A WETLAND FRAMEWORK FOR IMPACT ASSESSMENT AT STATUTORY SITES IN EASTERN ENGLAND

SITE ACCOUNTS

R&D Technical Report W6-068/TR2

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This document provides an assessment and summary of the ecohydrogeological characteristics of the wetland sites included in the project. The project provides guidance to Environment Agency staff and external agencies involved in hydrological and ecological impact assessment under the Conservation (Natural Habitats &c.) Regulations, 1994. For full details of the project, refer to R&D Technical Report W6-068/TR1.

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1. INTRODUCTION

1.1 Background

This part of the report provides an assessment and summary of the ecohydrogeological characteristics of the wetland sites included in the project. For full details of the project, refer to R&D Technical report W6-068/PR.

The site accounts provided are not intended to be comprehensive descriptions of the sites considered. Rather, they aim to summarise some of the key features salient to understanding possible water supply mechanisms in relation to the ecological characteristics of the sites, with particular reference to the 'key samples' (stand samples for which floristic and environmental data are available). The accounts are based on information available to us, and in some cases may need to be modified as further data are obtained. WETMECs thought to occur at the sites are listed, but these are based primarily on the 'key samples' and it is possible that other WETMECs occur in unsampled parts of some sites. A summary of the WETMECs recognised is provided in Table A3_1.

Table A3_1. Summary of Water Supply Mechanism Types (WETMECs)

WETMEC:	Summary Description
1 Permanent Seepage Slope	Wetland fed by 'permanent' springs or seepages. Usually sloping. Water level permanently near surface (water visible or oozes underfoot).
2 Intermittent Seepage	Wetland fed by intermittent springs and seepages, or groundwater always shallowly subsurface. Often sloping. A 'dry' analogue of Type 1.
3 Fluctuating Seepage Basin	Small hollows with quite strongly fluctuating water levels. Often with standing water, but water level can sink subsurface in dry periods. Often no outflow.
4 Seepage Percolation Basins	Small hollows and some 'floodplains' fed mainly by groundwater inputs, often through (or beneath) a rather loose vegetation mat. Water table often close to surface, usually not flooded. Often with a permanent outflow.
5 Summer 'Dry' Percolation Surfaces	A drier analogue of Type 4 (often partly drained Type 4), but groundwater inputs often mainly canalised through dykes *etc.,* with limited transmission through the peat. Surface often may mainly receive just precipitation inputs, at least during low groundwater periods.
6 Surface Water Percolation Floodplains	Wet areas in floodplains, often around open water or on reflooded peat workings, fed by lateral flow of surface water (from rivers *etc.*) through (or beneath) a loose vegetation mat. Also receive episodic surface flooding).
7 Summer 'Dry' Floodplains	Floodplains and hollows fed mainly by episodic inundation by surface water but with little transmission of water through the peat. Often flooded in winter but sometimes with quite low summer water tables.
8 Valley Bottom Wetlands	Poorly drained valley bottom areas, often saturated in winter but with fairly low summer water tables. Water sources often not known. Not normally flooded from rivers, though some examples were formerly active floodplains.
9 Drained Ombrogenous Surfaces	Drained surfaces on ombrogenous peat, fed directly and exclusively by precipitation. Excludes 'rain-fed legacy-telluric sites', *i.e.* surfaces once fed by telluric water but now precipitation-dependent because of drainage.

Background information on location and conservation designations (etc.) is provided in Table A3_2, with primary information sources shown in Table A3_3. For much of the information on probable hydrogeological mechanisms we are particularly indebted to accounts for individual sites produced by Hydrogeological Services International (HSI), as part of the installation of the Agency piezometer network and as part of the assessment of the possible impact of groundwater extraction upon sites of particular conservation importance (HSI–ECUS 1998, 1999). In addition HSI (2000) produced some additional site accounts specifically for this Wetland Framework project, collating information on sites which have hitherto received rather little consideration.

