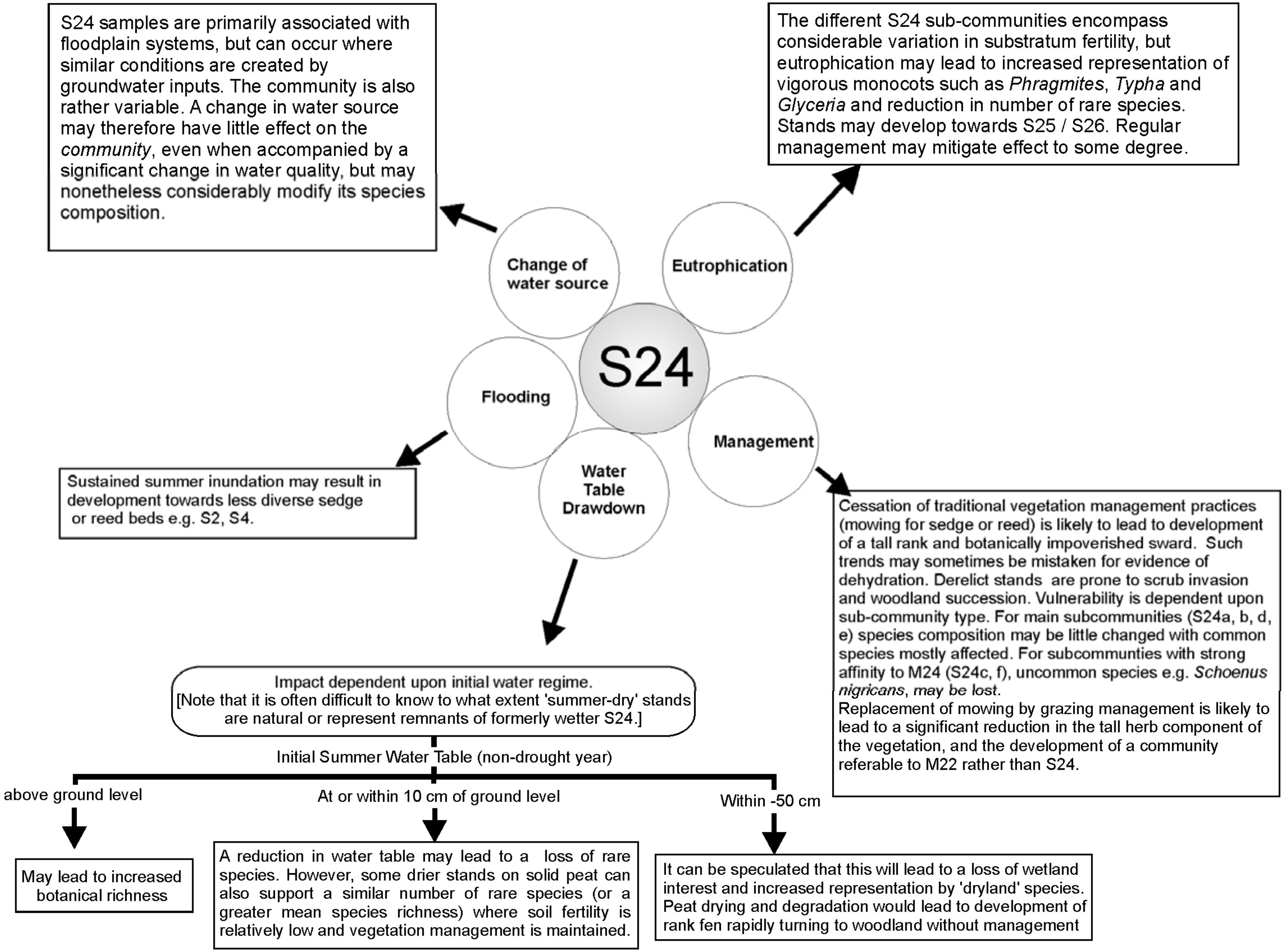


Figure 23.4 Possible effects of environmental change on stands of S24

23.4.2 Restorability

As with all restoration measures, likely success depends on the cause of the damage, and how far the starting conditions deviate from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information ia available on the restoration of S24 stands, but the following observations can be made:

- Scrub removal and reinstatement of a regular vegetation management regime can be expected to improve stand quality when the scrub is fairly recent; the effectiveness and desirability of clearance of mature fen woodland is much less clear.
- The potential for restoring high grade stands to dehydrated sites through re-wetting is largely untested (most pertinent fen restoration trials are at a relatively early phase).
- Sites which have become enriched as a consequence of drying may need the removal of surface layers of peat before restoration of S24 is feasible.

23.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently no data to better inform the temporal water table characteristics of S24 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of S24 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- S24 is very localised in Britain, but the habitat that it typically occupies appears to be considerably wider than the distribution of the community. The reason why apparently suitable habitats do not support S24 is not known.
- Data on the areal extent of S24 are lacking.
- Possible differences in environmental conditions influencing the six sub-communities have not been explored in detail here.
- A re-analysis, re-consideration and possible revision of the status and compass of S24 in relation to related syntaxa is required, and may be a pre-requisite for the identification of meaningful environmental thresholds for examples of this vegetation type.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

24 S27 (*Carex rostrata–Potentilla palustris*) tall herb fen

24.1 Context

Examples of the S27 community have been included in the "transition mire and quaking bog" SAC interest feature. [See Tables 3.1 and 3.3]

24.1.1 Concept and status

Vegetation broadly similar to that encompassed within S27 has been described from Britain by various workers. In particular, Spence (1964) recognised several relevant *noda* from Scotland, and Wheeler (1980a) identified a *Potentillo-Caricetum rostratae* community from lowland England and Wales. Rodwell (1995) subsequently amalgamated these (and other) units into S27, more or less in the sense proposed by Wheeler (1980a).

The main difficulty with S27 is its relationship with M9 (primarily with M9-2). In his original classification, the distinction between the *Potentillo-Caricetum* (S27) and *Acrocladio-Caricetum* (M9-2) made by Wheeler for lowland England and Wales was comparatively clear, because the available dataset admitted some clear floristic distinctions. However, the incorporation of the Scottish data by Rodwell resulted in the inclusion of a number of samples that were intermediate between the two communities, and led to an inevitable blurring of their boundaries. Likewise, additional data from England (particularly Cumbria) and Wales have had a similar consequence in the FENBASE dataset. The relationship between available samples allocated to S27 and M9-2 (M9b) (on the basis of their MATCH coefficients), is shown on a DCA ordination (see Figure 11.1). There is considerable overlap between the two units, and whilst it is possible that a better split could be made than that of the existing S27 and M9b (M9-2), it is also likely that any subdivision would be largely arbitrary.

As well as the existence of samples transitional with M9-2, one of the problems of S27 is that the unit is largely distinguished from M9-2 by negative features (the absence of certain species). It therefore has a tendency to become the default repository for a number of (often species-poor) samples that show some common features, but also considerable variation. In view of this, any attempt to segregate better S27 and M9-2 might best aim to provide a tighter, more consistent, definition of M9-2 rather than to focus on S27.

24.1.2 Floristic composition

Although supporting a large number of species in total, most stands of S27 are relatively species-poor (Table 24.1). The community is fairly heterogeneous, and can have a variety of dominant species, of which *Carex rostrata* is the most frequent. Others include *Carex elata* (especially in stands transitional to S1), *Carex nigra* (especially in stands transitional to fen meadow), *Juncus subnodulosus* (especially in stands transitional to M22) and *Phragmites australis* (especially in stands transitional to various reed-dominated communities). *Potentilla palustris* is often abundant, as – somewhat less frequently – is *Menyanthes trifoliata.* Herbaceous associates are variable, and bryophytes range from near-absent to prominent patches.

Rodwell (1995) recognised two sub-communities of S27: *Carex rostrata–Equisetum fluviatile* sub-community (S27a) and *Lysimachia vulgaris* sub-community (S27b).

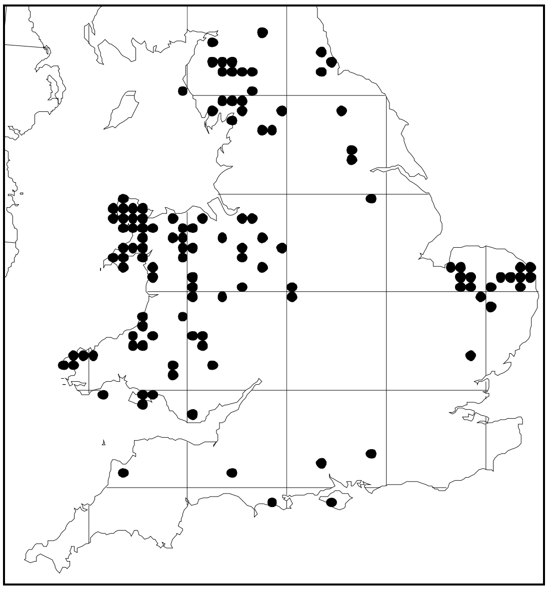
Table 24.1 Number of species recorded in samples of S27

	Total	Mean	SE	Minimum	Maximum
All species (spp 4 m^{-2})	278	18.3	0.09	6	37
Mire species (spp 4 m^{-2})	156	15.0	0.08	5	30
Rare mire species (spp 4 m^{-2})	30	1.0	0.08	0	8

* These include: *Calamagrostis canescens, Calamagrostis stricta, Calliergon giganteum, Carex acuta, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Cicuta virosa, Cladium mariscus, Dactylorhiza praetermissa, Eleocharis uniglumis, Eriophorum gracile, Eriophorum latifolium, Hypericum undulatum, Lysimachia thyrsiflora, Osmunda regalis, Peucedanum palustre, Potamogeton coloratus, Ranunculus lingua, Rhizomnium pseudopunctatum, Sium latifolium, Sparganium natans, Sphagnum contortum, Sphagnum platyphyllum, Sphagnum teres, Stellaria palustris, Thelypteris palustris, Utricularia minor.*

24.1.3 Distribution

In England and Wales, the S27 community has been recorded from 188 wetland sites (FENBASE database) (Figure 24.1). It is a very widespread community but is most frequent in, and characteristic of, Northern and Western Britain. It tends to be localized and only fragmentarily developed in much of the South and East.



Data from FenBASE database

Figure 24.1 Distribution of S27 in England and Wales (from FenBASE database)

24.1.4 Landscape situation and topography

S27 is almost exclusively a community of topogenous situations and is frequently developed as a buoyant or loose mat of vegetation. If often forms part of a zonation or successional sequence in basin wetlands or around the margins of open water, but it may be found as part of a mosaic of vegetation types in floodplain wetlands and soligenous situations. In Broadland S27 is scarce, and largely confined to small sumps along the floodplain margins in some sites. It occasionally occurs in the lagg of raised bogs.

24.1.5 Substratum

Mainly occurs as a buoyant or quaking infill within basins (or turf ponds) or as hydroseral vegetation raft along the margins of lakes and pools. It is also sometimes found on more solid peat, particularly where this is soft and spongy. Some examples in basins occur on deep (more than three metre) peat (such as Cranberry Rough) or on a deep alluvial infill (such as Esthwaite North Fen, Cumbria), but many examples occur on shallow (< 0.5 m) peat in shallow basins (such as Dowrog Common, Pembrokeshire) and along the margins of floodplains (such as Catfield Fen, Norfolk). Rodwell (1995) observes that the community can also occur on humic gleys.

24.1.6 Zonation and succession

In some sites where the community adjoins open water (such as Esthwaite North Fen and Sunbiggin Tarn in Cumbria) and various loch-side locations in Scotland (Spence, 1964), S27 can form part of a distinctive, and apparently natural, centripetal zonation, often as a fairly narrow band sandwiched between deeper water swamp communities and drier peripheral fen or fen carr. However, the majority of examples of S27 examined did not occur in this situation, nor did they show a particularly clear zonation. More usually they form a mosaic with a variety of wetter or drier communities, with inconsistent and often unconformable relationships, created sometimes by local variations in topography. In a few sites, the community occupies the lagg of an ombrogenous bog system (such as Abbots Moss (Cheshire), Malham Tarn Moss (Yorkshire)), but in many such contexts it is developed only fragmentarily, if at all, and the lagg is largely occupied by wooded vegetation (such as Cors y Llyn, Radnor).

A particularly large and wet example of S27 occurs in a complex mosaic with various swamp types, at the South-Western end of Rhôs Gôch Common (Radnor), in places showing a fairly clear zonation eastwards through bands of M5 and M4 into a gently rising dome of ombrogenous peat. It seems likely that at this site the S27 complex, which occurs on very shallow peat over lake clays, is the result of recolonisation of a largely skinned, cut-over surface. Many of the other hollows which are occupied by S27 also seem to represent excavations of some type, whether for peat (such as Newton Reigny Moss, Cumbria), fish ponds (such as Malham Tarn Fen), duck decoys (such as Catfield Fen), clay workings (such as Dowrog Common) or marl pits (such as Nether Whitlaw Moss, Selkirkshire). Some of the basin mires in which the community occurs may possess relatively undisturbed post-glacial hydroseral sequences, but the occurrence of past peat digging is often poorly known and may well have been more pervasive than is currently recognised. In lowland England and Wales, S27 seems often to be indicative of some past disturbance, sometimes coupled with nutrient enrichment, and these features may well account for the species poverty of some examples of the community.

The natural role of S27 in the terrestrialisation of topogenous hollows is uncertain, not least because the community does not have a sufficiently clear macrofossil signature to permit its confident identification from stratigraphical data (and, in particular, to enable its distinction from M9-2). On the limited evidence examined, it appears that M9-2 may have made a more important contribution to the infilling of many basins than S27, and that the latter may sometimes be found more as a fairly recent, perhaps enrichment-induced development (perhaps from former M9-2), or as relatively species-poor vegetation that has recolonised disturbed topogenous surfaces.

Small acidic, sometimes ombrotrophic, patches are evident within some stands of S27 and in some sites (such as Parc Newydd, Anglesey) quite extensive *Sphagnum*-dominated surfaces may have developed, at least in part, from former S27. Such acidification is particularly prevalent on buoyant surfaces which are rarely, if ever, flooded by base-rich water. Rodwell (1995) also appears to recognise this: "*small patches of Sphagnum squarrosum and S. fimbriatum are sometimes found within stands of the community, where, for example, the surfaces of floating rafts are maintained at a high enough level to be free of frequent inundation*"; curiously, he also comments that "*conditions remain … sufficiently base-rich and calcareous to inhibit the development of ombrotrophic nuclei and the formation of a Sphagnum carpet*". It is not clear how he reconciles these two statements, but from our data the second of them appears, at least at face value, to be incorrect.

Occasional flooding, particularly with base-rich water, may be important in preventing the development of ombrotrophic nuclei and succession to community types associated with more acidic conditions (such as *Carex rostrata–Sphagnum squarrosum* mire (M5), *Carex rostrata–Sphagnum recurvum* mire (M4)). For example, telluric conditions in the lagg zone of basins such as Abbots Moss (Cheshire) probably constrain the spread of the ombrotrophic surface and maintain conditions favourable for S27. Nonetheless, floating surfaces of S27 which do not receive minerotrophic flood are prone to ombrotrophication.

24.2 Water supply mechanism and conceptual model

S27 occurs within a variety of WETMECs, in ombrogenous, topogenous, rheo-topogenous and rheophilous conditions, but never soligenous. Some basins containing the community appear primarily to be rainwater-fed, with seasonally dynamic water tables and minerotrophic conditions provided by the shallowness of the peat infill (contact with underlying mineral material) or by local rain-generated run-off.

Rodwell (1995) states that "*conditions rarely seem to be stagnant; stands commonly experience some unseasonal flooding and the community seems best developed around areas of diffuse lateral water flow near gentle inflow and outflow streams. It is also found in more obviously soligenous situations: where for example throughput ameliorates ombrotrophic conditions around and within some raised mires*". However, it is not really possible to concur with the emphasis of this statement: (a) although conditions associated with S27 are rarely completely stagnant, this community is generally more associated with stagno-topogenous basins than many others (such as M9-2) and its substrata can have particularly low oxidation–reduction potentials; (b) in our experience, the community is best developed in topogenous basins rather than alongside streams; and (c) we do not concur with its occurrence in soligenous contexts on definitional grounds: our concept of soligenous is narrower than that of Rodwell (what he calls 'soligenous' in this context is encompassed within 'rheo-topogenous' in our terminology).

Twenty-one per cent of stands were found in WETMEC 13 (Seepage Percolation Basins, such as Parc Newydd (Anglesey), Silver Tarn (Cumbria)), 21 per cent in WETMEC 20 (Percolation Basins, such as Dowrog Common (Pembrokeshire), Emer Bog (Hampshire)), and 15 per cent in WETMEC 6 (Surface Water Percolation Floodplains, such as Biglands Bog (Cumbria), Sutton Broad (Norfolk)) and 10 per cent in WETMEC 18 (Percolation Troughs, such as Cliburn Moss (Cumbria), Cors Gyfelog ((Caernarfon)). A few examples also occurred within WETMECs 3, 4, 5, 12, 14 and 16.

24.3 Regimes

24.3.1 Water regime

Mean values for annual rainfall and evapotranspiration for the sites examined are given in Table 24.2, together with together with mean recorded values for summer water table associated with stands of S27.

Table 24.2 Rainfall, potential evaporation and water table data for S27 stands

	Mean	Minimum	Maximum
Rainfall (mm a^{-1})	889	561	1,826
Potential evaporation (mm a^{-1})	582	462	646
Mean summer water table (cm)	2.2	–50	30.6

The community is often found as a buoyant raft, particularly in topogenous situations, and the water level of the raft may be close to the surface year round (although there may be some shallow flooding, especially after heavy rain). Other examples, particularly in shallow basins, are more firmly anchored to the substratum and may experience greater degrees of drying and flooding (the latter even during the summer months). Summer water tables lower than 20 cm bgl were recorded from Betley Mere (Staffs), Cornard Mere (Suffolk), Cors Blaencanog Fach (Cardigan), Cors Llanllugan (Montgomery) and Silver Tarn (Cumbria). In at least some of these sites, the community occurs in locations subject to lowered water tables and is almost certainly a persistent relict of once wetter conditions. However, relatively low summer water tables (deeper than 10 cm bgl) may be a natural feature of examples of the community in some small ground hollows (such as Swannington Upgate Common) or floodplain margins (such as Catfield Fen), especially in dry summers. Such basins may also experience quite deep winter flooding.

Specific time-series data for stands of S27 are not available. It is therefore not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Summer water levels typically at or above surface, particularly where forming a semi-floating raft, but may experience a wide range of conditions and episodically low summer water tables are not necessarily detrimental to the community (though they may determine its particular floristic expression).
- Association with a buoyant raft or loose turf pond infill may provide some vertical mobility and water storage and facilitate lateral recharge, thereby providing some hydrological stability.
- Occasional flooding, particularly with base-rich water, may be important in preventing the development of ombrotrophic nuclei and succession to community types associated with more acidic conditions (such as *Carex rostrata–Sphagnum squarrosum* mire (M5), *Carex rostrata–Sphagnum recurvum* mire (M4)). Telluric conditions in the lagg zone of basins such as Abbots Moss probably constrain the spread of the ombrotrophic surface and maintain conditions favourable for S27. Nonetheless, floating surfaces of S27 which do not receive minerotrophic flood are prone to ombrotrophication.