1.2 Wetland sites in the Eastern Region: Scope of study

The wetland sites considered in this report are essentially 'fens', *i.e.* semi-terrestrial wetland sites with a (fairly) high water table. This compass excludes bodies of open water (but may include marginal vegetation) and areas of wet grassland (even though some of these may be drained derivatives of former fen). The selection of sites for inclusion has essentially been determined by data availability. Almost all of the fen sites for which floristic, ecological and hydrogeological data available are have been included. The sites have been allocated to four regions:

Broadland

This includes the fens developed on the floodplains of the main Broadland rivers (Ant, Bure, Thurne, Waveney and Yare); it also includes the small number of valleyhead fens that immediately adjoin these, and some Suffolk coastal marshes. The bedrock of all of these sites is Crag underlain by Chalk (but separated from this by Eocene clays in the more easterly examples). Many sites appear to be fed primarily by surface water and a few primarily by groundwater (both valleyhead and floodplain examples). In some sites both surface water and groundwater may provide important inputs, but in general rather little is known about the quantitative contribution of these sources in such situations. Many sites occur in more-or-less intact floodplains, but in some examples adjoining areas of former wetland have been drained and converted to agriculture. In most such cases the residual areas of fen adjoin the rivers and may retain much of their natural water supply mechanism, but a small number are now isolated from the rivers and appear to be more dependent now upon groundwater inputs than was probably once the case.

East Anglian Valleyhead Fens

This category includes a large number of sites, mostly fed by groundwater and usually close to the headwaters of small streams. A small number of these sites are located lower down the valleys and are (partly) on river floodplains. The bedrock of most of these sites is Chalk or, in the more eastern areas, Crag. Along the western edge of the region some examples are associated with Greensand. Many sites appear to be fed primarily from a bedrock aquifer, but a small number seem to be fed primarily from Drift. Some sites may receive important water inputs from both bedrock and drift aquifers (sometimes as separate sources but more usually mixed). In such cases the proportionate contribution of Drift and bedrock water is not well established. A very small number of sites appear to be mainly fed by surface water.

Fenland

The once extensive floodplain fens of the Fenland basin have been reduced to a small number of isolated remnants which are grouped together here. This category excludes the groundwater-fed fens in tributary valleys along the eastern margin of the Fenland basin, which are included under East Anglian Valleyhead Fens. The agricultural conversion of the Fenland basin, and catastrophic loss of wetland habitat, is well known. The four sites considered here not only represent a tiny remnant of the original wetland area, they are also divorced from their natural water supply mechanisms. All are located close to the margin of the Fenland basin, but groundwater is not considered to be a significant supply. Two (Wicken Fen and Woodwalton Fen) are embanked above the adjoining agricultural land and have low-permeability bunds in an attempt to retain water, some of which is introduced surface water. The other two (Holme Fen and Lakenheath Poor's Fen) are effectively part of the agricultural drainage system and their surface is fed by precipitation.

South-East Midlands Valleyhead Fens

This region includes a number of scattered, small, groundwater-fed sites located west and southwest of the Fenland basin, mainly with Jurassic bedrocks (primarily Oxford Clay and various limestones). The sites included here are all small and scattered, and obviously fed by groundwater discharge. Some are not SSSIs. This is particularly the case for a series of sites in the south-west of the region (in Buckinghamshire), at the heads of small valleys draining into the R Ouzel. These have been included partly because, as they are located over Jurassic Clays, they represent spring-fed fens which appear to be unambiguously fed from sand and gravel lenses within the drift. However, some sites in the north of the region (Northamptonshire, Cambridgeshire and Rutland) are fed by water from Jurassic limestones and one site (Sutton Heath), supports a vegetation similar to some of the chalkwater-fed fens of East Anglia. Some wetland sites on Greensand in Bedfordshire and Buckinghamshire were originally to have been included in the this study but have been left out because of sparsity of information, and because the sites are rather scarce and variable in character so that it is considered that analysis of their ecohydrological relationships requires information on comparable sites on Cretaceous and Tertiary sandstones in other parts of Southern England.

Table A3_2. Location and conservation status of sites examined.