Sub-optimal or damaging water levels

- Strongly sub-surface winter and summer water levels are outside of the normal range of this community. It can therefore be speculated that this would lead to a loss of wetland species and increased representation by dryland species. Partial drainage, if accompanied by vegetation management, may lead to an increase in species richness as a form of fen meadow becomes established. Further peat drying and degradation would lead to development of rank fen rapidly becoming wooded without management. Nonetheless, the persistence of patches of this community in dry, eutrophic sites such as Cornard Mere indicates that it can be surprisingly tolerant of prolonged periods of low water, albeit in an impoverished form.

- Prolonged, deep inundation, particularly in the spring or summer months, is likely to kill some species and lead to development of a less diverse form of S27, or swamp vegetation types (such as S9, S10). However, such conditions may provide a basis for hydroseral regeneration of semi-floating S27 surfaces.

24.3.2 Nutrients/hydrochemistry

Typically found in situations of intermediate base status, but covers a wide range. Conditions are generally of moderate fertility. The community can occur in mosaics with either rich- or poor-fen vegetation, apparently mediated by fairly small differences in water and substratum chemistry, as well as by water regime. S27 shows considerable floristic overlap with (the generally more uncommon) M9-2 and it would be of considerable value to identify the salient environmental differences between the two communities. That these are not immediately obvious is probably because: (a) the communities overlap and the allocation of samples is sometimes difficult; (b) both communities occupy a rather wide environmental range, probably because both can persist in an impoverished, but nonetheless identifiable, form for quite long periods in adverse conditions; and (c) different, and uncorrelated, environmental variables may favour one or the other communities in different circumstances. Overall, in relatively base-rich conditions M9-2 tends to occur in less fertile circumstances than does S27, but M9-2 is generally also less associated with acidic conditions and in these circumstances the stands that occur are more usually referable to S27, even in low fertility locations. In some cases, because S27 is generally distinguished negatively from M9-2 (by the absence of diagnostic species), stands may become allocated to S27 by default, based on a general deficiency of species, and this may obfuscate the detection of environmental distinctions, especially in circumstances where species poverty is a reflection of relatively recent recolonisation of disturbed surfaces.

Figures for pH, conductivity and substratum fertility measured in stands of S27 are presented in Table 24.3. The lowest pH circumstances associated with this community were recorded from the laggs of basin bogs (such as Abbots Moss) and from the edge of some of the Broadland floodplains (such as Catfield Fen). The cause of the low pH in these latter examples is not really known. Possibilities include sulphate release caused by the oxidative drying of sulphide-rich substrata, or some influence of adjoining base-poor mineral deposits (some limited evidence supports both of these possibilities).

Highest fertilities were found at Cridmore Bog (Isle of Wight), possibly due to flooding by sewage effluent-enriched water from the River Medina, and at Cliburn Moss (Cumbria), Skipwith Common (Yorkshire) and Emer Bog (Hampshire), all of which may receive some run-off from adjoining agricultural land. The very high EC value of 2,150 µS cm^{-1} was recorded from a rather dry patch of S27 embedded with *Glyceria maxima*-dominated vegetation at Cornard Mere (Suffolk), but the reason for the high value is not known.

Table 24.3 pH, conductivity and substratum fertility measured in stands of S27

Variable	Mean	SE	Minimum	Maximum
Water pH	5.7	0.02	4.6	7.0
Soil pH	5.6	0.02	4.5	7.1
Water conductivity (µS cm^{-1})	260	1.4	38	2,150
Substratum fertility[1] (mg phytometer)	13.6	0.24	2	50

[1] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility < 8 mg, high fertility > 18 mg.

Wheeler and Shaw (1991a) reported a mean increment (April to September) in dry weight of above ground standing crop of 212 g dry wt. m^{-2}. This low productivity reflects the typically low fertility of the substratum.

24.3.3 Management

S27 can be fairly stable in the absence of management, and the wetness of the substratum may mean that stands are infrequently grazed even where open to stock. However, stands may be subject to light grazing, which generally appears to have a beneficial effect on species density and may retard scrub invasion. Rodwell (1995) suggests that grazing may favour the dominance of *Juncus* species.

In the longer term, natural successional process in unmanaged locations may result in considerable scrub development (W2 or W3) in former S27 stands (such as Pigott and Wilson, 1978). Natural successional processes may also mean that where the community is established on a buoyant raft, conservation of this vegetation type may eventually require rejuvenation of the hydroseral conditions (by excavation of the substratum).

24.4 Implications for decision making

24.4.1 Vulnerability

Conservation management involves ensuring moderate fertility and intermediate base status, and relatively high water levels. It may require maintenance of hydroseral conditions (peat excavation). Stands of S27 may be resistant to moderate nutrient inputs, but high levels of eutrophication lead to impoverishment, with an increased prominence of species like *Agrostis stolonifera, Juncus effusus* and *Phragmites australis.* This may be perceived as a long-term threat to particularly eutrophic examples of S27 (such as Cridmore Bog, Emer Bog). Examples in basins may be particularly vulnerable to inflow of agricultural nutrients from adjoining farmland, and there is circumstantial evidence that this occurs at a number of sites. At Sunbiggin Tarn, located within moorland, an apparent former stand of S27 has been impoverished as a consequence of being used as a roosting site by black-headed gulls (*Larus ridibundus*)

The vulnerability of stands of S27 to changes in water supply depends considerably upon their precise water supply mechanism. Where the water level in basins with this vegetation is directly determined by aquifer water tables, the key question of vulnerability may be the degree of water level reduction which can be accommodated by a buoyant surface before significant grounding and drying occurs. In other sites, developed over low-permeability deposits and where the water level is potentially controlled by the level of the outfall as well as by rates of water inflow, a reduction of aquifer water tables may not have such a direct effect. However, this same feature may make these sites, and communities, more vulnerable to increased drainage in the fen, especially if groundwater inputs are not strong. Nonetheless, it appears that established examples of S27 may be quite persistent in unfavourably low summer water conditions, though probably in an impoverished form.

Figure 24.2 outlines some of the possible floristic impacts of changes to the stand environment.

The possible effects of environmental change on stands of S27

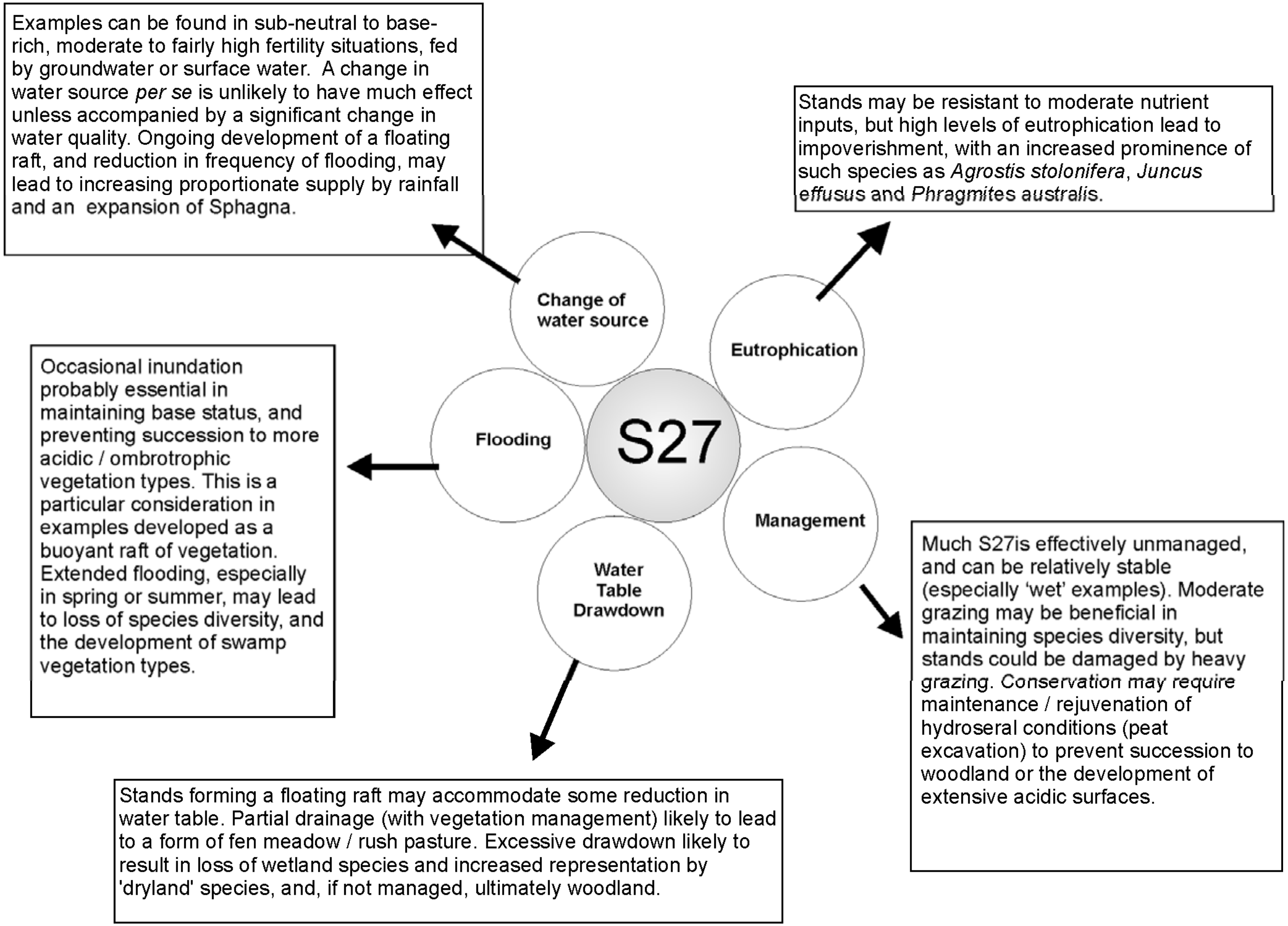


Figure 24.2 Possible effects of environmental change on stands of S27

24.4.2 Restorability

As with all restoration measures, likely success depends on the cause of the damage and how far the starting conditions deviate from the objective, both in time and conditions (such as numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on the restoration of S27 stands, but the following observations can be made:

- Where the community has been recently damaged, but this has not been intensive, corrective management may be sufficient to rehabilitate S27 in the short to medium term.
- Prolonged water drawdown which has resulted in both the grounding of the floating raft, and mineralisation of nutrients from the peat, may require many years and major operations such as peat removal to reverse.
- Reversal of problems caused by nutrient enrichment is likely to be difficult, especially where excess nutrient capital cannot be removed by management. Physical removal of enriched sediments may provide one solution to this, but in the wet basins typically occupied by S27, the resulting disturbance may help spread enriched material into less affected locations. A removal strategy may therefore only be viable where there is some control over the water level, where the whole basin is to be stripped or where the surface is so degraded that further deterioration is unlikely.

24.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here include the following:

- There are currently no data to better inform the temporal water table characteristics of S27 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions on the vulnerability of S27 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological studies at representative sites.
- Data on the spatial extent of S27 are lacking.
- Possible differences in environmental conditions influencing the two sub-communities have not been explored here.
- S27 shows considerable floristic overlap with (the generally more uncommon) M9-2 and it would be of some interest to identify the salient environmental differences between the two communities. A pre-requisite for this is likely to be an improved characterisation of the distinction between S27 and M9-2.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

PART 4:

FURTHER WORK AND REFERENCES

25 Further work

25.1 Introduction

The *Wetland Framework* described here attempts to bring together different features of wetlands, in particular to identify links between wetland topography, hydrology, hydrogeology, hydrochemistry, ecology, vegetation, and conservation interest. The analysis has been based entirely on existing data from a range of wetland sites across England and Wales.

During the course of the work, various issues relating to data availability and reliability have arisen. Discussions have taken place about how the Framework could be applied to ongoing work by the Environment Agency and conservation agencies. Some of these issues have been discussed in previous sections, but here we provide more specific recommendations for further work, as well as considering ways in which the project could be taken forward.

25.2 Availability and requirements for hydrological data

25.2.1 Hydrological monitoring network

Piezometric and water level monitoring in wetlands is generally sparse, and many sites have few, if any, hydrometric data. Some sites in England and Wales have monitoring installations put in for various purposes (for example, by a water company as a condition of licensed water abstraction) and in East Anglia, installation of a hydrological monitoring network on over 50 sites was completed by the Environment Agency in 1997. However, even in monitored sites, installations are not always sufficient or appropriate, especially with regard to making an ecohydrological assessment of those parts of the sites of particular conservation interest. We identify the following limitations:

- No piezometric, dipwell or gauge-board data are available for most sites. In general, we would not prioritise an indiscriminate expansion of the existing networks, but there is a need for targeted hydrometric data from a number of critical sites. It would also be appropriate to test the proposed properties of some WETMECs by establishing hydrological monitoring across a series of type sites.

Recommendation 1

The properties of selected WETMECS should be tested by establishment of appropriate hydrological monitoring across a series of "type sites". These need to be chosen to reflect geographical variation, variation in the likely characteristics of the WETMEC, and also a range of contexts including those subject to different water supply impacts (namely abstraction and surface drainage). Such a monitoring network could be developed as a basis for obtaining consistent comparable data between sites. Particular consideration should be given to the development of a dipwell network across a representative series of WETMECs and community types.

- In some sites, piezometers are located at a considerable distance from the main area of wetland ecological and conservational interest and their relevance to this is uncertain. In these cases, installation of additional piezometers closer to the critical wetland areas would be desirable. There is a particular need for liaison between experienced vegetation ecologists and hydrologists about the best location for monitoring installations. For example, it is not unknown for piezometers that have ostensibly been installed with reference to a specific vegetation type to actually be located in vegetation that does not belong to the community in question, or which is atypical.

- Even where piezometers are quite close to the main areas of interest, topographical differences and substratum heterogeneity may prevent simple extrapolation of their data to the wetland areas. Existing locations have sometimes been determined by practical and access considerations and installation of a larger number of piezometers may be neither practicable nor desirable (because of possible damage). However, in some sites there could be merit in some temporary piezometer installations as part of a targeted investigation into groundwater–fen water regime investigations (see below).

Recommendation 2

There should be discussion between experienced vegetation ecologists and hydrologists about the best location for monitoring installations. Where access or other issues prevent a permanent installation, consideration should be given to the use of temporary piezometer installations at targeted locations.

- In most sites, there are no dipwells within the wetland areas to provide information about variation in water levels with respect to the ground surface. This information is essential to enable interpretation or prediction of ecological response. Dip-levels in hand-driven perforated tubes are often sufficient for this purpose, but they must be accurately levelled and well anchored, especially in sites with buoyant vegetation surfaces (National Groundwater and Contaminated Land Centre, 2003). The location of dipwells needs to be targeted carefully to maximise the ecohydrological information that can be derived from them, and (where relevant) to ensure that they are located in good or representative examples of the vegetation types they are investigating.

- It may be necessary to confirm whether existing dipwells and piezometers are adequately anchored and accurately levelled (preferably to Ordnance Datum), as this is not always the case and, obviously, critically affects the value of their data.

Recommendation 3

Dipwells must be accurately levelled and well anchored, especially in sites with buoyant vegetation surfaces. Existing installations should be checked.

- There is an acute need for consistent criteria relating to piezometer and dipwell design; it is now well established that different screening configurations can have a bearing on the results obtained from *in situ* measurements of hydraulic conductivity, and in some cases these effects are likely to extend to measurements of water level change (particularly where these are collected at frequent time intervals by automatic loggers).This same requirement for consistency applies to instrumented networks; a wide range of automatic loggers are now available on the market, and guidance is needed on which products are likely to be suitable and where. Guidance documents are available from the Environment Agency, including a Hydrometric Manual, Hydrometry AMS Work Instructions, and *A guide to monitoring water levels and flows at* wetlands (NGCLC, 2003).

Recommendation 4

Reference should be made to existing guidance on piezometer and dipwell design, and datalogger performance, when designing wetland monitoring installations.

- It is highly desirable to establish reliable local records of rainfall.
- As far as relationships with plant growth and distribution are concerned, the most relevant water table measurements relate to the position of the water table relative to the soil surface (or rooting zone), not to Ordnance Datum. The relation between water levels recorded in piezometers, dipwells and gauge boards, and the soil surface is not always known, especially – but not exclusively – for non-agency structures.

Recommendation 5

The position of the water table relative to the soil surface at each installation must always be established, as this is the most relevant measurement with respect to plant growth and distribution. Periodic measurements of the elevation of the soil surface relative to a fixed datum should also be made, to take account of *inter alia* substratum buoyancy and peat accumulation.

25.2.2 Reports on piezometer and other data

Reports can provide a useful summary of the data available from monitoring, with some interpretation. However, we consider that the usefulness and ease of interpretation of some reports could be increased if account was taken of the following points:

- Provision of a simple map of the site would be helpful, showing *all* of the monitoring points (including structures installed for purposes other than that being reported).
- Where possible, hydrographs should be presented with results plotted on the same vertical axis, or at least using the same vertical scale.
- The ground level at each installation should be indicated (both on tables and graphs). This assists interpretation and helps detect data discrepancies. It would also be useful for the ground level of strategic parts of the wetland surface to be indicated, where known.
- Critical consideration should be given to the validity of extrapolations of piezometric data to water conditions within the wetland, particularly with regard to assumptions of hydraulic continuity.
- A summary conceptual cross-section of the site should always be presented along with the monitoring data, and preferably a summary paragraph about the conceptual ecohydrological understanding of the site. If the monitoring leads to a change in conceptual understanding, this should be highlighted.

Recommendation 6

Hydrological monitoring reports should include a simple map and a conceptual cross-section of the site, and ground levels at each installation (piezometer, gauge board, dipwell). Where practicable, hydrographs should be plotted on the same vertical axis, or at least using the same vertical scale.

25.2.3 Topographical data

One of the biggest constraints on the assessment of water mechanisms in many wetlands, and on the ecohydrological use of piezometric (and other) data, is the absence of detailed topographical information for the sites. General topographical surveys undoubtedly have value, but we recommend that any topographical investigations are targeted to questions relevant to the ecohydrological characteristics, mechanisms or conservation features of the sites, rather than – or in addition to – general topographical determinations.

The difficulty of making accurate topographical measurements in flat sites with spongy or irregular surfaces should be fully appreciated, and appropriate levelling techniques should be adopted to accommodate this. In some cases where critical information is required, it may be necessary to use techniques such as water manometry rather than standard surveying equipment. Where surfaces are tussocky, or otherwise strongly irregular, considerable thought may be needed as to what constitutes the base-level for the soil surface. Groome (2007) used four separate categorisations of surface level when examining the hydrodynamics of a valleyhead mire in Surrey: peat (soil) level, moss level, tussock level and mean level (the mean of the three preceding terms). LIDAR (Light Detection and Ranging) surveys can often be extremely useful in providing a gross topographical characterisation of wetland sites, but care must be taken with regard to the influence of vegetation structure upon the identity of the reflection target. For example, it is possible for LIDAR plots to depict variation in vegetation height rather than in the underlying topography. This procedure is also not appropriate for some detailed topographical investigations (such as for assessing directions of hydraulic gradients in visually flat sites).

Contour maps are a helpful way of expressing the results of topographical surveys, but careful consideration should be given to the contour intervals used. These are likely to depend on the topographical context being examined, as well as upon the irregularity of the surface accuracy of the surveying method used. For sloping systems, contour intervals of 10–20 cm or coarser may be appropriate, whereas consideration of visually flat sites could benefit from contour intervals of five cm – though these may be largely meaningless in surfaces which are strongly tussocked or otherwise irregular.

Recommendation 7

Topographical surveys are essential to aid interpretation of water supply mechanisms in wetlands, and should be carefully targeted to answer the ecohydrological questions under investigation. Careful attention needs to be given to appropriate levelling techniques and off-the-peg solutions are not always adequate.

25.2.4 Top-layer characteristics

One of the most important outcomes of the Framework analyses is that they highlight the difficulties of making predictions of water regimes within wetlands based just upon general piezometric data and broad hydrological models. In particular, the analyses suggest that local variation in top-layer conditions in and near the wetland have a great impact upon water supply and conditions relevant to the conservation interest of the site. This top-layer effect includes well-known features such as lithological variation within Drift deposits coupled with features more localised, or specific, to the wetland, such as induration layers below the site, organic seals lining the site, and variation in the character of the peat infill (from an effective aquitard to highly transmissive material). [See Chapter 5: Top-layer controls, for more details.]

- The top-layer effect may have little consequence to development of regional groundwater models for the vicinity of the site, but may be critical to the water supply and retention characteristics of the wetland itself or of particular locations within it. As it can show considerable small-scale variation, top-layer variation means that groundwater models relating to the wetland areas may have limited practical value without adequate local assessment and calibration based on actual field conditions.

- Simple stratigraphical surveys of top-layer characteristics may provide a valuable pre-requisite for any planned hydrological monitoring installation, to inform their location and the subsequent interpretation of results. Borehole logs should always be recorded, but there may also be the need for supplementary coring information in the surroundings of monitoring structures, to establish the local stratigraphical contexts.

Recommendation 8

Installation of hydrological monitoring structures, and interpretation of their data, should be made with an awareness of the potential importance of top-layer controls upon the hydrodynamics of wetlands. Simple stratigraphic surveys of top-layer characteristics should be made to inform the location of monitoring installations and interpretation of data.

- The quantitative importance of the top-layer effect, or even its precise character, has been little investigated in England and Wales. There is a need for a more rigorous assessment of this feature across a representative range of wetlands in England and Wales, with particular respect to the distribution of vegetation types.

Recommendation 9

The importance of the top-layer effect should be investigated across a representative range of wetlands in England and Wales, with particular respect to the distribution of vegetation types.

25.2.5 Wetland infill as a surrogate variable

The size and potential variability of some wetland systems means that it may be difficult to install sufficient monitoring points to characterise adequately the ecohydrological features of the entire area. Moreover, unless such investigations are carefully targeted, there is always a danger of merely accumulating an even bigger dataset which remains difficult to interpret. However, as a wider scale understanding of the ecohydrological functioning of sites is undoubtedly required, consideration may be given to the use and calibration of surrogate information. Our analyses have used such data (such as knowledge of peat types and underlying material) where available – but they are far from comprehensive. Peat stratigraphical data can be acquired fairly easily and, as they do not require repeated sampling, one cost-effective approach to investigating ecohydrological mechanisms would be to carry out surveys of the stratigraphical characteristics of wetland sites. These can provide information on likely present conditions and constraints on water supply, help to document changes that have occurred within the wetland and provide invaluable insights into wetland mechanisms (van Wirdum *et al*., 1997). Stratigraphical surveys can also provide important guidance about appropriate locations for new piezometer and dipwell installations.

Recommendation 10

Consideration of "surrogate" information (such as knowledge of peat types and underlying material) is recommended to enable a wider scale understanding of the ecohydrological functioning of wetland sites.

25.3 Availability and requirements for ecological information

Whilst a multitude of ecological studies could be carried out in wetlands in England and Wales, from the perspective of the Environment Agency and conservation organisations the most important are those concerned with establishing the occurrence of environmental or management change and the sensitivity and vulnerability of wetland vegetation types to this, especially those of EU habitat importance. There is a particular need to identify changes that have occurred, or which may be expected to occur, in response to changing water conditions and to distinguish these from changes in response to other processes (nutrient enrichment, management dereliction and natural succession). There is also a need for vegetation (plant community) surveys at many sites, to serve not only as an evaluative tool but also the basis for future targeted ecohydrological investigations.

25.3.1 Vegetation surveys

We consider that site vegetation surveys are necessary for the broad description of wetlands and for assessment of the vegetation resource. They can also help guide the emphasis of monitoring efforts in wetlands and inform the location of hydrometric installations, so that these are placed in ecologically relevant situations. In Britain, the

National Vegetation Classification (NVC) provides the *de facto* standard for vegetation survey, though it should be appreciated that not all of its units necessarily form clear or compelling segregates of the range of variation in wetland vegetation, nor are all examples of wetland vegetation well-accommodated in its syntaxa (including some quite widespread types) (see Part 3). Such considerations suggest the need for a circumspect approach to this undoubtedly valuable categorisation of British plant communities and, as wetland communities may be particularly problematic, point to the need for experienced surveyors in their assessment. Surveys need to be resourced sufficiently well to ensure that they are carried out rigorously, and require surveyors with a good knowledge of bryophyte species (as well as vascular plants), as these are critical to the assessment of many wetland community types.

We also hold the view that even thorough, properly conducted vegetation surveys do *not* by themselves provide an adequate or sensitive tool for monitoring vegetation or ecological change, except in gross terms. This is not least because of the problems of community definition and recognition, the different standards that may be applied by different workers, and the difficulty of identifying (and mapping) community limits across diffuse boundaries.

Recommendation 11

Up-to-date plant community-level survey coverage is a basic requirement for all statutory wetland sites, not least as a platform upon which to base many of the recommendations made elsewhere in this section. Vegetation surveys and monitoring should be carried out by experienced surveyors along with other approaches to identify ecological change.

25.3.2 Vegetation monitoring

Some assessment of ongoing vegetation change is desirable at many sites. The inappropriateness of NVC surveys for monitoring change has already been noted, but standard, quantitative monitoring protocols in wetlands also have limitations. They have proved to be resource intensive, can be difficult to interpret and are not necessarily reliable. Random sampling strategies are often not carried out with sufficient intensity to provide a reliable estimate of vegetation composition (Wheeler and Shaw, 1991). The sampling of permanent plots can provide a reliable indication of change within the plot, but provides no information for the rest of the vegetation. An approach which encompasses the less-intensive sampling of a large number of permanent areas may provide a cost-effective compromise, and a less formal methodology specifically targeted at identifying particular foci of change has been proposed for assessing change (Wheeler, Shaw and Hodgson, 1999). Monitoring on a six-year cycle is likely to be appropriate in most cases.

Recommendation 12

Common Standards Monitoring is the approach recommended for baseline monitoring effort. More detailed monitoring methods (such as that proposed by Wheeler *et al.*, 1999) to answer specific questions will often be required to supplement this.

A limitation of many monitoring schemes is the lack of informed interpretation of their results in terms of working out their implications for identifying and assessing environmental change. This partly reflects the absence of a well-established basis for assessing the indicator value of individual species, or groups of species with regard to the main environmental factors (pH, fertility and water regime) and management influences. Wheeler *et al*. (1999) developed a simple model (FENFIBS) to predict the likely environmental interpretation of observed floristic change. This integrated, and attempted to discriminate between, effects of water regime, nutrient richness and dereliction, but the model requires more development and validation for general use. Various models have already been developed in the Netherlands (for example, Barendregt *et al.* (1986), Gremmen *et al*. (1990) and Latour, Reiling and Wiertz (1993)), but these do not encompass the range of wetlands found in England and Wales, and even for comparable types their transferability would need to be established. The Dutch methods could be explored further for their applicability to England and Wales, though the scope of the datasets on which these models are based, and their implicit assumptions, need to be established. In any case, ecological models should be used only as a tool to assist decision-making, not as a substitute for careful, factually based assessment and evaluation. Many changes that occur in wetlands are intrinsic and natural and are not necessarily a response to damage; where possible, these need to be distinguished from damaging events.

25.3.3 Common Standards Monitoring

The JNCC's Common Standards Monitoring (CSM) scheme (JNCC, 2004) for assessing the condition and status of protected areas is widely used and has considerable value. However, it does have some limitations and in the work reported here three main problems have been encountered, all of which have resulted in sites being allocated a less favourable condition status than they appear to deserve. As such designations as 'unfavourable, declining' have considerable implications, not least for perceptions of inappropriate management or unsuitable environmental conditions, it is important that these issues are considered. [It should be recognised that there are many instances where specification of an 'unfavourable, declining' status for wetland sites is both well-founded and fair.]

- Unfavourable condition assessments appear sometimes to be based on the absence of key species which are, in fact, still present. This appears to arise as a result of inadequate surveys (see 25.3.1) where, for example, bryophyte species have not always been well recorded. It is also sometimes the case that a number of indicator species have always been restricted to a small portion of a site, which was not examined during the re-survey.
- Some condition assessments have been made on a whole-site basis, and specification of unfavourable status may actually apply to peripheral habitats rather than to the wetland area of principal conservation interest. For example, a seepage fen site may sometimes be designated as 'unfavourable, declining' because of a high proportion of scrub invading grassland surrounding the mire, not because the seepage slope is itself deteriorating. This problem could be overcome by an appropriate subdivision of the site, perhaps using WETMECs as units of condition assessment..
- In some instances, wetland sites that have been assigned an unfavourable condition status have shown little evidence for significant change since the 1970s, and perhaps earlier. This could be a consequence of either of the two problems identified above, or perhaps of an unrealistic appraisal of the expected quality of the site. This problem may sometimes be a consequence of the application of globally specified positive indicator species and cover thresholds as necessary requirements for a good-condition status (JNCC, 2004), at little-damaged sites where these species may never have been present. Consideration of past species records for the sites, where these are available, may help to better inform their current status.

As with vegetation surveys, we would point to the need for a sensitive and circumspect, and ideally flexible, approach to site condition monitoring.

Recommendation 13

CSM examinations should be adequately resourced and not just carried out by quick inspection. A thorough check should be made for indicator species, but lists of these would be better tailored to the ecological characteristics, likely optimal species occurrences and past species records of individual wetland sites rather than as part of a global species list. Cover thresholds may also need to be reconsidered, to avoid negative assessment of sites which are actually in perfectly good condition. Where wetland sites clearly contain more than one wetland type, these should be distinguished and evaluated separately. WETMECs would provide a basis for such subdivision, and are potentially more useful assessment units than are communities; an individual WETMEC can support several states of damage or modification (see Smallburgh map) whereas a community is more likely to correspond to a specific set of conditions which are – except where significant ongoing change is taking place – intrinsically in good condition for the community concerned.

25.3.4 Environmental baselines and change

Direct assessment of some environmental changes can be made by a series of *in situ* measurements. The need for records of the wetland water table from dipwells has already been identified, but, for assessing favourable status and potential threats, there is an equally important need to assess changes in water quality and soil characteristics.

- Key environmental determinations are base status (pH) and nutrient richness, as these can be of equal, or even greater, importance than water level in affecting floristic quality.

- Measurements of water and soil pH can be made fairly easily and are particularly useful in sites where base depletion is suspected. Electrical conductivity of water samples is also worth determining, as a simple surrogate estimate of overall ionic composition. However, both pH and EC measurements are to some degree technique-dependent and different workers can generate somewhat different values from the same material. Some base-line pH and EC data (from the 1980s) are available for certain sites, but they are not comprehensive. Because these measurements are simple, they could be incorporated into a six-yearly vegetation monitoring programme. However, at sites where changes in water quality are suspected, there may be a need for more regular monitoring and wider scale investigations to detect the patterns and extent of ionic change. The nature of any such investigations would need to be determined on a site-specific basis rather than by application of an imposed standard monitoring regime. For example, assessment of the extent of brackish water incursions into the wetlands may need conductivity measurements to be made reactively at times of tidal surges, not at pre-determined sampling occasions.

Recommendation 14

Standardised investigative and monitoring protocols need to be developed for simple water quality measurements (including pH, conductivity), and of enrichment. pH and conductivity determinations could be incorporated into a six-yearly vegetation monitoring programme. Where enrichment is judged to be a problem, nutrient-richness data could be obtained using a phytometric method, targeted at locations of potential or actual nutrient enrichment.

- Meaningful measurement of the fertility of wetland substrata is often surprisingly difficult. Concentrations of N, P and K in water and soil samples from wetlands can be measured easily, but often bear little relationship to on-site conditions (for example, measured concentrations are sometimes found to be consistently low in locations which, assessed on other criteria, are strongly eutrophic). Measurement of nutrient concentrations in water and soil samples can also be prone to considerable variation induced by differences in sampling and analytical procedures. Assessment of the overall fertility of soil samples, using phytometric response, has proved to be a more reliable and sensitive investigative procedure than water and soil chemical measurements in wetlands (Wheeler, Shaw and Cook, 1992). Base-line phytometric data (from the 1980s) are available from a large number of wetland sites, but by no means from all, and no subsequent data are available from most sites. Fertility assessments should not be made indiscriminately, but should be targeted to specific, vulnerable vegetation types and locations, particularly with regard to perceived threats and individual water supply mechanisms. Although it would be useful to have fertility data from a wide range of locations, in a resource-limited circumstance it may be realistic only to collect such data from situations where there is reason to suspect potential or actual nutrient enrichment. In such sites, a return sampling frequency of six years would be appropriate. There will often be a need to assess the extent and nature of enrichment gradients within the wetland, rather than just determine fertility at predetermined plots. Quite often, whilst peripheral parts of a wetland may experience considerable enrichment, other parts can be largely unaffected.

- By themselves, data on environmental change may have limited value unless some biological significance can be attached to them. For example, an increase in fertility in an already fertile wetland may have few biological consequences, whereas a comparable increase in a low-fertility site may induce substantial change. For assessment of significance, data both on environmental changes and species changes are desirable.
- The relationship between the holistic ecohydrological approach advocated here for assessing species and community distributions in wetlands and the ‘sum exceedance value’ approach developed for wet meadows could be explored usefully, with a possible view to developing synergistic analytical and descriptive procedures.

Recommendation 15

Explore the relationship between the holistic ecohydrological approach advocated here for assessing species and community distributions in wetlands and the ‘sum exceedance value’ approach (developed for wet meadows), with a possible view to developing synergistic analytical and descriptive procedures.

25.3.5 Community tolerances

Whilst a definitive assessment of the sensitivities of different plant communities and species to environmental conditions and changes in these would be welcome, this project has highlighted some of the difficulties inherent in providing more than just generic guidelines. In most cases, whilst the general relationship between environmental conditions and the occurrences of individual species can be established, it is not yet possible to provide exact figures that accurately quantify thresholds in the relationships between individual species and their environment. It is even more difficult to identify clear relationships between environmental conditions and community distributions, as communities are themselves variable, and sometimes debatable, entities. For both species and communities, the problem is partly due to intrinsic variability in response, lack of equilibrium conditions, and interactions amongst variables – as well as, frequently, insufficient data. For these reasons, we have deliberately not tried to specify threshold or optimal values in the Framework (the numerical data provided should be taken as observed values, not definitive evidence for tolerances).

Recommendation 16

Any suggested specification of environmental thresholds and optima for wetland species and communities should be treated with considerable caution and circumspection.

25.4 Terms and Categories

25.4.1 Terminology

- The challenges presented by wetland terminology have been discussed elsewhere in this report (Chapter 2). Some rationalisations have been suggested and some consistent usages applied. There is a clear need for the adoption of a standard terminology by workers in wetlands and it is hoped that the proposals made here will provide an appropriate starting point for this.
- There are still terms which are ambiguous in scope or usage (such as groundwater) and there would be considerable merit in attempting to further rationalise these.

25.4.2 Data categories

- A series of subdivisions of various types of wetland features has been identified and used in this report (Appendix 2). These were used in the data analyses made, but some of them may have a more generic and universal value (such as the proposed subdivisions of the pH scale) and could usefully be adopted more generally.
- Some of the categories used are familiar and of long-standing usage, but these do not always have clear definitions – or their definitions are not necessarily well known to all user groups. This applies, for example, to types of sediments (types of peat, muds, marl, silt, clay and so on). It would be helpful to identify a coherent short-list of the main categories in use, and to provide guidance on their recognition in the field.

Recommendation 17

An expert group, with representatives from the various disciplines involved, could be convened to rationalise issues of terminology and data categories, to provide some standardisation amongst the various user groups and, where possible, to ensure compatibility with usages elsewhere in Europe.

25.5 Furthering the Framework

There are various ways in which the work described here could be taken forward to develop the *Wetland Framework*:

i. Include wetland types and wetlands from other regions (such as Scotland and Ireland, upland England and Wales).

ii. Update the Framework with targeted long-term monitoring and interpretation of vegetation, vegetation stress and environmental variables on key sites.

iii. Expand and enhance the Framework by integrating information and mechanisms from other wetland habitats (wet grassland, wet woodland, wet heath and dune slacks).

iv. Provide a user's guide that addresses: (i) How do I determine a WETMEC or series of WETMECS on a given site? (ii) How do I translate the WETMEC information into site condition requirement and critical values that can be used in site management and environmental impact assessment (as Review of Consents)?

v. The compass of a user's guide could be extended into a practical field handbook for describing and investigating wetlands. This could *inter alia* include guidance on the recognition of wetland types, vegetation types and other features of wetlands (such as peat and sediment types). It could also, where possible, include recommended methods for certain field measurements.

Recommendation 18

A practical field handbook could be produced to assist in the determination and description of wetlands, wetland types and wetland features. Guidance could be provided – including helpful hints and summary statements – on the field recognition of wetland types (including WETMECs), key vegetation types, substratum types and so on. It could also include details of recommended methods for key field environmental or hydrological determinations, at least for those where some measure of agreement is possible amongst wetland practitioners.

vi. Consideration could be given to the establishment of an expert panel to resolve any conflicts or disagreements between the different user groups with respect to conservation objectives for wetland sites and their relationship to considerations of water regime and water quality.

Recommendation 19

An expert panel should be established to resolve any conflicts or disagreements between the different user groups with respect to conservation objectives for wetland sites and their relationship to considerations of water regime and water quality. This needs to take account of hydrogeological, hydrological and biological information, including historical information of past species records and assessments of the former condition of wetland sites. Such a group could be particularly useful for providing expert judgment in situations where reliable data are in short supply.

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Note: references cited in the site accounts are not necessarily repeated here unless referred to in the main text.

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Appendix 1 Glossaries

1 Glossary of terms

1.1 General terms used in the text

These definitions relate to the usage of terms in this report, and are not necessarily general definitions. Words underlined are defined elsewhere in the glossary. See Chapter 2 for more details of terminology and the particular use of words marked in bold type.