Site Name	County	Grid Ref.	EA Area[1]	SSSI (+ name if composite site)	Name of SAC of which site is component	Name of SPA of which site is component	Name of Ramsar site of which site is component	Natural Area
Broadland								
Barnby Broad & North Cove	Suffolk	TM480910	E	√	The Broads	Broadland	Broadland	The Broads
Benacre Broad	Suffolk	TM530810	E	Benacre to Easton Bavents	Benacre to Easton Bavents Lagoons	Benacre to Easton Bavents		Suffolk Coast & Heaths
Easton Broad and Frostenden Valley	Suffolk	TM4979	E	Benacre to Easton Bavents		Benacre to Easton Bavents		Suffolk Coast & Heaths
Berry Hall Fens (Barton Fen)	Norfolk	TG3523	E	Ant Broads & Marshes	The Broads	Broadland	Broadland	The Broads
Broad Fen, Dilham	Norfolk	TG343255	E	√	The Broads	Broadland	Broadland	The Broads
Burgh Common	Norfolk	TG440117	E	Burgh Common & Muckfleet Marshes	The Broads	Broadland	Broadland	The Broads
Catfield & Irstead Fens	Norfolk	TG3620	E	Ant Broads & Marshes	The Broads	Broadland	Broadland	The Broads
Decoy Carr, Acle	Norfolk	TG405090	E	√	The Broads	Broadland	Broadland	The Broads
Drabblegate Common	Norfolk	TG199284	E					
Ducan's Marsh, & Carleton Broad	Norfolk	TG339027	E	√	The Broads	Broadland	Broadland	The Broads
East Ruston Common	Norfolk	TG340280	E	√				The Broads
Hall Farm Fen (Hemsby Common)	Norfolk	TG481170	E	√	The Broads	Broadland	Broadland	The Broads
Hickling Broad Marshes	Norfolk	TG4021	E	Upper Thurne Br. & Marshes	The Broads	Broadland	Broadland	The Broads
Hulver Ground (Horning)	Norfolk	TG360178	E					The Broads
Limpenhoe Meadows	Norfolk	TG399031	E	√	The Broads	Broadland	Broadland	The Broads
Poplar Farm Meadows, Langley	Norfolk	TG370021	E	√	The Broads	Broadland	Broadland	The Broads
Reedham Marshes	Norfolk	TG3619	E	Ant Broads & Marshes	The Broads	Broadland	Broadland	The Broads
Smallburgh Fen	Norfolk	TG327246	E	√	The Broads	Broadland	Broadland	The Broads
Strumpshaw and Bradeston Marsh	Norfolk	TG3306	E	Ant Broads & Marshes	The Broads	Broadland	Broadland	The Broads

Site Name	County	Grid Ref.	EA Area[1]	SSSI (+ name if composite site)	Name of SAC of which site is component	Name of SPA of which site is component	Name of Ramsar site of which site is component	Natural Area
Sutton Broad	Norfolk	TG3723	E	Ant Broads & Marshes	The Broads	Broadland	Broadland	The Broads
Sutton Fens	Norfolk	TG370230	E	Ant Broads & Marshes	The Broads	Broadland	Broadland	The Broads
Upton Fen & Doles	Norfolk	TG390137	E	Upton Broad & Marshes	The Broads	Broadland	Broadland	The Broads
Walberswick (Westwood & Dingle Marshes)	Suffolk	TM475645	E	Minsmere to Walberswick Heaths & Marshes	Minsmere to Walberswick Heaths and Marshes	Minsmere-Walberswick	√	Suffolk Coast & Heaths
Wheatfen	Norfolk	TG3205	E	Yare Broads & Marshes	The Broads	Broadland	Broadland	The Broads
Woodbastwick Fens & Marshes	Norfolk	TG3316	E	Bure Broads & Marshes	The Broads	Broadland	Broadland	The Broads
East Anglia Valley Fens								
Aslacton Parish Land (Bunwell Common)	Norfolk	TM156918	E	√				The Broads
Badley Moor, Dereham	Norfolk	TG013117	E	√	Norfolk Valley Fens			East Anglian Plain
Barnham Broom Fen	Norfolk	TG070070	E					East Anglian Plain
Beetley Meadows	Norfolk	TF982174	E	√				East Anglian Plain
Booton Common	Norfolk	TG113230	E	√	Norfolk Valley Fens			North Norfolk
Buggs Hole Fen, Thelnetham	Suffolk	TM006792	C	√				East Anglian Plain
Buxton Heath	Norfolk	TG175218	E	√	Norfolk Valley Fens			North Norfolk
Cavenham-Icklingham	Suffolk			√				
Chippenham Fen	Cambs	TL648697	C	√	Fenland			The Fens
Cornard Mere	Suffolk	TL888389	E	√				East Anglian Plain
Coston Fen, Runhall	Norfolk	TG062066	E	√	Norfolk Valley Fens			East Anglian Plain
Cranberry Rough (Hockham Mere)	Norfolk	TL934936	C	√				Breckland
Dernford Fen	Cambs	TL472504	C	√				East Anglian Chalk
Dersingham Bog	Norfolk	TF675289	C	√	Roydon Common and Dersingham Bog			The Fens
East Walton Common	Norfolk	TF734164	C	√	Norfolk Valley Fens			North Norfolk

Site Name	County	Grid Ref.	EA Area[1]	SSSI (+ name if composite site)	Name of SAC of which site is component	Name of SPA of which site is component	Name of Ramsar site of which site is component	Natural Area
Flordon Common	Norfolk	TM183971	E	√	Norfolk Valley Fens			East Anglian Plain
Forncett Meadows	Norfolk	TM166926	E	√				East Anglian Plain
Foulden & Gooderstone Commons	Norfolk	TF762002	C	√	Norfolk Valley Fens			Breckland
Great Cressingham Fen	Norfolk	TF848022	C	√	Norfolk Valley Fens			Breckland
Holly Farm Meadow, (Wendling Poor's)	Norfolk	TF936131	E	√				Breckland
Holt Lowes	Norfolk	TG088375	E	√	Norfolk Valley Fens			North Norfolk
Hopton Fen	Suffolk	TL990800	C	√				Breckland
Kenninghall & Banham Fens	Norfolk	TM041875	C	√				East Anglian Plain
Middle Harling Fen	Norfolk	TL989852	C	√				Breckland
Newbourn Springs	Suffolk	TM272434	E	√				Suffolk Coast & Heaths
Pakenham Meadows	Suffolk	TL934686	C	√				East Anglian Plain
Pashford Poors Fen, Lakenheath	Suffolk	TL732835	E	√				Breckland
Potter & Scarning Fens	Norfolk	TF982120	E	√	Norfolk Valley Fens			
Redgrave & Lopham Fens	Suffolk/ Norfolk	TM050797	E	√	Waveney and Little Ouse Valley Fens		√	East Anglian Plain
Roydon Common	Norfolk	TF685225	C	√	Roydon Common and Dersingham Bog		√	North Norfolk
Roydon Fen (Diss)	Norfolk	TM103798	E					
Sawston Hall Meadows	Cambs	TL491491	C	√				East Anglian Chalk
Sheringham & Beeston Regis Commons	Norfolk	TG164424	E	√	Norfolk Valley Fens			North Norfolk
Southrepps Common	Norfolk	TG261350	E	√	Norfolk Valley Fens			North Norfolk
Swangey Fen	Norfolk	TM015932	C	√	Norfolk Valley Fens			East Anglian Plain
Swannington Upgate Common	Norfolk	TG148181	E	√				The Broads
Thelnetham Fens	Suffolk	TM017790	C	[Blo'Norton & Thelnetham Fens]	Waveney and Little Ouse Valley Fens			East Anglian Plain
Thriplow Meadows	Cambs	TL437470	C	√				
Weston Fen	Suffolk	TL981787	C	√	Waveney and Little Ouse Valley Fens			Breckland
Whitwell Common	Norfolk	TG088206	E	√				East Anglian Plain