Acidic	Here used for wetlands with water strongly dominated by H^+ (and usually so_4) (pH below 4.5)
Acrotelm	The uppermost, active layer of a peat deposit, most often used with regard to an undamaged raised bog, comprising the living plant cover passing downwards into recently dead plant material and thence to fresh peat. It forms the largely oxygenated surface layer with high hydraulic conductivity, within which the water level fluctuates and the main water movement occurs (cf. Catotelm).
Allochthonous	Of imported origin (cf. Autochthonous); often refers to material inwashed into wetlands.
Allogenic	Induced by external factors (cf. Autogenic).
Anisotropic	Having properties that differ according to the direction of measurement (for example, hydraulic conductivity of peat may be higher if measured laterally rather than vertically).
Anoxic	Lacking free oxygen.
Aquifer	Water-bearing substratum, at full moisture capacity.
Aquitard	A zone of low hydraulic conductivity where the flow of groundwater between aquifers is restricted. If completely impermeable, it is called an aquiclude.
Autochthonous	Formed in situ (cf. Allochthonous); often refers to peats and muds formed and deposited within wetlands.
Autogenic	Self-made [caused by reactions of organisms themselves] (cf. Allogenic).
Basal substratum	The layer of mineral material immediately underlying the paludogenic deposit (wetland infill) in a wetland site.
Base-poor	Here used for low pH wetlands, deficient in base cations; pH range 4.5 to 5.5.
Base-rich	Here used for high pH wetlands, rich in base cations and, often, bicarbonate; pH range 6.5 to 8.0.
Basin	Used variously to describe hollows in the landscape – these may occur at various scales, from great synclinal basins, through the basins of large lakes and lochs, to small depressions.
Basin mire	The term basin mire is mostly used by authors to refer to mires developed in fairly small depressions.
Baulk (balk)	Narrow ridge of peat, usually separating different parts of peat workings.
Bluff, marshy bluff	A (relatively) steep sloping face forming part of a valleyside; sometimes associated with seepages and can represent surfaces oversteepened by solifluction and other erosive processes.
Bog	Widely used as a generic term for ombrotrophic mires.
Bottom	Used mainly as a generic term to refer to a range of topogenous situations (basins, flats, floodplains and troughs).

Bund	A bank of peat or other material, effectively an elongate dam for retaining water in (parts of) wetlands.
Bulk density	The amount of solid material per unit volume.
Calthion	Vegetation of the calthion phytosociological alliance (relatively fertile wet grassland and fen meadow, such as M22).
Caricion davallianae species	Species which are particularly characteristic of the caricion davallianae phytosociological alliance (which includes M10 and M13), for example *Carex lepidocarpa, Carex pulicaris, Dactylorhiza incarnata, Epipactis palustris, Eriophorum latifolium, Parnassia palustris, Pinguicula vulgaris, Aneura pinguis, Campylium stellatum, Drepanocladus revolvens, Fissidens adianthoides* and *Scorpidium scorpioides*.
Carr	The common East Anglian usage of tree-covered fen is adopted here (in some parts of Northern Britain the term has the wider meanings of fen, wet boggy ground or a meadow derived by the drainage of a mire).
Catotelm	The lower, so-called inert layer of a peatland. The catotelm underlies the acrotelm and is permanently saturated, mainly anoxic and usually of lower hydraulic conductivity and storage capacity than the acrotelm.
Centripetal	Tending towards a centre (the opposite of centrifugal).
Climax ecosystem	The mature or stabilised stage in a successional series of communities beyond which directional change in species composition no longer occurs.
Diplotelmic	Literally 'two marshed' (*gr.*), 'two layers of mire'. In raised bogs, this refers to the typical occurrence of an uppermost active layer (the acrotelm) and a lower so-called inert layer (the catotelm).
Discharge zone	Zone of groundwater water movement into a wetland.
Draw-down	Refers to the fall in water level caused by a steepened hydraulic gradient, for example as a result of water movement to drains or ditches.
Drains	Usually ditches within or alongside stands dug with the primary intention of drainage and in which the water level is usually well below the surface of the adjoining mire, except in exceptionally wet conditions.
Durchströmungsmoore	(*German*) percolating mires.
Dykes	Dykes are ditches within more or less flat sites which generally have a consistently high water table.
Dy	(*Swedish*) an oozy, colloidal, often inwashed organic deposit in unproductive pools and lakes.
Dysaptic	Refers to a two-layered surface in which plants rooted on solid peat grow up through an overlying buoyant or quaking surface.
Dystrophic	Literally 'defectively nourished' (*gr.*); used to refer to unproductive, peaty pools and lakes with much dissolved organic material and, often, deposits of dy.
Eastern england	The administrative region of the Environment Agency – Anglian region
Ecology	The branch of biology which deals with the relations of living organisms to their surroundings, their habits and modes of life, and so on (note that ecology is a discipline, not a feature, so that strictly speaking sites cannot be said to have an 'ecology').
Endotelmic flow	Flow of water sourced from within the wetland itself (rather than from external sources) cf. Exotelmic.
Eutrophic	Nutrient-enriched (not necessarily also base-rich, but often so).

Evapotranspiration	Loss of water from the soil by evaporation from the surface and by transpiration from the plants growing thereon; the volume of water lost in this way.
Exotelmic flow	Flow of water within a wetland derived, at least in part, from sources outwith the wetland, cf. Endotelmic.
Fen	Often used as a generic term for all minerotrophic mires (see rich fen and poor fen); can include mires on peat and normally wet mineral deposits (tufa and so on). The everyday, and place-name, usage of 'fen' is nowadays particularly associated with East Anglia, but the old english 'fenn', cognate with the old frisian 'fenne' and the middle dutch 'venne' seems to have had a much wider usage and compass, being the common word for marshy ground and including habitats that would now often be called 'bog' – a breadth of use which is preserved in the modern dutch 'veen'.
Fenatic	An enthusiast of fens; normally harmless.
Floodplains	Refers to more or less flat valley-bottom surfaces alongside relatively mature watercourses and episodically flooded by these (such as most of the broadland mires).
Flow Track	Used as a generic term for distinct, linear zones of focussed surface or near-surface water flow within wetlands, and includes runnels, soakways and water tracks.
Flush	Usually sloping surfaces, kept wet by downslope surface or near-surface flow or water over a low-permeability material. Groundwater flushes and flushed surfaces are surfaces upon an aquitard, located below a spring or seepage line, and irrigated primarily by surface, or near-surface flow of water derived from groundwater outflow upslope of them.
Fluvial deposition	Material deposited by a watercourse.
Fluviogenous wetlands	Riverside wetlands that are directly flooded with river water, in whole, or part.
Geology	The science or study of the earth's crust and associated strata; note that this represents a discipline, not a feature, so that strictly speaking sites do not have a 'geology'.
Grazing marshes / grazing levels	This term often particularly applies to areas of (partly) claimed floodplain wetlands which are summer-dry; it is not, however, specific to these.
Groundwater	Used primarily to refer to water in, or sourced from, a bedrock or drift aquifer; although peat may form a local aquifer, in this report 'groundwater' is not normally used for the water within wetland substrata, to avoid possible confusion with regard to peat deposits which are groundwater-fed and those that are not.
Guanotrophication	Nutrient enrichment from bird droppings (especially sea-birds).
Headwater fen	Haslam (1965) used this term in much the same sense as valleyhead wetland is used here.
Helophyte	A plant typical of marshy or lake-edge environments in which the shoots/leaves are mostly or entirely above the water level (such as reed) (*cf.* Hydrophyte).
Hill slope wetland	Soligenous wetlands developed as patches on a hill side.
Hover	A buoyant raft of vegetation over water or fluid muds; also known as quag, schwingmoor or scraw.
Humification (von post scale)	Degree of decomposition (of peat) [production of humus from the decay of organic matter as a result of microbial action].

Hummocks	Elevated mounds created by the growth of bryophytes, especially *Sphagnum* species.
Hydraulic conductivity [*k*; k_{sat}]	The rate at which water moves through a material. K_{sat} denotes saturated hydraulic conductivity: the rate at which water moves through a saturated material.
Hydraulic gradient	The change in hydraulic head or water surface elevation over a given distance.
Hydraulic head	The difference in pressure-head between two hydraulically connected points.
Hydromorphology	Used here synonymously with hydrotopography.
Hydroperiod	The pattern of water level fluctuation with time in a wetland
Hydrophyte	A plant typical of aquatic environments in which the leaves or shoots are mostly submerged or floating (such as water lily) (*cf.* Helophyte)
Hydrosere (hydroseral)	Can be used generically to encompass all seral process of vegetation change within wetlands (both paludification and terrestrialisation), but often, and arguably more appropriately, restricted to be more or less synonymous with the terrestrialisation of open water.
Hydrostatic pressure	The pressure created by the weight of water acting upon itself.
Hydrotopographical element	Unit with distinctive water supply and, sometimes, distinctive topography in response to this. Many wetlands contain a number of such elements, and the same element may occur in wetlands belonging to different situation types.
Hydrotopography	An ill-defined term which is usually used to mean the shape of the wetland and its situation with respect to the cause(s) of its wetness (apparent sources of water).
Lacustrine wetland	A generic term for wetlands around lakes and pools.
Lagg	A moat-like strip of fen around the margins of some raised bogs; normally used to refer to a distinctive (often wet) structure rather than just the minerotrophic fringe which normally occurs where any ombrogenous deposit contacts adjoining mineral ground or minerotrophic peat.
Lawn	Noticeably even (level) surfaces on flat or sloping ground.
Littoral colonisation	Encroachment of vegetation by rooting on accumulating peat and muds.
Macrofossils	Plant or animal remains preserved in peat which can be identified without the use of a high-powered microscope (such as stems, leaves and roots but not pollen grains).
Marl	Particles of calcite, usually suspended in water or forming a fine-grained sediment
Marsh	Seasonally dry wetlands on mineral soils.
Mesotrophic	Of moderate nutrient status (not necessarily also sub-neutral).
Meteoric water	Precipitation.
Microtope	A part of a mire where the plant cover and all other physical components of the environment associated with it are uniform; often more or less equivalent to a stand.
Minerotrophic	Fed by telluric water.
Minerotrophic mire	Mire whose surface is irrigated both by precipitation and telluric water.
Mire	A general term for habitats with consistently high, but rarely above-surface, water tables; it is sometimes applied specifically to peat-producing ecosystems but here used more broadly as a synonym for ‘permanent telmatic wetlands’.

Molinion	Vegetation of the Molinion caeruleae phytosociological alliance (such as *Molinia* meadows, M24, M25)
Oligotrophic	Low fertility, nutrient poor (not necessarily also base poor).
Ombrogenous	Wetland developed under the exclusive influence of precipitation.
Ombrotrophic	Wetland surface fed directly and exclusively by water derived from the atmosphere (rain, snow, fog and so on).
Ombrotrophic bog	Bog with surface irrigated more or less exclusively by precipitation inputs.
Ontogeny / ontogenesis	History of development.
Open water transition mire	Used by Goode (1972) and Ratcliffe (1977) as a hydrotopographical unit to refer to water-fringe wetlands, but usage can be ambiguous as water fringes can be embedded within other hydrotopographical units (such as basin mires)
Palaeoecology	The study of the relationship between past organisms and the environment in which they lived.
Paludification (paludosere)	The development of wetland directly over formerly dry ground through impeded drainage or an increase in water supply.
Paludal, paludic,	Paludal and paludic are derived from the latin *palus*, meaning a marsh or wet ground; telmatic has a similar compass of meaning, but is of Greek derivation ($\tau\varepsilon\lambda\mu\alpha$).it seems likely that both *palus* and $\tau\varepsilon\lambda\mu\alpha$ have a similar compass of meaning, though there is a tendency (not followed here) for telmatic (and telmatology) to be used with specific reference to peat-based wetlands.
Paludogenic deposit	Deposits formed as part of the wetland mire itself – such as peat, lake muds, alluvial clays – and can vary considerably in character and properties; can included both allochthonous and autochthonous material (see Chapter 5).
Paludology	Study of wetlands (literally, of marshes); telmatology has a similar meaning and is preferred by some workers because this word does not combine Latin and Greek roots.
Peatland	All areas with peat, including sites with natural or semi-natural vegetation and areas converted to agriculture and forestry or used for peat extraction.
Peat pits	Excavated hollows within wetlands.
Perched water mound	Refers to the water mound developed within a raised bog as a result of impeded drainage and storage of water derived solely from precipitation (perched above the level of regional groundwater levels).
Percolation	Used to refer to diffuse water flow through a (usually topogenous) wetland deposit.
Permeability	The capacity of a porous medium for transmitting water.
Phreatic	The level in the ground at which the hydrostatic pressure is equal to atmospheric pressure is defined as the water table or phreatic surface (the water table in equilibrium with the atmosphere).
Poor fen	Minerotrophic mire, typically of pH less than 5.5.
Precipitation	Deposition of water on the earth's surface by rain, snow, mist, frost, condensation and so on; the quantity of water so deposited.
Quag, quaggy	Quaking, often buoyant, surfaces within wetlands. [OED: ‘a marshy or boggy spot, *esp.* one covered with a layer of turf which shakes or yields when walked on’]
Raised bog	Name given to a dome or domes of ombrogenous peat formed above the regional groundwater table, mainly in basins and floodplains; dome may be bordered by a rand and lagg.

Rand	A 'rim, margin, or border', cognate with the Swedish and Danish 'rand' of similar meaning. Following Swedish telmatologists, 'rand' is used here specifically to refer to the rather dry, and often steeply sloping, margin of a raised bog, which often directly adjoins a peripheral lagg.
Recharge zone	Zone within a wetland acting as a water supply.
Redox potential (Eh, Eh[10])	A scale that indicates the oxidation–reduction status of a medium. The redox potential of a system (Eh) is analogous to the pH of a system; higher values indicate better aeration and oxidising conditions. Waterlogging of soils typically leads to depletion in oxygen and to a lowering of Eh, but because soils often contain other chemical sources of oxidising power that can support microbial activity, Eh values can continue to decline after the soil has become anoxic.
Rheophilous	Literally 'flow loving', and used often to refer to plants, communities or mire types that are particularly associated with lateral water flow within mires.
Rheo-topogenous*	Topogenous surfaces with significant lateral water movement (percolation).
Rheotrophic	Literally 'flow nourished', and refers to areas of mires where the hydrochemical (and hence nutritional) status is (partly) determined by enhanced, water-flow sourced, supply.
Rich fen	Minerotrophic mire, typically of pH more than about 5.5.
(Surface) Run-off	Water that reaches (or leaves) a mire either by overland flow or percolation through the upper layers of the adjoining substratum (due to gravity).
Rond	A slightly elevated narrow strip of drier land alongside rivers; includes bands of solid peat which separate rivers from wetter fens and turbaries, but sometimes also used for bunds of drier peat within the wetland; mainly dialectal (East Anglia); 'rand' and 'roddon' are sometimes used in a similar way in some other parts of Britain (but rand is generally used in a quite different sense by telmatologists).
Runnel	Small lines of water flow on fairly steep slopes and often on a skeletal substratum.
Schwingmoor	(German) floating vegetation mat / raft (cf. Hover, quag),
Seepage	Groundwater seepage is considered to be groundwater outflow from a mineral aquifer to the surface of a wetland (cf. Flush).
Sere	Plant successional sequence (as used in hydrosere, paludosere).
Situation type	The position the wetland occupies in the landscape, with particular emphasis on principal water supply. May include several different hydrotopographical elements.
Soakway	Water flow tracks within wetlands which can be detected by the contrast in their vegetation and wetness relative to the flanking mire; distinguished from a water track by having little or no obvious surface water.
Soligenous	Literally 'made by soil'; here, used to refer to wetness induced primarily by supply of telluric water sourced from mineral deposits adjoining a wetland.
Soligenous wetlands	Wetlands primarily kept wet by supply of telluric water with little impedance to outflow; most typical of relatively steep slopes where groundwater or run-off input produces surface-wet conditions. Wetlands on more or less flat surfaces are not usually classified here unless characterised by rates of water throughflow comparable to that on the steeper slopes. They often have thin deposits of peat and water movement is often more by surface flow than percolation through the peat.

Spring	Used to refer to a discrete focus of groundwater outflow from a mineral aquifer onto the ground surface, usually with visible water flow into a stream, runnel(s) or soakway; may occur as an area of enhanced outflow within a more diffuse seepage system.
Spring fen, seepage fen	Generic terms which include various types of soligenous wetlands fed by groundwater outflow, but not including flushes.
Spring mound	A (usually small) convex mound developed over strong groundwater upflows, often stabilised by inwashed mineral material or precipitated calcite (tufa mound).
(Peat) Stratigraphy	Description of the layering within a peat deposit based on the composition and character of the peat and mineral content.
Stagno-topogenous	Topogenous surfaces which have little water throughflow (percolation).
Stand	A relatively uniform patch of vegetation of distinctive species composition and appearance; can vary in size from very small (e.g. two m^2) to very large (e.g. one ha). The internal uniformity can sometimes encompass small scale, repeated, heterogeneity, such as is created by a microtopographical mosaic.
Sub-neutral	Wetlands with pH range around 5.5 to 6.5.
Sump	Small, shallow depressions within other hydrotopographical types of wetland.
Surface water	Water from pools and lakes, watercourses, land-drainage, surface run-off and so on (cf. Groundwater).
Swamp	Wetlands with emergent vegetation in shallow standing water (summer water table typically more than about 25 cm above ground level); note that in North American terminology, swamp is more often used to refer to forested wetlands.
Telluric water	A generic term for water that has been in contact with the mineral ground, as opposed to direct precipitation inputs (*meteoric water*); includes both groundwater and surface water.
Telmatic wetland	Wet, semi-terrestrial wetlands (not aquatic wetlands), subdivided into permanent, seasonal and fluctuating types; derived from the greek *telma* (τελμα), meaning 'pond, marsh, swamp'; 'paludal' and 'paludic' are Latin-derived equivalents.
Telmatology, telmatologist	The study of, or one who studies, telmatic wetlands, derived from the Greek τελμα, meaning 'pond, marsh, swamp' , and ολογία. Some workers prefer these terms to 'paludology' because the latter is of mixed Latin and Greek derivation.
Terrestrialisation	The transition of open water to dry, solid ground by the process of hydroseral succession, which occurs by gradual infilling with accumulating organic (with or without mineral) material, or sometimes by the initial formation of a floating raft of vegetation (quag, *schwingmoor*).
Top layer	Generic term for the substratum of a wetland (paludogenic deposit) and its immediately underlying mineral material (basal substratum).
Topogenous	Wetness induced by topography and poor drainage of telluric water (hollows and so on)
Topogenous wetlands	Telluric wetlands in which high water level is maintained by impeded drainage (detention) of water inputs.
Trough	The unqualified term 'trough' is used to refer to elongate, mostly valley-bottom contexts which are neither valleyheads nor floodplains.
Tufa	Generally coarse precipitate of calcite.

Tufa mounds	Convex domes of precipitated calcite with variable amounts of organic material; small examples are effectively calcite-based spring-heads, but large examples can support a wide range of wetland vegetation and represent a rather different unit.
Tump	The opposite of sump: small elevations within wetlands (note that this is not a nonce-word – it comes from the OED: 'a clump of trees or shrubs; a clump of grass, esp. one forming a dry spot in a bog or fen').
Turf pond	Reflooded (and usually revegetated) peat workings, typically 0.5 to 0.8 m deep (cf peat pit).
Tussocks	Elevated mounds created by the growth of caespitose vascular plants, such as *Molinia caerulea* or *Schoenus nigricans*; tussocks can sometimes coalesce to form elevated platforms.
Valley fen, valley mire	A term so widely used and in a variety of different ways as to be a source of much confusion; it is perhaps most often used by UK workers to refer to valleyhead wetlands, but it has also been used in a quite different sense: for example, Haslam (1965) specifically used this term in almost the opposite sense to refer to floodplain systems (she used headwater fen to refer to the valley fens of some other UK workers).
Valleyhead wetland	Wetlands associated with the headwaters and upper reaches of valleys; mainly soligenous (such as new forest valley mires).
Valleyside wetland	Soligenous wetlands developed along a valley slope.
Water body	A generic term for a depression containing open water; includes pools, lakes, streams, dykes, drains and so on.
Water level	A generic term for water surface and water table.
Water meadow	Alluvial wetland with hydrological characteristics largely determined by a specific management regime.
Water surface	Surface of standing water.
Water table	Below-ground free water surface.
Water track	Trackways of preferential water movement through wetlands; distinguished from a soakway by having more open water.