Site Name	County	Grid Ref.	EA Area[1]	SSSI (+ name if composite site)	Name of SAC of which site is component	Name of SPA of which site is component	Name of Ramsar site of which site is component	Natural Area
Fenland								
Holme Fen		TL205895	C	√				The Fens
Lakenheath Poor's Fen	Suffolk	TL701827	C	√				The Fens
Wicken Sedge Fen	Cambs	TL555700	C	√	Fenland			The Fens
Woodwalton Fen	Cambs	TL230840	C	√	Fenland			The Fens
South East Midlands Valley Fens								
Blackend Spinney	Bucks	SP857253	?					?
Bonemills Hollow	Cambs	TF038013	N	√				Lincs & Rutland Limestone
Clack Fen	Bucks	SP855275	?					?
Drayton Parslow Fen	Bucks	SP848280	?					?
Drayton Parslow North Fen	Bucks	SP832289	?					?
Nash Fen	Bucks	SP794336	?					?
Pilch Fields	Bucks	SP747323	?					?
Shacklewell Hollow	Rutland	SK977078	N	√				?
Sutton Heath & Bog	Cambs	TF090000	N	√				Lincs & Rutland Limestone
Syresham Marshy Meadow	N'hants	SP638426	C	√				?
Tingewick Meadows	Bucks	SP652313	?	√				Thames & Avon Vales
Valley Farm Fen, Soulbury	Bucks	SP896254	?					?

[1]: indicates Environment Agency Area within Anglian Region. (E = East; C = Central)

Table A3_3. Sources of information for the sites examined.

Site Name	County	FenBASE data[2]	W & S Dossier[3]	NVC survey	B.U. Dossier[4]	Hydrological monitoring[5]	HSI Monitoring Dossier[6]	Mont.-Wat. report, 1999[7]	WLMP[8]	AMP3, HD or WF Site Dossier[9]	Personal consultees[10]
Broadland											
Barnby Broad & North Cove	Suffolk	√							√		
Benacre Broad	Suffolk	√		1998					√	1999	
Easton Broad and Frostenden Valley	Suffolk	√							√	1999	
Berry Hall Fens (Barton Fen)	Norfolk	√									
Broad Fen, Dilham	Norfolk	√			√				√	2000	R. Andrews
Burgh Common	Norfolk	√			√				√	1998	
Catfield & Irstead Fens	Norfolk	√			√	EA	1996	√		1998	G. van Wirdum
Decoy Carr, Acle	Norfolk	√	√			EA	1998	√	√		(Owner)
Drabblegate Common	Norfolk	√									
Ducan's Marsh, & Carleton Broad	Norfolk	√	√	1993	√	EA	1998	√	√		
East Ruston Common	Norfolk	√	√		√	EA			√		R. Andrews
Hall Farm Fen (Hemsby Common)	Norfolk	√	√						√	1998	
Hickling Broad Marshes	Norfolk	√							√		H. Bowell (NWT)
Hulver Ground (Horning)	Norfolk	√									
Limpenhoe Meadows	Norfolk	√			√	EA	1996	√	√		
Poplar Farm Meadows, Langley	Norfolk	√			√	EA	1998	√	√		
Reedham Marshes	Norfolk	√									
Smallburgh Fen	Norfolk	√	√		√	EA	1996	√	√		
Strumpshaw and Bradeston Marsh	Norfolk	√							√	1998	
Sutton Broad	Norfolk	√									
Sutton Fen	Norfolk	√									A. Baird, R. Money, R. Andrews

Site Name	County	FenBASE data[2]	W & S Dossier[3]	NVC survey	B.U. Dossier[4]	Hydrological monitoring[5]	HSI Monitoring Dossier[6]	Mont.-Wat. report, 1999[7]	WLMP[8]	AMP3, HD or WF Site Dossier[9]	Personal consultees[10]
Upton Fen & Doles	Norfolk	√			√	EA	√	√	√		G. van Wirdum; H. Bowell (NWT); J. Wells
Walberswick (Westwood & Dingle Marshes)	Suffolk	√		1997					√	1999	
Wheatfen	Norfolk	√							√	2000	P. Ellis
Woodbastwick Fens & Marshes	Norfolk	√							√	2000	R. Southwood (EN)
East Anglia Valley Fens											
Aslacton Parish Land (Bunwell Common)	Norfolk	√	√	1993	√	EA	1996	√	√		S. Rothera (EN)
Badley Moor, Dereham	Norfolk	√	√	1993	√	EA	1996	√	√		
Barnham Broom Fen	Norfolk	√	√								
Beetley Meadows	Norfolk	√	√	1992	√	EA	1998/1996	√		1998	
Booton Common	Norfolk	√	√	1992	√	EA	1996	√	√		H. Bowell (NWT)
Buggs Hole Fen, Thelnetham	Suffolk	√	√		√	EA			?		M. Harding
Buxton Heath	Norfolk	√	√	1992	√	EA	1996	√	√		D. Boeye
Cavenham-Icklingham	Suffolk		√	1996		EA/AW	1998	√			
Chippenham Fen	Cambs	√	√	1996	√				√	2000	M. Musgrave
Cornard Mere	Suffolk	√	√	1991							
Coston Fen, Runhall	Norfolk	√	√	1992	√	AW			√	1998	
Cranberry Rough (Hockham Mere)	Norfolk	√	√		√				√	2000	H. Bowell (NWT)
Dernford Fen	Cambs	√	√							1998	
Dersingham Bog	Norfolk	√	√	1990	√	EA	1998	√	√		P. Holms (EN)
East Walton Common	Norfolk	√	√	1992	√	EA	1996	√			P. Lambley (EN)
Flordon Common	Norfolk	√	√	1993	√				√	2000	
Forncett Meadows	Norfolk	√	√	1992	√	EA	1996	√	√		S. Tolhurst
Foulden & Gooderstone Commons	Norfolk	√	√	1992	√	EA	√	√	√	1998	

Site Name	County	FenBASE data[2]	W & S Dossier[3]	NVC survey	B.U. Dossier[4]	Hydrological monitoring[5]	HSI Monitoring Dossier[6]	Mont.-Wat. report, 1999[7]	WLMP[8]	AMP3, HD or WF Site Dossier[9]	Personal consultees[10]
Great Cressingham Fen	Norfolk	√	√	1992	√	EA	1996	√	1996	1998	G. Saul
Holly Farm Meadow, (Wendling Poor's)	Norfolk	√	√		√	EA	1996	√			
Holt Lowes	Norfolk	√	√	1993	√	EA	1996	√			
Hopton Fen	Suffolk	√	√	1991	√	EA	1998	√	√		
Kenninghall & Banham Fens	Norfolk	√	√	1993	√	EA	1998	√	√	1998	
Middle Harling Fen	Norfolk	√	√	1992	√	EA	1998	√	?		
Newbourn Springs	Suffolk	√	√	1990							M. Harding
Pakenham Meadows	Suffolk	√	√						1997		M. Harding
Pashford Poors Fen, Lakenheath	Suffolk	√	√		√	EA	√	√	Draft 1996		
Potter & Scarning Fens	Norfolk	√	√	1993	√	EA	1996	√	√	1999	H. Bowell (NWT)
Redgrave & Lopham Fens	Suffolk/Norfolk	√	√	1992-1994	√	AW/SWT			√		A. Excell (SWT), M. Harding
Roydon Common	Norfolk	√	√	1992		EA	1998	√	√	1999	P. Lambley (EN)
Roydon Fen (Diss)	Norfolk	√	√	1991	√	EA	1996	√			
Sawston Hall Meadows	Cambs	√	√		√					1998	
Sheringham & Beeston Regis Commons	Norfolk	√	√	1993		EA	1996	√		1998	K. Durrant
Southrepps Common	Norfolk	√	√	1993	√					2000	P. Lambley (EN)
Swangey Fen	Norfolk	√	√	1992	√	EA	1998	√	1997	1999	Otter Trust
Swannington Upgate Common	Norfolk	√	√	1993	√	EA	1996	√			
Thelnetham Fens	Suffolk	√	√	1991	√	EA	1996	√	1996		M. Harding
Thriplow Meadows	Cambs		√								
Weston Fen	Suffolk	√	√	1992	√	EA	1998	√	√		
Whitwell Common	Norfolk	√	√	1992		AW			√	1998	P. Lambley (EN)
Fenland											
Holme Fen	Cambs	√									A. Bowley (EN)