1.2 Names of plant species referred to in the text

Flowering plants (excluding grasses, sedges and rushes)

Alnus glutinosa	Alder
Anagallis tenella	Bog pimpernel
Andromeda polifolia	Bog rosemary
Apium graveolens	Wild celery
Bartsia alpina	Alpine bartsia
Berula erecta	Lesser water parsnip
Betula pubescens	Downy birch
Calluna vulgaris	Heather
Ceratophyllum demersum	Rigid hornwort
Cicuta virosa	Cowbane
Cirsium acaulon	Dwarf thistle
Cirsium arvense	Creeping thistle
Cirsium dissectum	Meadow thistle
Cirsium palustre	Marsh thistle
Corallorhiza trifida	Coralroot orchid
Crepis paludosa	Marsh hawk's-beard
Dactylorhiza incarnata	Early marsh orchid
Dactylorhiza praetermissa	Southern marsh orchid
Dactylorhiza traunsteineri	Pugsley's marsh orchid
Drosera intermedia	Oblong-leaved sundew
Drosera longifolia (= D. anglica)	Great sundew
Drosera rotundifolia	Common sundew
Empetrum nigrum	Crowberry
Epilobium hirsutum	Great hairy willow-herb
Epipactis palustris	Marsh helleborine
Erica ciliaris	Dorset heath
Erica tetralix	Crossed-leaved heath
Eupatorium cannabinum	Hemp agrimony
Euphrasia pseudokerneri	Eyebright species
Filipendula ulmaria	Meadowsweet
Galium aparine	Common cleavers
Galium palustre	Common marsh bedstraw
Gymnadenia conopsea	Fragrant orchid
Hammarbya paludosa	Bog orchid
Hippurus vulgaris	Mare's tail
Hottonia palustris	Water violet
Hydrocharis morsus-ranae	Frog-bit
Hydrocotyle vulgaris	Marsh penny-wort
Hypericum elodes	Marsh St. John's wort
Hypericum undulatum	Wavy St. John's wort
Iris pseudacorus	Yellow flag iris
Lathyrus palustris	Marsh pea
Liparis loeselii	Fen orchid
Listera ovata	Common twayblade
Lysimachia thyrsiflora	Tufted loosestrife
Lysimachia vulgaris	Yellow loosestrife
Mentha aquatica	Water mint
Menyanthes trifoliata	Bog bean
Myrica gale	Bog myrtle
Narthecium ossifragum	Bog asphodel
Oenanthe lachenalii	Parsley water dropwort
Ophrys apifera	Bee orchid
Parentucellia viscosa	Yellow bartsia
Parnassia palustris	Grass of Parnassus
Pedicularis palustris	Marsh lousewort
Pedicularis sylvatica	Lousewort
Peucedanum palustre	Milk parsley
Pinguicula lusitanica	Pale butterwort
Pinguicula vulgaris	Common butterwort
Pinus	Pine
Potamogeton coloratus	Fen pondweed
Potamogeton polygonifolius	Bog pondweed
Potentilla erecta	Tormentil
Potentilla palustris	Marsh cinquefoil
Primula farinosa	Bird's-eye primrose
Pyrola rotundifolia	Round-leaved wintergreen
Ranunculus flammula	Lesser spearwort
Ranunculus lingua	Greater spearwort
Ranunculus trichophyllus	Thread-leaved water crowfoot
Rhododendron ponticum	Rhododendron
Rorippa nasturtium-aquatica	Water cress
Rorippa palustris	Marsh yellow cress
Rumex hydrolapathum	Water dock
Sagina nodosa	Knotted pearlwort
Salix cinerea	Grey willow
Salix fragilis	Crack willow

Salix pentandra	Bay willow
Scheuchzeria palustris	Rannoch rush
Schoenus nigricans	Black bog-rush
Selinum carvifolia	Cambridge milk parsley
Sium latifolium	Greater water parsnip
Sonchus palustris	Marsh sow-thistle
Sparganium minimum	Least bur-reed
Stellaria palustris	Marsh stitchwort
Stratiotes aloides	Water soldier
Succisa pratensis	Devil's-bit scabious
Symphytum officinalis	Common comfrey
Thalictrum flavum	Common meadow-rue
Trifolium spp.	Clover species
Triglochin palustre	Marsh arrow-grass
Typha angustifolia	Lesser bulrush/ reedmace
Typha latifolia	Greater bulrush/ reedmace
Urtica dioica	Nettle
Utricularia minor	Lesser bladderwort
Utricularia intermedia	Intermediate bladderwort
Utricularia vulgaris	Greater bladderwort
Vaccinium oxycoccos	Cranberry
Viola palustris	Marsh violet
Viola persicifolia	Fen violet

Grasses, sedges and rushes

Agrostis canina	Velvet bent
Agrostis stolonifera	Creeping bent
Arrhenatherum elatius	False oat grass
Blysmus compressus	Flat sedge
Briza media	Quaking grass
Calamagrostis canescens	Purple small reed
Calamagrostis stricta	Narrow small reed
Carex acutiformis	Lesser pond sedge
Carex appropinquata	Fibrous tussock sedge
Carex binervis	Green-ribbed sedge
Carex diandra	Lesser tussock sedge
Carex dioica	Dioecious sedge
Carex disticha	Brown sedge
Carex echinata	Star sedge
Carex elata	Tufted sedge
Carex hostiana	Tawny sedge
Carex lasiocarpa	Slender sedge
Carex limosa	Mud sedge
Carex magellanica	Bog sedge
Carex panicea	Carnation sedge
Carex paniculata	Greater tussock sedge
Carex pauciflora	Few-flowered sedge
Carex pseudocyperus	Hop or cyperus sedge
Carex pulicaris	Flea sedge
Carex rostrata	Bottle sedge
Carex viridula ssp. brachyrrhyncha (= C. lepidocarpa)	Long-stalked yellow sedge
Carex viridula ssp. oedocarpa (= C. demissa)	Common yellow sedge
Cladium mariscus	Saw sedge (great fen sedge)
Deschampsia cespitosa	Tufted hair grass
Eleocharis multicaulis	Many-stalked spike rush
Eleocharis quinqueflora	Few-flowered spike rush
Eleocharis uniglumis	Slender spike rush
Eleogiton fluitans	Floating club rush
Eriophorum angustifolium	Common cottongrass
Eriophorum gracile	Slender cottongrass
Eriophorum latifolium	Broad-leaved cottongrass
Eriophorum vaginatum	Hare's-tail cottongrass
Festuca arundinacea	Tall fescue
Glyceria maxima	Reed sweet-grass
Juncus acutiflorus	Sharp flowered rush
Juncus alpino-articulatus	Alpine rush
Juncus bulbosus	Bulbous rush
Juncus effusus	Soft rush
Juncus inflexus	Hard rush
Juncus subnodulosus	Blunt-flowered rush
Molinia caerulea	Purple moor grass
Phalaris arundinacea	Reed canary-grass
Phragmites australis (= P. communis)	Common reed
Rhynchospora alba	White beak-sedge
Scirpus cespitosus	Deer grass
Scirpus lacustris	Common club-rush
Scirpus maritima	Sea club-rush

Lower plants

Mosses*:*
Bryum pseudotriquetrum
Calliergon cuspidatum
Calliergon giganteum
Campylium elodes
Campylium stellatum
Cinclidium stygium
Cratoneuron commutatum
Dicranum undulatum
Drepanocladus exannulatus
Drepanocladus lycopodioides
Drepanocladus revolvens
Drepanocladus vernicosus
Fissidens adianthoides
Gymnostomum recurvirostrum
Homalothecium nitens
Paludella squarrosa
Philonotis calcarea
Philonotis fontana
Plagiomnium elatum
Plagiomnium ellipticum
Rhizomnium pseudopunctatum
Scorpidium scorpioides
Sphagnum spp (bog mosses)

Liverworts*:*
Aneura pinguis
Cladopodiella fluitans
Leiocolea rutheana
Moerckia hibernica = M. flotoviana
Pellia endiviifolia
Preissia quadrata
Riccardia chamedryfolia
Riccardia multifida

Other:
Chara spp. (stoneworts)
Lycopodiella inundatum (marsh clubmoss)
Cladonia spp. (lichen)
Selaginella selaginoides (lesser clubmoss)

Ferns and horsetails

Dryopteris cristata	Crested buckler-fern
Equisetum fluviatile	Water horsetail
Equisetum telmateia	Great horsetail
Equisetum variegatum	Variegated horsetail
Osmunda regalis	Royal fern
Thelypteris palustris	Marsh fern

1.3 Names of plant communities referred to in the text

(See also Table 3.2)

NVC[1] Code	NVC name	"English" name[2]
(PPC)	[No equivalent]	Slender sedge–Milk parsley fens
(CM)	[No equivalent]	Saw sedge–Purple moor grass fens
(BDc)	[No equivalent]	
M3	*Eriophorum angustifolium* bog pool community	Common cottongrass community
M4	*Carex rostrata–Sphagnum recurvum* mire	Bottle sedge–Bog moss community
M5	*Carex rostrata–Sphagnum squarrosum* mire	Bottle sedge–Squarrose bog moss community
M6	*Carex echinata–Sphagnum recurvum/ auriculatum* mire	Star sedge–Bog moss community
M9	*Carex rostrata–Calliergon cuspidatum* mire	Bottle sedge–Brown moss community. (Slender sedge fens)
M9-1	*Carex lasiocarpa–Scorpidium* mire	Slender sedge–Hooked scorpion-moss community
M9-2	*Carex diandra–Calliergon* mire	Lesser tussock sedge–Brown moss community.
M9-3	*Carex diandra–Peucedanum palustre* mire	Lesser tussock sedge–Milk parsley community.
M10	*Pinguicula vulgaris–Carex dioica* mire	Butterwort–Dioecious sedge community
M13	*Schoenus nigricans–Juncus subnodulosus* mire	Black bog rush–Blunt-flowered rush community
M14	*Schoenus nigricans–Narthecium ossifragum* mire	Black bog rush–Bog asphodel community
M15	*Scirpus cespitosus–Erica tetralix* wet heath	Deer grass– Cross-leaved heath community
M17	*Scirpus cespitosus–Eriophorum vaginatum* blanket mire	Deer grass–Cottongrass community

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1 NVC = National Vegetation Classification (Rodwell, 1991a,b; 1995).

2 Note that these common names are provided for guidance, and are not necessarily 'officially' accepted.

NVC[1] Code	NVC name	"English" name[2]
M18	*Erica tetralix–Sphagnum papillosum* raised and blanket mire	Cross-leaved heath–Bog moss community
M21	*Narthecium ossifragum–Sphagnum papillosum* valley mire	Bog asphodel–Bog moss community
M22	*Juncus subnodulosus–Cirsium palustre* fen meadow	Blunt-flowered rush–Marsh thistle community.
M23	*Juncus effusus/ acutiflorus–Galium palustre* rush pasture	Rush–Marsh bedstraw community
M24	*Molinia caerulea–Cirsium dissectum* fen meadow	Purple moor grass–Meadow thistle community
M25	*Molinia caerulea–Potentilla erecta* mire	Purple moor grass–Tormentil community
M26	*Molinia caerulea–Crepis paludosa* mire	Purple moor grass–Marsh hawksbeard
M29	*Hypericum elodes–Potamogeton polygonifolius* soakway	Marsh St John's Wort–Bog pondweed community
S1	*Carex elata* sedge swamp	Tufted sedge community
S2	*Cladium mariscus* sedge swamp	Saw sedge community
S4	*Phragmites australis* swamp and reed-beds	Common reed community
S5	*Glyceria maxima* swamp	Reed sweet-grass community
S9	*Carex rostrata* swamp	Bottle sedge community
S24	*Phragmites australis–Peucedanum palustre* fen	Common reed–Milk parsley community
S25	*Phragmites australis–Eupatorium cannabinum* fen	Common reed–Hemp agrimony community
S26	*Phragmites australis– Urtica dioica* fen	Common reed–Nettle community
S27	*Carex rostrata–Potentilla palustris* fen	Bottle sedge–Marsh cinquefoil community.
S28	*Phalaris arundinacea* tall-herb fen	Reed canary-grass community
W3	*Salix pentandra–Carex rostrata* woodland	Bay willow–Bottle sedge woodland
W4	*Betula pubescens–Molinia caerulea* woodland	Downy birch–Purple moor grass woodland
W5	*Alnus glutinosa–Carex paniculata* woodland	Common alder–Greater tussock sedge woodland

2 List of abbreviations

agl	Above ground level
bgl	Below ground level
Eh^{10}	Oxidation–reduction (redox) potential (see glossary) at 10 cm depth
K_{corr}	Conductivity of a solution, corrected for the contribution made by hydrogen ions.
HCO_3	Bicarbonate.
$Fertility_{Phal}$	Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently, the technique of phytometry was developed (Wheeler, Shaw and Cook, 1992). This involves measuring the biomass of test species (phytometers – in this case reed canary grass *Phalaris arundinacea*) grown on soil samples. Typical phytometer yields (dry wt.): low fertility < 8 mg, high fertility > 18 mg.
pH	A value on a scale of one to 14 which gives a measure of the acidity or alkalinity of a medium (such as soil or water). Seven is neutral pH.
PE	Potential evapotranspiration. The amount of water that would evaporate or transpire from a surface if water supply were unlimited.
PAL depth	Depth of wetland deposits, including peat, gyttja, lake muds and so on.
SE	Standard error.
spp.	Species.

Appendix 2
Data Sources and Analyses

1 Sites examined

Sites used in the study are listed in Table 1.1. Additional sites from which samples were examined to validate WETMECs are shown in Table 1.2. See Appendix 3 for site accounts.

Table 1.1: Sites included in the study

Site	***County***
Eastern England	
Badley Moor	Norfolk
Barnby Broad and North Cove	Suffolk
Barnham Broom Fen	Norfolk
Barton Broad	Norfolk
Beetley and Hoe Meadows	Norfolk
Benacre Broad	Suffolk
Berry Hall Fens	Norfolk
Booton Common	Norfolk
Broad Fen, Dilham	Norfolk
Bugg's Hole, Thelnetham	Suffolk
Bunwell Common (Aslacton Parish Land)	Norfolk
Burgh Common	Norfolk
Buxton Heath	Norfolk
Catfield and Irstead Fens	Norfolk
Cavenham Poor's Fen	Suffolk
Chippenham Fen	Cambridgeshire
Cornard Mere	Suffolk
Cranberry Rough	Norfolk
Decoy Carr, Acle	Norfolk
Dernford Fen	Cambridgeshire
Dersingham Bog	Norfolk
Drabblegate Common	Norfolk
Ducan's Marsh and Carleton Broad	Norfolk
Easton Broad and Frostenden Valley	Suffolk
East Ruston Common	Norfolk
East Walton Common	Norfolk
Flordon Common	Norfolk
Forncett Meadows	Norfolk
Foulden and Gooderstone Commons	Norfolk
Great Cressingham Fen	Norfolk
Hall Farm Fen (Hemsby)	
Hickling Broad Marshes	Norfolk
Holly Farm Meadow	Norfolk
Holme Fen	Cambridgeshire
Holt Lowes	Norfolk
Hopton Fen	Suffolk
Hulver Ground	Norfolk
Kenninghall and Banham Fens	Norfolk
Lakenheath Poors Fen	Suffolk
Limpenhoe Meadows	Norfolk
Middle Harling Fen	Norfolk
Ormesby Common	Norfolk
Pakenham Meadows	Suffolk

Site	***County***
Pashford Poors Fen, Lakenheath	Suffolk
Poplar Farm Meadows	Norfolk
Redgrave and Lopham Fens	Suffolk
Reedham Marshes	Norfolk
Roydon Common	Norfolk
Roydon Fen	Norfolk
Sawston Hall Meadows	Cambridgeshire
Scarning and Potters Fen	Norfolk
Shacklewell Hollow	Leicestershire
Sheringham and Beeston Regis Commons	Norfolk
Smallburgh Fen	Norfolk
Southrepps Common	Norfolk
Strumpshaw and Bradeston Marsh	Norfolk
Sutton Broad	Norfolk
Sutton Fens	Norfolk
Swangey Fen	Norfolk
Swannington Upgate Common	Norfolk
Thelnetham Fens	Suffolk
Thriplow Meadows	Cambridgeshire
Upton Fen and Doles	Norfolk
Walberswick (Westwood and Dingle Marshes)	Suffolk
Ward Marsh and Ranworth Flood	Norfolk
Weston Fen (Suffolk)	Suffolk
Wheatfen and Rockland	Norfolk
Whitwell Common	Norfolk
Wicken Fen	Cambridgeshire
Woodbastwick Fens and Marshes	Norfolk
Woodwalton Fen	Cambridgeshire
North-East England	
Great Close Mire (Malham)	West Yorkshire
Ha Mire (Malham)	West Yorkshire
Malham Moss	West Yorkshire
Newham Fen	Northumberland
Pilmoor	North Yorkshire
Skipwith Common	North Yorkshire
North-West England	
Biglands Bog	Cumbria
Birk Bank Moss	Cumbria
Bowness Common	Cumbria
Bowscale Moss	Cumbria
Cliburn Moss	Cumbria
Crosby Gill	Cumbria

Site	*County*
Esthwaite North Fen	Cumbria
Eycott Hill Mires	Cumbria
Great Candlestick Moss	Cumbria
Great Ludderburn Moss	Cumbria
Greendale Flushes	Cumbria
Hollas Moss	Cumbria
Knott End Moss	Cumbria
Leighton Moss (with Storrs Moss)	Lancashire
Meathop Moss	Cumbria
Moorthwaite Moss	Cumbria
Newton Reigny Moss	Cumbria
Nichols Moss	Cumbria
Silver Tarn	Cumbria
Stable Harvey Moss	Cumbria
Stagmire Moss	Cumbria
Sunbiggin Tarn and Moors	Cumbria
Tarn Moss	Cumbria
Thornhill Moss and Meadows	Cumbria
Walton Moss	Cumbria
Wedholme Flow	Cumbria
Southern England	
Acres Down	Hampshire
Arne (The Moors)	Dorset
Ashculm Turbary	Devon
Aylesbeare Common	Devon
Bicton Common	Devon
Boundway Hill	Hampshire
Bramshaw Wood Bog	Hampshire
Bransbury Common	Hampshire
Buckherd Bottom	Hampshire
Chilbolton Common	Hampshire
Chobham Common	Surrey
Church Moor	Hampshire
Clayhill Bottom	Hampshire
Cothill Fen	Oxfordshire
Cranes Moor (Hampshire)	Hampshire
Cridmore Bog	Isle of Wight
Denny Bog (west)	Hampshire
Emer Bog (Baddesley Common)	Hampshire
Folly Bog	Surrey
Fort Bog	Hampshire
Greywell Fen	Hampshire
Gritnam Bog	Hampshire
Hagthorn Bog	Surrey
Hartland Moor	Dorset
Holmhill Bog	Hampshire
Holmsley Bog	Hampshire
Hyde Bog	Dorset
Kinson Common	Dorset
Landford Bog	Wiltshire
Lords Oak Bog	Hampshire
Matley Bog	Hampshire
Morden Bog	Dorset
Retire Common	Cornwall
Rosenannon Bog and Downs	Cornwall
Shatterford Bottom	Hampshire
Shortheath Common	Hampshire

Site	*County*
Stoborough Heath	Dorset
Stockbridge Fen	Hampshire
Stoney Cross	Hampshire
Stoney Moors	Hampshire
Strodgemoor Bottom	Hampshire
The Moors (Bishop's Waltham)	Hampshire
Thursley Common	Surrey
Ventongimps Moor	Cornwall
Warwick Slade Bog	Hampshire
Widden Bottom	Hampshire
Wilverley Bog	Hampshire
Winfrith Heath – Whitcombe Vale	Dorset
South Midlands	
Blackend Spinney Fen	Buckinghamshire
Bonemills Hollow (Hornstock Valley)	Cambridgeshire
Clack Fen	Buckinghamshire
Drayton Parslow Fen	Buckinghamshire
Drayton Parslow North Fen	Buckinghamshire
Nares Gladley Marsh	Bedfordshire
Nash Fen	Buckinghamshire
Pilch Fields	Buckinghamshire
Sutton Heath and Bog	Cambridgeshire
Syresham Marshy Meadows	Northamptonshire
Tingewick Meadows	Buckinghamshire
Valley Farm Fen	Buckinghamshire
West Midlands	
Abbots Moss (South Moss and Shemmy Moss)	Cheshire
Betley Mere	Staffordshire
Cranberry Bog	Staffordshire
Brown Moss	Shropshire
Chartley Moss	Staffordshire
Fenns and Whixall Mosses	Shropshire/Flintshire
Flaxmere Moss	Cheshire
Forest Camp	Cheshire
Lin Can Moss	Shropshire
Loynton Moss	Staffordshire
Wybunbury Moss	Cheshire
Wales	
Banc y Mwldan	Ceredigion
Cors Bodeilio	Anglesey
Cors Erddreiniog (including Bryn Mwcog and Cors Nantisaf)	Anglesey
Cors Geirch	Gwynedd
Cors Goch	Anglesey
Cors Graianog	Gwynedd
Cors Gyfelog	Gwynedd
Cors Hirdre	Gwynedd
Cors Llyn Coethlyn	Powys
Cors y Farl	Anglesey
Cors y Llyn (Radnor)	Powys
Cwm Cadlan Grasslands	Powys
Dowrog Common	Pembrokeshire
Llyn y Fawnog	Conwy
Parc Newydd	Anglesey

Site	*County*
Pont y Spig	Monmouthshire
Rhos Goch (Rhos Goch Common)	Powys

Site	*County*
St. David's Airfield Heaths	Pembrokeshire
Trefeiddan Moor	Pembrokeshire

Table 1.2: Additional sites from which samples were examined to validate WETMECs

Site	*County*
Eastern England	
Blo' Norton Fen	Norfolk
Boughton Fen	Norfolk
Coston Fen	Norfolk
Dereham Rush Meadow	Norfolk
Mattishall Fen	Norfolk
Potter Heigham Marshes	Norfolk
Scoulton Mere	Norfolk
Thompson Common	Norfolk
North-West England	
Buckbarrow Farm Flush	Cumbria
Burney Tarn Mire	Cumbria
Southern England	
Catcott Heath	Somerset
Hense Moor	Devon
Holmsley Station Bog	Hampshire
Lashford Lane Fen	Oxfordshire
Lye Valley (Bullingdon Bog)	Oxfordshire
Shapwick Heath	Somerset
Spring Head, Axmouth	Devon
Stowell Meadow	Somerset
North-East England	
Agden Bog	South Yorkshire
Ashberry and Reins Wood	North Yorkshire
Askham Bog	North Yorkshire
Blackhall Rocks	Durham
Calver Sough	Derbyshire
Epworth Turbary	Lincolnshire
Fen Bogs, Lockton High Moor	North Yorkshire
Ford Moss	Northumberland
Ha Mire	West Yorkshire
Holburn Moss	Northumberland
Ripon Parks	West Yorkshire
Sand Dale	North Yorkshire
Seive Dale Fen	North Yorkshire
Shirley Pool	South Yorkshire
Swarth Moor	North Yorkshire
Thorne, Crowle and Goole Moors	South Yorkshire
Troutsdale	North Yorkshire
Went Ings Meadows	South Yorkshire
Whitwell Wood (Ginny Spring)	Derbyshire

2 Data sources

Various data sources contributed information for the sites (Table 1.1) and stands considered. The FENBASE database, held and maintained at the University of Sheffield, contained a large amount of relevant data, and was used extensively. For those sites selected for inclusion which had little or no existing FENBASE data, new stand-based data were collected using the FENBASE protocols.

2.1 Vegetation data

Two main types of vegetation data were available: species records (quadrat samples) and vegetation maps. The data used in the floristic analysis of communities, and the calculation of species-richness statistics, are sourced from all of the information for England and Wales held on the FENBASE database (10,499 quadrat samples from 951 wetland sites). These include quadrat data from a number of sources:

Bellamy (1967)	Mires in various parts of England
Wheeler (1975)	Rich-fen survey of lowland England and Wales
Wheeler and Shaw (1985), Shaw and Wheeler (1990, 1991)	Habitat survey of herbaceous fens in lowland Britain
Headley (1989)	Crymlyn Bog Survey
Smart (1992)	Survey of East Anglian Valleyhead Fens
Parmenter (1995)	Broadland Fen Survey
Fojt (1994)	Cumbria Mire Survey
England Field Unit (1984)	New Forest Mire Survey

These main data sources have been supplemented by published information and material in reports of the Countryside Council for Wales and English Nature, and by other miscellaneous data collected by ourselves or kindly made available by other workers, including W Fojt, G. Groome, P.S. Jones and R. Meade. All of these data have been collected using a protocol broadly similar to that adopted by the *National Vegetation Classification* and are thus essentially comparable. Data from the Welsh Lowland Peatland Survey and other potential sources have also been made available to us but have not been included here, because of their rather different approach to vegetation sampling.

Some of the analyses consider 'rare species'. Species rarity of wetland plant species has been assessed for Britain as a whole, not just for England and Wales, using the criteria outlined by Wheeler (1988).

2.2 Environmental data

The main source of environmental data has been the Habitat Survey made by Shaw and Wheeler (1985, 1990, 1991), updated with comparable data collected subsequently for various projects, including samples acquired specifically for the *Wetland Framework* project. Data from Broadland (Parmenter, 1995), which were collected and analysed using the same procedures and protocols as those used by Wheeler and Shaw, were included. The hydrochemical data provided by Bellamy (1967) have been used, together with various data in publications and unpublished reports, where these have been collected by methods comparable with those used by Wheeler and Shaw. However, the only data available for a phytometric assessment of soil fertility are those obtained by Wheeler and Shaw and by Parmenter (1995).

Stand-based environmental data available for the sites examined, and held on FENBASE, include measurements of:

Interstitial mire water: depth, pH, conductivity, alkalinity (HCO_3).
Mire soil: pH, oxidation–reduction potential (Eh), fertility (assessed phytometrically).
Soil extract concentrations: Ca, Mg, Na, Mn, Fe, Al, K, N, P.

Water level data

Three sources of water level data were available:

- FENBASE water level measurements;
- dipwell and gauge board measurements (a few sites – Environment Agency and other installations);
- estimated water level categories.

Categorised estimates of site water levels were made by individuals familiar with the sites (site managers and so on), for both 'winter' and 'summer' conditions. For details of the scale used, see Section 3.

Data on rainfall and potential evaporation were provided for the area relevant to each site by the Environment Agency from Low Flows 2000[1].

Stratigraphical data of the wetland deposits

Stratigraphical data of the wetland deposits (such as peat, alluvium, lake muds) at each stand provided a source of insight into possible water supply mechanisms, with information on the character and consolidation of the deposit being of particular value. The main source of stratigraphical data (and the only source for many sites) was stand-based information held on the FENBASE database. Detailed stratigraphical data were also available from published studies (though these could not always be related to specific stands), and from various unpublished reports. Where available, borehole logs (from piezometer installations and so on) were examined, but in general they did not provide much information on the specific character and composition of the wetland infill, though they did often indicate its depth.

2.3 Hydrogeological data

Hydrogeological data for many of the sites are available as borehole logs and summary interpretative reports for many of the sites in Eastern England, and from some sites elsewhere. Further interpretative reports (see Appendix 4) were commissioned for sites which were otherwise little known, mainly from Hydrogeological Services International

[1] With the permission of Wallingford Hydrosolutions Limited

(HSI), Environmental Project Consulting Group (New Forest sites) and Nottingham Trent University (West Midlands and some Cumbrian sites). Although not always known with certainty, the likely water sources and possible supply mechanisms were identified from these sources and collated into a series of short site accounts, which were circulated for comment and revision. Thus, the main water sources for each site outlined in the hydrogeological site accounts represent the best assessment, given existing information, based on expert judgement. It is accepted that for some sites, these assessments may require modification as new information becomes available.

Piezometric data

Piezometric data are available for many of the sites examined in Eastern England, especially from piezometers (and gauge boards) installed by the Environment Agency, and were used extensively in the Phase 1 study. However, comparable data are not available for most sites in other regions and they were omitted from the analyses of the full dataset.

3 Data types and categories

A range of data was derived from the data sources listed above and stored in a consistent and systematic database format. The data used for the main analyses were either continuous (ratio or interval data), derived mostly from on-site measurements, or ranked (ordinal) data, using ranked categories based on estimates or the categorisation of continuous variables. Not all of the continuous or ranked variables available were used in the analyses. A range of nominal data (either Boolean or multi-state variables) was also extracted from the data sources, but these data were used for descriptive purposes or as data selection criteria.

This section identifies the variables used in the project and defines the categories used for the ranked variables. The categories relate to conditions in and around individual *stands* (samples) and, unless otherwise specified, refer primarily to conditions in the main growing season (late spring to summer). The data type of each variable is also specified (Boolean, continuous, ranked or multi-state).

In the case of ranked variables, the rank numbers given form the quantitative values of the variables used in the analyses. Null is used for missing values or where the status is unknown. Zero, when used, means zero: a positive absence of the variable. The Boolean or multi-state variables were not used in the numerical analyses.

3.1 Vegetation variables

Community type Multi-state

NVC category of best fit to the stand sample. In a small number of cases the NVC categories were considered inappropriate and custom units were adopted.

Biodiversity terms

The following biodiversity categories (number of species per unit area) were used. Note that these are not mutually exclusive.

All species Continuous

Mire species Continuous

Fen species Continuous

Fen woodland [Carr] species Continuous

Bog species Continuous

Nationally rare species Continuous

Regionally rare species Continuous

Characteristic species Continuous

The ‘characteristic species’ term refers to the number of species present that are considered to be characteristic of a particular ‘target’ community, such as M13 or M21. The number of characteristic species for non-target communities is expressed in terms of a specified, related target community (Table 3.1), for example, the characteristic species term for a stand of M22 is expressed in terms of the number of M13 species present.

Table 3.1: Target communities used for the assessment of the number of characteristic species of specific wetland vegetation types

NVC ID	Community name	Target community containing characteristic species
M01	*Sphagnum auriculatum* bog pool	M21
M02	*Sphagnum cuspidatum/recurvum* bog pool	M18
M03	*Eriophorum angustifolium* bog pool	M18
M04	*Carex rostrata–Sphagnum recurvum* mire	M05
M05	*Carex rostrata–Sphagnum squarrosum* mire	M05
M06	*Cx.echinata–Sphagnum recurvum/auriculatum* mire	M05
M08	*Carex rostrata–Sphagnum warnstorfii* mire	'M09'
M9-1	*Carex lasiocarpa–Scorpidium scorpioides* mire	'M09'
M9-2	*Carex diandra–Calliergon* mire	'M09'
M9-3	*Carex diandra–Peucedanum palustre* mire	'M09'
M10	*Carex dioica–Pinguicula vulgaris* mire	M13
M13	*Schoenus nigricans–Juncus subnodulosus* mire	M13
M14	*Schoenus nigricans–Narthecium ossifragum* mire	M14
M15	*Scirpus cespitosus–Erica tetralix* wet heath	M21
M17	*Scirpus cespitosus–Eriophorum vaginatum* blanket mire	M18
M18	*Erica tetralix–Sphagnum* papillosum raised and blanket mire	M18
M19	*Calluna vulgaris–Eriophorum vaginatum* blanket mire	M18
M20	*Eriophorum vaginatum* blanket and raised mire	M18
M21	*Narthecium ossifragum–Sphagnum papillosum* valley mire	M21
M22	*Juncus subnodulosus–Cirsium palustre* fen meadow	M13
M24	*Molinia caerulea–Cirsium dissectum* fen meadow	M13
M25	*Molinia caerulea–Potentilla erecta* mire	M21
M29	*Hypericum elodes–Potamogeton polygonifolius* soakway	M14
S24	*Phragmites australis–Peucedanum palustre* fen	S24
S25	*Phragmites–Eupatorium* fen	S24
S26	*Phragmites australis–Urtica dioica* fen	S24
S27	*Carex rostrata–Potentilla palustris* fen	'M09'
B25	*Betulo–Dryopteridetum cristatae*	M05
B10	*Cladio–Molinietum*	M13

3.2 Hydrochemical and soil variables

pH	**Water pH**	Continuous
	Soil pH	Continuous

Base richness categories Ranked Value

These categories are based on the pH boundaries recognised by Wheeler and Proctor (2000) and relate broadly to subdivisions used by some other workers:

1:	Base-rich	pH 6.5 – 8.0	Fen	7
2:	Sub-neutral	pH 5.5 – 6.5	Fen	6
3:	Base-poor	pH 4.0 – 5.5	Bog (~poor fen)	5
4:	Acidic	pH < 4.0	Bog	4

Conductivity Continuous

Kcorr$_r$ values (µS cm^{-1})

Fertility Continuous

Phytometric estimates of soil fertility, obtained by growing a test species (*Phalaris arundinacea*) on soil samples in controlled conditions. Values are mean shoot dry weight (mg).

Fertility categories [Ranked

The fertility categories are based on an arbitrary subdivision of the phytometric scale, as proposed by Wheeler and Proctor (2000):

1:	Oligotrophic	< 8 mg phytometer
2:	Mesotrophic	8 – 18 mg phytometer
3:	Eutrophic	18 – 38 mg phytometer
4:	Hypertrophic	> 38 mg phytometer

Occurrence of calcite Ranked

0: None
1: On plants
2: Some marl in water/soil
3: Marly (milky) water
4: Much solid marl/tufa in organic soil
5 Marl/tufa-based; little organic material

Occurrence of ochre Ranked

0: None
1: Sporadic/seasonal
3: Some (dilute carrot soup)
4: Much (tomato soup)
5: Solid ochre deposits

3.3 Hydrological variables

Rainfall Continuous

Potential evaporation (PE) Continuous

[Both rainfall and PE data were available as estimates at site level]

Water table (summer) Continuous

Measured summer water table, relative to ground level (cm)

Wetness categories:

Summer water level Ranked

Winter water level Ranked

1:	very dry	(< –75 cm)
2:	dry	(–75 to –40 cm)
3:	rather dry	(–40 to –18 cm)
4:	sub-surface	(–18 to –5 cm)
5:	near surface	(–5 to +1 cm) (water readily oozes from footprints)
6:	above surface	(+1 to +10 cm)
7:	shallow swamp	(+10 to +25 cm)
8	swamp	(+25 to +50 cm)

Water flow (within stand) Ranked

Refers to visual evidence for water flow within the stand

0: no obvious flow
1: possible flow (where some flow seems likely but no visible evidence)
2: probable flow or winter only flow (wet slopes without visible surface flow)
3: visible summer flow
4: strong summer flow
5: streaming (in or alongside streams or strong water tracks)

Water outflow (from stand) Ranked

Refers to visual evidence for water flow *out of* the stand (runnels or streams draining the stand)

0: no obvious flow
1: possible flow (where some flow seems likely but no visible evidence!)
2: probable flow or winter only flow (wet slopes without visible surface flow)
3: visible summer flow
4: strong summer flow
5: streaming (in or alongside streams or strong water tracks)

3.4 Groundwater variables

Aquifer	**bedrock**	[AQUISOURCE]	Text/Multi-state
	drift	[DAQUISOURCE]	Text/Multi-state

Used to indicate the main bedrock or drift aquifer feeding the site. Categories are not pre-defined.

Aquifer type [AQUITYPE] Ranked

When more than one aquifer type is present, the highest ranking category should be selected.

Note that the former subdivision between bedrock and drift aquifer types has been abandoned as few reliable data are available.

0: None
1: More or less confined
2: Shallow surface water/unconfined (used to include thin drift 'aquifers')
3 Unconfined
4 Semi-confined
5: Semi-confined, strongly artesian

Piezometric head category Ranked

In the case of multiple aquifers, the category value refers to the greatest head.

0: None
1: Deep below peat
2: Shallow below peat
3: Within peat
4: More or less at surface
5: Well above surface

Groundwater outflow type Ranked / M-S

In the absence of data on the volumetric contribution of groundwater to the surface conditions of most of the fen sites, the strength of groundwater input has been categorised on the basis of observable features, using the scale:

0: No known inputs, or inputs trivial

1: Groundwater usually sub-surface in summer (includes marginal flushed areas that are summer-dry)

2: Groundwater near or at surface in summer in topogenous areas (such as flat surfaces or shallow depressions) without an obvious summer surface outflow

3: Sloping seepage faces and topogenous hollows with an obvious surface water outflow in summer

4: Stand containing, or influenced by, strong springs and springheads

5: Stand containing, or influenced by, an active spring mound.

Proximity to groundwater outflow Ranked

[In some situations (such as larger topogenous mires with deep peat), it is not clear to what extent there is upward flow to the surface. Unless the localisation of such upflows is reasonably certain, in sites with a suspected groundwater input, the distance selected should be that to the margin or to obvious surface groundwater features (such as springs), whichever is the nearer]

0: None

1: > 100 m

2: 30 – 100 m

3: 10 – 30 m

4: 3 – 10 m

5: Adjoining/within

Level of surface below groundwater outflow level Ranked

This term estimates the topographical relationship between the stand and visible groundwater supply features, mainly to assess whether the rooting zone is upslope or downslope of the apparent position of such inputs:

0: No inflows or much above outflow

1: 1–2 m above outflow

2: < 1 m above outflow

3: Slightly above outflow

4: More or less level with outflow (use should include, for example, spring mounds where the surface is kept wet by upflow)

5: Downslope of outflow

Groundwater features

The following features associated with present or past groundwater supply have been recorded; they serve only for descriptive purposes and have only been used in analyses and data selection criteria:

Spring head Boolean

Spring mound Boolean

Soligenous slope Boolean

Intermittent soligenous slope Boolean

Runnels [RUNNELS] Boolean

Soakway Boolean

Water track Boolean

[N.B. Not all of these features are exclusively associated with groundwater supply to wetlands, but they are grouped together here for convenience]

3.5 Surface water supply variables

Surface water supply variables distinguish two main situations – **upslope** (marginal) inputs (surface-run-off, drain inflow) and **downslope** (water body) inputs (lakes, dykes, streams, rivers). These categories refer to surface water inflows that are upstream and downstream (respectively) of the *stand.* Marginal surface inflows do not (normally) have a drainage function, whereas water bodies can sometimes serve both as drains and water sources, depending on the hydraulic gradient. Thus a river flowing through a site, or a lateral stream flowing *through* a stand, is considered to be a water body whereas a ditch flowing *into* a stand is considered to be a marginal input. The status of dykes depends upon whether they are connected to a marginal input or a water body (if both, then normally they were regarded to form part of the water body).

An additional complication is created in some sites where surface flows originate in (or very near) the wetland, as opposed to surface water inflows which usually originate well outside of the wetland. Surface flow tracks that originate within the wetland were distinguished as a separate category (endotelmic flows). This category can include surface flow tracks which are sourced from seepages, surface flows in ombrogenous mires and surface flows in surface-water fed mires, where the flow-track originates from within the mire rather than from an exotelmic surface water source. Note that streams entering mires that are sourced from well outwith the mire boundary are considered to be surface water inputs.

Marginal surface water inflows Ranked

In the absence of data on the volumetric contribution of surface water to the surface conditions of most of the fen sites, the strength of surface water input has been categorised on the basis of observable features, using the scale:

- 0: No known inputs, or inputs trivial (includes occasional surface run-off from permeable soils)
- 1: Within drains *(*includes water in drains that is normally below mire surface in summer)
- 2: Surface run-off (likely occurrence judged on basis of soil/rock in catchment, HOST category and so on)
- 3: Under-drainage inflow
- 4: Ditch discharge into stand
- 5: Stream discharge into stand.

Proximity to run-off inflows Ranked

- 0: None
- 1: > 100 m
- 2: 30–100 m
- 3: 10–30 m
- 4: 3–10 m
- 5: Adjoining/within

Level of surface below run-off inflow level Ranked

- 0: No inflows or much above run-off inflow
- 1: 1–2 m above run-off inflow
- 2: < 1 m above run-off inflow
- 3: Slightly above run-off inflow
- 4: More or less level with run-off inflow
- 5: Downstream of run-off inflow

Distance from water body Ranked

‘Water body’ is used here to refer to features such as lakes, pools, watercourses and some dykes, which have a potential water supply function, at least during part of the year.

0: Adjoining/within
1: 3–10 m
2: 10–30 m
3: 30–100 m
4 > 100 m
5: No water body

Level of surface above water body Ranked

0: Below water body water level
1: Mostly level with water body water level
2: Slightly above water body water level
3: < 1 m above water body water level
4: > 1 m above water body water level
5: No water body or much above water body water level

Proximity to upland margin Ranked

‘Upland margin’ refers to the upslope edge of the part of the mire where the stand occurs.

0: None
1: > 100 m
2: 30–100 m
3: 10–30 m
4: 3–10 m
5: Adjoining

Endotelmic flow Ranked

Refers to visual evidence for surface water flow *within* the stand that is not obviously a product of inflow from specific external sources. Excludes small runnel systems associated with seepages.

0: None or not obvious
–1: Former flow line
1: Winter-only surface flow (dry in summer, or a soakway)
2: Summer pools (disconnected pools along apparent flow line)
3: Probable summer flow (continuous water tracks without visible summer flow)
4: Visible summer flow
5: Strong summer flow

Proximity to drains Ranked

0: None
1: > 100 m
2: 30–100 m
3: 10–30 m
4: 3–10 m
5: Adjoining

Level of surface above drain water level Ranked

This category represents both the potential for drainage of the stand and to some extent, for water supply. In some contexts it can duplicate the information in Water Course Inputs (which uses a similar scale), and when the ditches are in free hydraulic connection with the watercourse, the values for both fields will be the same.

0: No drains nearby or lower than water body water level
1: More or less level with water body water level
2: Slightly above water body water level
3: < 1 m above water body water level
4: 1–2 m above water body water level
5: Very much above water body water level

Other surface water features

The following features associated with present or past groundwater supply have been recorded; they serve only for descriptive purposes and have only been used in analyses and data selection criteria:

Regular summer flooding Boolean

Regular winter flooding Boolean

Impeded drainage [Boolean

'Impeded drainage' was recorded mainly in topogenous stands where the high water table is maintained by blockage of the outflow. In many situations this is likely to be artificial (a sluice or a dam), but some natural impedances to outflow can also be included.

Interceptor drains or ridges Boolean

Presence of catchwater ditches or elevated surfaces between stand and apparent water source.

3.6 Wetland substratum variables

The term 'wetland substratum' refers to the assemblage of deposits that have formed in wetland conditions. Pre-eminently this includes peat, but it also includes organic muds (gyttja), marls and sedimentary silts and clays. The material immediately underlying the wetland infill is referred to as the basal substratum.

Wetland substratum permeability categories

The character of the wetland infill at each stand has been categorised on a seven-point ranked scale. The categories are based on the observed character of the wetland infill, but the rank values may reflect crudely the permeability of this. Four separate variables have been determined for each stand, each using the same scale. The **surface layer** terms refer to the uppermost 30 to 50 cm of the profile, including the rooting zone, and have been estimated for the stand itself and for the surface-layer characteristics upslope and downslope of the stands. The 'upslope' and 'downslope' terms aim to characterise surface layer conditions between the stand and the supposed water source or sink. The **lower layer** term relates to any deposit present in the profile between the surface layer and the underlying basal substratum. If the profile was stratified in either of the surface layer or lower layer zones, the main substratum category with the lowest rank value (permeability) was recorded. No assessment was made of the lower layer characteristics upslope and downslope of the stand. In some samples with a shallow wetland deposit, there was no lower layer and the surface layer rested directly upon the basal substratum, and in a very few examples with a skeletal substratum, the surface layer was also absent and the basal substratum was exposed at the surface. Where the substratum upslope of the stand was mineral ground, the surface layer characteristics were categorised using the basal substratum permeability categories (below).

Surface layer permeability (within stand) Ranked

Surface layer permeability (upslope of stand) Ranked

Surface layer permeability (downslope of stand) Ranked

Lower layer permeability (within stand) Ranked

1: Stiff clay or silt
2: Dense, solid, well-humified peat
3: Well-decomposed, firm peat (includes much catotelm peat in bogs)
4: Firm, moderately decomposed peat (typically herbaceous)
5: Fresh herbaceous peat (may be more or less continuous hydroseral infill) (includes much acrotelm peat in bogs)
6: Loose plant material/fresh herbaceous peat (may be semi-floating hydroseral mat)
7: Very loose plant material, usually at edge of water bodies; effectively water with rhizomes

Basal substratum permeability categories Ranked

The basal substratum refers to the mineral material that immediately underlies the wetland infill. Its character at each stand has been categorised on a seven-point ranked scale. The categories are based on the observed character of the material, but the rank values may reflect crudely the permeability of this.

1: Heavy silt/clay; low-permeability bedrock
2: Silt/clay loam
3: Sandy clays/silts
4: Sandy clay/silt loams
5 Sandy loams
6: Sand/gravel; high permeability bedrock
7: Coarse gravel

Stability of surface (quakiness) Ranked

1: Solid
2: Firm
3: Soft
4: Very soft
5: Semi-floating/quaking
6: Floating

Slope [flatness] Ranked

Note that for clarity in some contexts and analyses the degree of slope is expressed as a flatness term, in which [FLATNESS] = (6 – [SLOPE])

1: More or less flat
2: Very gentle
3: Slight
4: Moderate
5: Steep

PAL (Peat and Alluvium) Depth
Continuous

Total depth of the wetland infill below the stand, including peat, alluvium, lake muds.

Peat thickness Ranked

Marl thickness Ranked

Tufa thickness Ranked

Ranked categorisation of the thickness of peat, marl or tufa beneath the stand were made according to the following scale:

0:	± None	
1:	Very thin	(< 20 cm)
2:	Thin	(< 50 cm)
3:	Moderate	(50–150 cm)
4:	Fairly deep	(1.5–3 m)
5:	Deep	(3–5 m)
6:	Very deep	(> 5 m)

Cut-over surface Boolean

Presence or absence of past peat removal – generic category.

Possibly peat cut Boolean

Surface thought likely to have been cut over but little or no surface evidence.

Turf pond Boolean

Reflooded, tank-like peat pit with summer water table well above base of pit.

Peat pit Boolean

Unflooded peat working, with summer water table near or below base of pit.

Baulk Boolean

Uncut, or less deeply cut, peat surface within a peat cutting complex, usually a narrow ridge.

Block cut Boolean

Milled Boolean

Other disturbance Boolean

Hydrosere Boolean

Hydroseral colonisation of former natural pool or turf pond.

4 Canonical correspondence analysis (CCA) and relationships amongst variables

4.1 Rationale and terms included

CCA is a multivariate analytical technique which can be used to help identify the relationships between environmental variables and variation in the species composition of vegetation (see Box 4.1). The procedure helps to identify which variables are most important in accounting for the main extracted directions of floristic variation, and in so doing also shows the inter-relationships between different environmental variables.

CCA was used to explore the relationships between environmental variables and vegetation, with a view to identifying some of the main ecohydrological processes relevant to wetland vegetation (and thereby the identification of WETMECs). The entire dataset was examined and numerous subsidiary analyses were also made on data subsets. The CCA analysis was based on scores of water and water-related variables, that is, variables relating to: water level and flow, rainfall and potential evaporation; height of the surface in relation to any known groundwater and surface water sources, and distance from these; topographical context of the stand (slopes and so on); characteristics of the upper and lower layers of wetland infill within the stands (and between the stands and any known water sources or sinks); and characteristics of the uppermost layer of mineral material below the wetland infill of the stand (referred to as the basal substratum). Other variables for which data were available (such as vegetation, hydrochemistry, topography and landscape situation of the site) were excluded from this analysis.

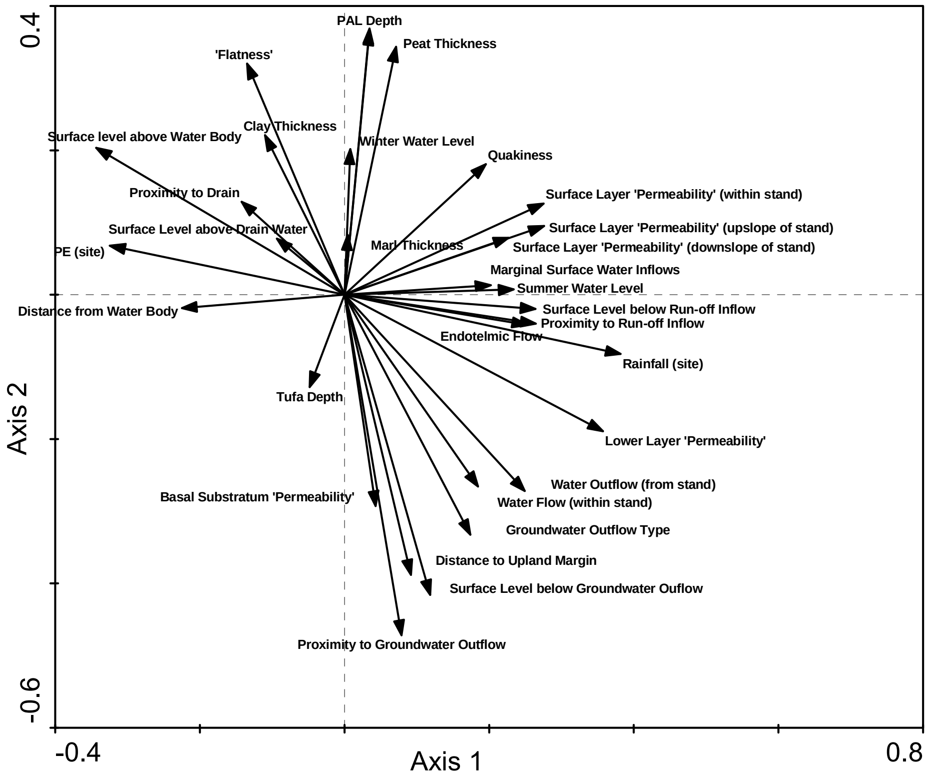
Box 4.1: Canonical correspondence analysis

Like the more familiar principal components analysis, canonical correspondence analysis is an ordination procedure. Whereas the aim of classification is to summarize (reduce the complexity of) a dataset by amalgamating samples with similar characteristics into classes (clusters), ordination procedures simplify datasets by identifying the main gradients of variation (linked patterns of change) within them. For example, a set of quantitative vegetation data containing, say, 56 species can be thought of as a 56-dimensional system where each dimension encompasses variation in the abundance of one individual species. However, although each dimension is nominally independent of all others, in most datasets several species show correlated patterns of changing abundance across the samples, which means that it is possible to identify linked trends (or gradients) of changing species composition within the dataset. Ordination procedures attempt to identify the main gradients of linked floristic change and calculate axes (typically one to three) which correspond to these and against which the original samples can be plotted in positions which best reflect their compositional similarity with one another. One important outcome of this procedure is that the floristic gradients (derived axes) can be correlated with environmental variables, to determine possible causes of the gradient of floristic change. The CCA procedure essentially identifies and extracts the main gradients of change in vegetation composition and performs a multiple regression of several environmental variables against one or more of these gradients, whilst optimising the fit between environmental and floristic gradients. Like all correlative procedures, CCA does not demonstrate causality between floristic gradients and changing environmental conditions, but it is suggestive of links and forms a basis for hypothesis generation.

4.2 Canonical correspondence analysis (CCA) of all samples

The results for Axes 1 and 2 of a CCA analysis of all of the samples used in the *Wetland Framework*, based on the scores of water and water-related variables, are shown in Figure 4.1 (Box 4.2 provides some notes on interpreting CCA diagrams). Only Axes 1 and 2 have been plotted, as examination of Axes 1 and 3 provides few additional insights. For clarity, individual samples have not been plotted on the ordination.

The CCA diagram (Figure 4.1) points to a number of significant inter-relationships within the dataset. In interpreting these it is important to remember that: (a) the relationships shown represent the interactions amongst the variables in the context of optimising the relationship between all variables to help detect overall patterns; this does not necessarily always correspond to their pair-wise correlative relationships; and (b) the diagram is a biplot, which expresses the environmental variables in terms of their relationship to variation in vegetation composition (the axes) (see Box 4.2). In the following interpretation of the CCA ordination the values of pair-wise correlations between some terms are also given, especially when they differ from the relationships as summarised by CCA.



Terms included are explained and units given in data types and categories (above). Unless otherwise indicated, variables refer to individual stands. Abbreviations are: PAL: Peat and Alluvium; PE: Potential Evaporation

Figure 4.1 Axes 1 and 2 of a CCA ordination of species composition and values of water and water-related variables in all samples included in the analysis

Box 4.2: Interpretation of CCA biplots

CCA diagrams are typically plotted as biplots of species and environmental variables. Where present, plotted points represent individual stands and their position reflects their floristic similarity (the more similar they are, the closer they are together). The *x* and *y* axes which enclose each diagram are the two main gradients of floristic change. In some instances, with large number of samples, the individual sample points are not plotted for clarity, but the axes still refer to the main gradients of floristic change.

The arrows on the diagrams represent the degree to which measured environmental variables relate to the floristic axes. In essence, the closer their angle is to any one axis, the stronger is the relationship of the variable to that axis, whilst the longer the arrow, the greater importance it has in accounting for floristic variation.

The arrows all start from a common origin and indicate positive relationships, but they can also be envisaged as extending backwards, on the other side of the origin, as a negative relationship. Thus, clusters of arrows pointing in the same direction represent cross-correlated variables; arrows pointing in opposite directions are negatively related; and arrows orthogonal to each other are independent of one another. Note that these relationships represent the overall *interactions* between variables, as best as they can be expressed in a two-dimensional system, and the position of each variable represents a compromise based on all of its relationships. Thus it is possible, for example, for two variables to be positively correlated on a pair-wise comparison, but to appear to be independent of one another when considered in the context of all of the variables to which they are related. A consequence of this is that the expressed relationship between pairs of variables is not fixed and can depend in part on which other variables are included within the dataset. Another is that some individual samples may not correspond well to the components of the environmental pattern as plotted, especially those which contain a rare or anomalous (in the context of the dataset) combination of environmental conditions or species. On average, the further stand points are plotted along the length of an arrow, the greater the value of the variable is likely to be for that stand, though again as this diagram summarises multidimensional variation, there is not necessarily an exact relationship between the characteristics of any one stand and its position with respect to an environmental variable.

The main conclusions that emerge from the CCA ordination are listed below. All pair-wise correlations mentioned are statistically significant ($P < 0.05$) unless otherwise stated.

4.2.1 Summer water level

i. Summer water level is closely associated with the first (main) axis of species variation, although it does not account for a particularly large amount of variation overall[1]. As an interaction term it is almost orthogonal (unrelated) to winter water level, which is closely associated with Axis 2. [However, on a pair-wise comparison winter and summer water tables are quite strongly correlated ($r = 0.612$)]

ii. Variation in summer water level is, overall, related to rainfall, surface run-off inflow and within-site endotelmic flow, whilst rainfall is negatively related to PE. The significance of this is probably mainly that many of the stands that are wettest in summer tend to occur in regions with highest rainfall and greatest surface run-off. [Interestingly, in a pair-wise comparison summer water table is not very strongly correlated with surface run-off ($r = 0.170$)]

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[1] This fits with observations made by Wheeler and Shaw (1995) who found that in a CCA ordination of wetland samples which also included hydrochemical and substratum terms, variation is summer water level was less important in accounting for floristic variation than base richness (most important) and fertility terms.

4.2.2 Groundwater outflow

i. Terms relating to groundwater outflow are cross correlated and form a loose cluster. They are broadly negatively related to Axis 2, but also show a variable degree of positive skew towards Axis 1. This suggests that groundwater outflow has considerable independence from summer water levels, though there is a tendency for stands with high rates of groundwater outflow to be wetter than average (the pair-wise correlation between groundwater outflow and summer water levels is $r = 0.291$). The groundwater outflow terms are also strongly associated with estimates of basal substratum permeability, and this persists in pair-wise correlations.

ii. Estimated summer surface water flow within the stands, and summer surface outflow from the stands are closely related. Higher estimated flow rates are most closely associated with the groundwater group of terms, with a weaker relationship to the 'summer water level – surface run-off – rainfall' group.

iii. The groundwater outflow terms are generally positively associated with sloping surfaces (negative flatness) and are negatively associated with higher winter water levels and deep peat. Groundwater-fed sites thus tend to be sloping, have shallow peat and are less wet in winter than are many other systems, though it is not difficult to find exceptions to these general trends.

iv. The more strongly sloping surfaces (which are particularly associated with groundwater outflow) have a slight positive association with higher summer water levels, whereas flatter surfaces have a slight negative association, though again there are many individual exceptions to these overall relationships.

4.2.3 Surface run-off inflow

i. Surface run-off is generally a much less important term in the dataset than is groundwater outflow. In the ordination it is closely associated with higher rainfall sites, and a pair-wise correlation with rainfall amount gives $r = 0.456$. The overall relationships suggest that it is largely independent of slope and, perhaps more surprisingly, basal substratum permeability (surface run-off and basal substratum permeability terms also show a weak, non-significant, negative pair-wise correlation ($r = -0.108$)).

4.2.4 Wetland infill and surface characteristics

i. Great peat depths are closely associated with higher winter water levels, possibly because most deep-peat sites occur in topogenous situations, some of which experience winter flooding. Deep peat is, however, not related to high summer water tables, probably because many deep peat sites have been partly drained or receive only limited summer recharge, which does not compensate fully for evapotranspirative losses (in a pair-wise comparison peat depth has a very small, non-significant, negative, correlation with summer water level ($r = -0.057$)).

ii. Quakiness (surface stability) occupies a position between peat depth and summer water level on the CCA diagram. Although peat depth and summer water level are nearly independent of each other, both in the CCA ordination and in pair-wise correlation, high quakiness is positively correlated with both of them, especially summer water level, in pair-wise comparisons (peat depth: $r = 0.222$; summer water level: $r = 0.519$). Thus loose, quaking or buoyant surfaces are mostly associated with deep peat locations and are characterised by fairly high summer water tables, whereas solid surfaces on deep peat often have rather low summer water tables. Quakiness is also strongly related to the surface layer permeability term (in a pair-wise correlation $r = 0.723$), suggesting that one reason why deep peat samples with quaking surfaces may be wetter than those on solid peat is because they are more readily recharged. Of course, as there is a tendency for summer-wet sites to occur in high rainfall areas it is difficult to disentangle, from the CCA diagram, the significance of high hydraulic conductivity from high rainfall in relation to summer water levels. However, both quakiness and surface layer permeability values are more strongly related to higher summer water levels than they are to higher rainfall.

iii. Depth of tufa is associated with the groundwater outflow terms, but makes limited contribution to accounting for floristic variation overall, probably because tufa deposition is scarce amongst the available samples. In the CCA ordination, and in pair-wise correlation, tufa depth and summer water Level show very little relation, which is compatible with field observations that some of the highest tufa mounds tend to be drier than lower ones. Rather surprisingly, depth of marl shows little association with groundwater outflow, both in the CCA ordination and in pair-wise correlation with the groundwater terms. Possible explanations for this are that (a) deep deposits of marl are mostly associated with deep peat and PAL deposits and with flat surfaces, all of which are generally negatively associated with groundwater outflow; and (b) deep marl deposits may occur in basins which now have limited supply from groundwater outflow, perhaps partly because the accumulated marl acts as a local aquitard.

iv. Depth of clay, marl and peat are all positively associated with the total depth of wetland infill (PAL) and with flat sites. This is probably because the thickest deposits of all infill types tend to be associated with the deepest basins. Sites with thick deposits of clay show a slight negative association with summer water levels.

4.2.5 Drainage terms

i. The top-left quadrant of the ordination (low loadings on Axis 1, high loadings on Axis 2) is largely occupied by ‘drainage terms’, features that may be expected to lead to low summer water tables, and the terms show varying degrees of negative association with summer water level and rainfall. Note that of the terms included here ‘water bodies’ include lakes, pools, watercourses and dykes which may have the potential to recharge adjoining areas of topogenous fen in appropriate circumstances. In the ordination, increasing distance from a water body is identified as a drainage term in much the same way as proximity to a drain.

4.2.6 Overall interpretations

Subject to the caveats of Box 4.2, the following interpretation is provided of Figure 4.1:

- Floristic Axis 1 (the main direction of species composition variation) corresponds to a gradient of summer water table, in which high water tables are particularly associated with rainfall totals, and low water tables with proximity to drainage structures and distance from potential surface water sources.

- Floristic Axis 2 (the second most important direction of species composition variation) corresponds largely to a topogenous–soligenous gradient, in which the topogenous sites are generally on deeper peat and wetter in winter than the sloping soligenous sites.
- The soligenous sites mostly have groundwater outflow as their primary source of telluric water; groundwater is generally less important in topogenous situations, for various reasons, though there are many exceptions to this generalisation.
- Surface run-off can be significant in both topogenous and soligenous situations, but is generally less important than groundwater outflow, especially in soligenous sites. Its importance increases in high rainfall regions.
- Groundwater outflow on soligenous slopes is generally, but not exclusively, associated with a high permeability basal substratum.
- The presence of a loose, quaking or buoyant surface layer is associated with high summer water tables, especially in topogenous circumstances, which may be indicative of some hydroregulatory function by the surface layer.

Some of these inter-relationships are explored further in Chapter 5.

5 Cluster analysis and identification of WETMECs

5.1 Rationale and terms included

The rationale of the cluster analysis was to identify recurrent quantitative combinations of the water and water-related variables that had been scored for individual stands (samples). The analysis was based on the scores of variables relating to water level and flow; height of the surface in relation to any known groundwater and surface water sources, and distance from these; topographical context of the stand; characteristics of the upper and lower layers of wetland infill within the stands (and between the stands and any known water sources or sinks); and characteristics of the uppermost layer of mineral material below the wetland infill of the stand (referred to as the 'basal substratum'). Other variables for which data were available (such as vegetation, hydrochemistry, topography and landscape situation of the site) were excluded from the analysis. Rainfall and potential evaporation data were included in a preliminary analysis, but were excluded from the final cluster model as it was found they detracted from the clarity of the clustering[1].

The clusters created by the cluster analysis essentially represent composite units reflecting the co-occurrence of combinations of the hydrological, topographical and stratigraphical variables included. There are some potential limitations to this composite approach, because disparate sets of variables can potentially vary independently of each other and have limits that do not necessarily coincide. This can potentially lead to a series of ill-defined entities based on idiosyncratic combinations of values and variables that are difficult to interpret; and different units in different parts of the same classification can potentially be defined by different sets of variables (for example, some units could be related mainly to, say, water source whilst others could be primarily related to peat depth). On the other hand, as the water regime in particular stands is in many cases an expression of the interactions between contrasting hydrogeological, topographical and stratigraphical variables, the potential benefit of a clustering model based on all of these is that it provides a holistic approach which can help identify interactions between recurrent combinations of variables, as well as the combinations themselves. In the event, the analyses suggest that the benefits of the composite approach have much outweighed any potential disadvantages.

5.2 Clustering method

The clustering method used was based on a sequential hierarchical agglomerative fusion of samples in which each successive cluster is formed by the dichotomous fusion of sample pairs, which minimises the increase in the error sum of squares of the dataset (Wards Method, Box 5.1). The procedure allows for the inclusion of missing values. Variables were not differentially weighted but the range of all variables was standardised before the analysis. The 36-cluster stage was selected for examination based on a

[1] Whilst this may seem surprising, even rainfall-dependent systems such as ombrogenous mires occur over a wide climatic range, from dry parts of Eastern England (*e.g.* Thorne Moors) to wet parts of Cumbria (*e.g.* Wedholme Flow).

Moving Average Best Cut Significance Test (t-Statistic). The 36-cluster model was refined by reallocation of some samples using a k-Means Analysis, based on Euclidean Sum of Squares. This procedure helps to correct misclassification of samples which can occur, particularly to samples added at an early stage of the fusion process, as cluster compositions change with the addition of new members. It also permits the identification of outliers and exemplars for each cluster. Some 10 per cent of the samples were reallocated in the present analysis, based on the 36-cluster tree.

Box 5.1: Ward's method of cluster analysis

'Multivariate cluster analysis' refers to a number of numerical techniques, all of which aim to identify distinct clusters (classes) of samples based on their overall similarity with one another in respect of a particular set of variables. For vegetation classification, the samples are usually quadrats and the variables are the species that occur in them; the resulting clusters correspond to plant community types. For this investigation, the samples were stands and the variables were sets of water and water-related variables recorded for them. 'Ward's method' (Ward, 1963) is a powerful agglomerative, polythetic clustering technique which successively groups (fuses) individual samples into higher order clusters which are themselves successively grouped together until only a single cluster – containing all of the samples – remains. Unlike many agglomerative procedures, at any one fusion stage Ward's method does not join together the two samples (or clusters) that are individually most similar to one another. Instead it joins together those two samples or clusters which, on fusion, will lead to the smallest increment in the error sum of squares for the whole dataset. These may or may not be the most similar pair. The method is 'space contracting' – that is, it usually generates a robust and clean classification, without problems of 'chaining', and where the main clusters are clearly identified – but this is often at the cost of forcing ambiguous individuals into the main units. The process therefore optimises the discrimination of the principal data classes at the (possible) expense of the accuracy of its indication of the transitions amongst them and the allocation of some individual samples.

5.3 Ward's Method dendrogram

The Wards Method dendrogram is shown in Figure 5.1. For caveats about interpreting the dendrogram, see Box 5.2. The dendrogram shows the classification of samples. Note that each end-cluster is not necessarily equivalent to a WETMEC. The labels attached provide a partial interpretation of the content of the clusters, by identifying the character of the constituent members of each. Several significant features of the classification may be noted:

i. Five main groups of wetland have been recognised: (i) ombrogenous and near-ombrogenous mires (fed primarily by rainfall); (ii) floodplains (fed mainly from watercourses); (iii) floodplains and valley bottoms fed mainly by groundwater (and often part-drained); (iv) seepage systems; and (v) other systems fed mainly by water flow from the upland margins, sometimes mainly groundwater-sourced (such as flushes), but sometimes with limited (or no known) groundwater supply.

ii. Although the main units are interpretable in topographical terms, these terms were not included in the analysis but have emerged from this. Thus, for example, 'floodplain' and 'ombrogenous' were not specified *a priori* as variables. Nor, and with particular relevance to ombrogenous mires, were rainfall data included as clustering variables.

iii. In general the classification does not the display most of the possible problems attendant on the generation of composite clusters (see above). Rather, different variable-sets have tended to segregate within the hierarchy, fairly consistently in different clusters.

iv. This has, however, resulted in repetition of certain ‘water supply’ types. For example, ‘open water fringe’ wetlands form three widely separate end groups, segregated (mainly) by their primary water source. Similarly there are essentially two series of troughs, soakways, water tracks and (to some extent) basins, depending on whether groundwater is the main water source, or just a contributing source (or largely absent). A case can be made for proposing that these end units essentially work in the same way and differ only in their main water source, and that, for the purposes of water supply mechanisms, they should be combined. It is a moot point as to whether, say, open water fringe mires are best seen as a single unit which can be subdivided into three water-source types or as essentially the same end-unit segregate of the three water-source types. Ward’s Method classification of the available data suggests the latter approach.

v. Clusters 32 to 36 are in some respects more ambiguous than the others. They are essentially united by being fed by a probably rather small proportion of groundwater (or, in some cases, none) but by being summer-wet. They include samples which have surface water drainage as their main (or only) telluric water source, along with samples which appear to have limited groundwater supply *and* limited surface water inflow (but which are usually in high rainfall locations). An additional difficulty with some of these samples is that the actual importance of groundwater has been difficult to assess with available information.

Box 5.2: Interpretation of Ward’s Method dendrogram

In interpreting the cluster analysis dendrogram, several caveats and constraints must be recognised:

- As the units are composite in character, different clusters within the classification may effectively be defined by different sets of variables.
- The clustering identifies recurrent sets of scored characteristics and these effectively represent the combinations that most frequently recur in the dataset.
- The clusters are necessarily a reflection of the data available; variations in the number of samples with similar degrees of shared similarity affects the outcome of the classification. Thus, small sets of samples with distinctive combinations of shared characteristics may become subsumed within broader groups, despite their distinctiveness.
- All other things being equal, large sets of samples with shared characteristics may form higher order clusters within the dendrogram than equally distinctive sets represented by only a small number of samples. This means that clusters occupying the same approximate level in the hierarchy do not necessarily have the same level of cohesion and distinctiveness and that, for some purposes, it may be desirable to identify end groups at different levels in the hierarchy.

These considerations (and others) mean that the architecture of the clustering dendrogram is potentially determined by various influences, in addition to the distinctiveness of the recurrent characteristics of the clusters. Thus, any clustering model is best seen as a tool to assist the interpretation of the data available, not as an exact solution.

5.4 Abstraction of WETMECs from Ward’s Method clusters

Cluster analysis procedures vary considerably in their propensities and the application of a single clustering method does not necessarily generate an easily interpretable, or optimal, clustering solution. Cluster outputs are therefore better seen as a tool to assist interpretation than as an exact solution.

The larger dataset used in the present analysis has generally produced a much less ambiguous dendrogram than was the case in the Phase 1 analysis. Nonetheless, as discussed above (5.3), there is a degree of parallelism between some end groups and a case could be made for merging these into the same WETMEC, albeit at the expense of the dendrogram hierarchy. However, unlike Phase 1, it was decided not to adopt this approach. This was because the dendrogram is coherent and the parallel end groups are based on identifiable differences. It was therefore both possible and appropriate to use the unmodified results of the 36-cluster model as a basis for the abstraction of WETMECs. However, whilst the abstraction of WETMECs has neither modified the contents of individual clusters nor their hierarchical relationships, each end cluster does not necessarily correspond to a separate WETMEC. Some end group sub-clusters were sufficiently similar to one another so that, for practical reasons, they were considered best grouped as sub-types of a single WETMEC. This means that different end groups of the 36-cluster model may have either the status of a WETMEC or a WETMEC sub-type, and this has reduced the 36 end clusters to 20 named WETMECs. It is possible that as more data become available, it would be desirable to elevate some sub-types to a separate WETMEC (Cluster 10, WETMEC 7a, is a potential candidate for this). As the character of the individual clusters has been preserved in the sub-types, this could easily be done.

Whilst the 36-cluster model was used as the main basis for abstracting WETMECs, the classification tree was also examined at other, finer, levels (mainly the 72-cluster model) to check for the existence of interpretable sub-groups within each 36-level cluster. Some clear subdivisions of certain 36-level clusters emerged and where this was the case, they provided a basis for the recognition of further WETMEC sub-types.

Interpretation of the Ward's Method clusters in terms of water supply mechanisms was made by consideration of the known features of each group, in some cases accompanied by a number of subsidiary analyses (multivariate and other). The results of these are not presented individually, except in some cases where they are outlined for specific WETMECs.

Interpretation of water supply mechanisms, and constraints upon this, has been predicated on the proposition that the summer water table is of greatest importance in determining the species composition of most types of wetland vegetation. Supporting evidence for this is provided by Wheeler (1999a), and it does not imply that winter water levels are of no importance to vegetation composition. A consequence of this may be that surface run-off (rain-generated run-off and drain, ditch and stream inflow) appears to be of less importance in some WETMECs than might have been the case if controls on winter water tables had also been considered. The Phase 1 study (in Eastern England) had earlier pointed to a small role of surface run-off with respect to summer water tables in most sites and partly because of this, the expanded study specifically included sites in high rainfall regions and low-permeability rocks and soils, where run-off was thought likely to be more important to summer conditions. However, it emerged that many of the potential run-off fed sites in Cumbria and Wales were also partly groundwater-fed, mostly by fissure flow from minor, probably superficial, aquifers. These have been clustered into different end groups (and allocated to different WETMECs), from those samples where groundwater is clearly the dominant telluric water source, but the actual contribution of groundwater *versus* run-off is in no case known, and will require on-site investigation to be established. It seems probable that purely run-off fed examples of at least topogenous mires occur in some regions, but it is of interest that very few were identified in this investigation.

5.5 Validation

The validity and utility of the WETMECs identified has, as far as possible, been checked by reference to some samples that were not included in the multivariate analyses. These included additional samples from sites included in this study, as well as samples from sites that were not included. These latter (see Table 1.2) include some sites from regions that were not targeted in the initial site selection process. Samples used for validation were from locations from which sufficient information was available to permit their allocation to WETMECs, but in many cases less was known about them than for the analysed samples, especially with regard to their hydrogeological status.

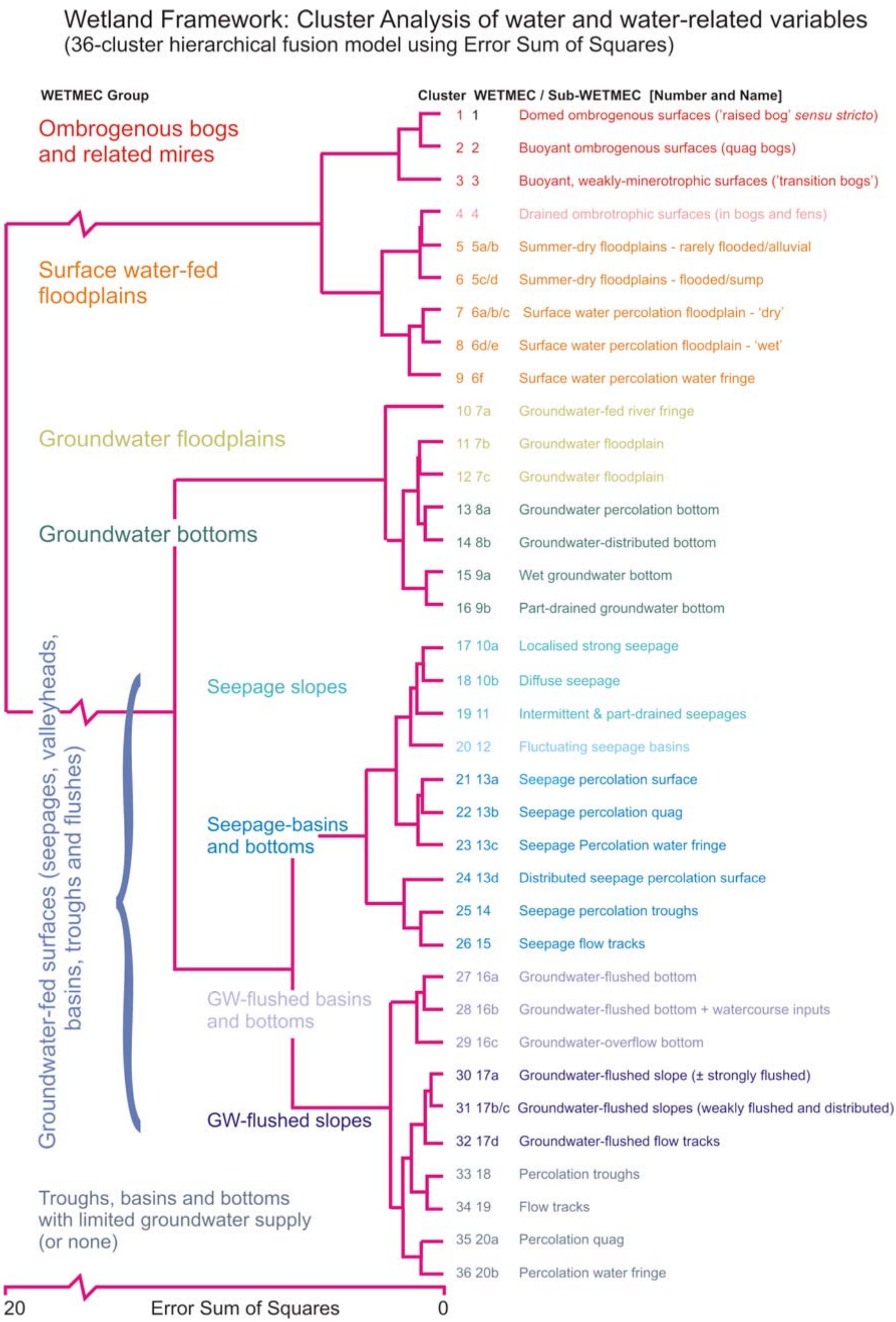

Figure 5.1 Cluster analysis of water and water-related variables (36-cluster hierarchical fusion model using Error Sum of Squares)

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