Site Name	County	FenBASE data[2]	W & S Dossier[3]	NVC survey	B.U. Dossier[4]	Hydrological monitoring[5]	HSI Monitoring Dossier[6]	Mont.-Wat. report, 1999[7]	WLMP[8]	AMP3, HD or WF Site Dossier[9]	Personal consultees[10]
Lakenheath Poor's Fen	Suffolk	√		1992	√				√		
Wicken Sedge Fen	Cambs	√		√	√				1996		A. Cawston (NT)
Woodwalton Fen	Cambs	√		√					[Draft 1996]		A. Bowley (EN)
South East Midlands Valley Fens											
Blackend Spinney	Bucks	√								2000	
Bonemills Hollow	Cambs	√				EA?	?	?			
Clack Fen	Bucks	√								2000	
Drayton Parslow Fen	Bucks	√									
Drayton Parslow North Fen	Bucks	√									
Nash Fen	Bucks	√								2000	
Pilch Fields	Bucks	√								2000	
Shacklewell Hollow	Rutland	√				EA	1998	?		2000	
Sutton Heath & Bog	Cambs	√				EA	1998	√		1999	
Syresham Marshy Meadow	N'hants	√								2000	
Tingewick Meadows	Bucks	√								2000	
Valley Farm Fen, Soulbury	Bucks	√								2000	

Footnotes: 1. References for individual sites are listed in Volume 1; 2. Data available within the FenBASE database held at Sheffield University; 3. Wheeler & Shaw site dossiers (1992) (English Nature); 4. Birmingham University wetland site dossiers (1987); 5. Organisation undertaking hydrological monitoring; 6. HSI site reports on Environment Agency hydrological monitoring installations; 7. Montgomery-Watson reports on results of Environment Agency hydrological monitoring; 8. Water Level Management Plans (only those given dates have been consulted); 9. HSI/ECUS site dossiers compiled for AMP3 (1998) or Habitats Directive Review of Consents (1999) or HSI dossiers compiled for this project (2000); 10. Mostly via a questionnaire sent to consultees, sometimes supplemented by telephone, email discussion etc.

2. BROADLAND

2.1 BARNBY BROAD AND NORTH COVE

SUFFOLK: TM480905

***Status*: SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland**

Key Samples: 3

WETMECs: Type 4 (broad and surroundings); Type 5 (grazing levels)

Description: An isolated, and rather little known, area of undrained fen, partly hydroseral, surrounding a small broad at the southern edge of the Waveney floodplain, adjacent to the upland. It is separated from the Waveney by a series of partly-drained grazing levels.

Vegetation: The drained levels which separate the broad from the river retain some wetland interest in the vicinity of the broad, mainly fen meadow (M22, M24) and taller fen (S25, S26), locally with much *Sphagnum* (especially *S. palustre*). Nearer the river, water levels are lower and the vegetation is a rather 'dry' form of fen meadow, grading into grassland,. The broad itself is mainly surrounded by carr, but with patches of herbaceous vegetation. These include some floating mats of vegetation around the broad margin, some of which contain much *Sphagnum* (especially *S. subnitens*). The site has obvious floristic and physiographic similarities with Upton Broad (*q.v.*).

Substratum: The upland slopes quite steeply down to the broad, and also below the peat surface, and much of the valley infill near the broad is of relatively similar depth (5–6 m). Unusually, brushwood peat is only well developed at the very edge of the valley and much of the infill, both beneath and beyond the broad, is a distinctive, thick, fresh moss peat (with much *Homalothecium nitens* and *Paludella squarrosa* – the latter now extinct in Britain). The peat type and sequence found here is characteristic of hydroseral successions in calcareous basins in parts of northern Britain[1], but is most unusual in a Broadland context[2]. It is suggestive of a long-lived phase of quagfen, developed in especially wet, near-swamp conditions.

Water Supply: There is clear evidence of groundwater seepage on the upland slopes below the road on the S side of Barnby Broad and it is likely that groundwater is major water source to the broad. Separated from the Waveney by drained levels, the broad usually receives no direct river inputs (it is not known whether extreme river flooding events affect the broad). It is possible that the thick moss peats reflect the influence of former strong seepage inputs, which may have helped to maintain a permanently wet 'basin' at the edge of the floodplain.

Conclusion: Primarily fed by groundwater.

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[1] In fen basins in northern Britain (*e.g.* Scottish Borders), this peat is often a precursor to the establishment of *Sphagnum* peat and raised bog development, but there is no stratigraphical evidence for this sequence at Barnby.

[2] Comparable peat occurs extensively in pre-Roman deposits at Buckenham & Hassingham (Yare valley). Thick hypnoid moss peat has also been found in abundance at Ranworth (Bure valley), but it is not known if this contains *Homalothecium* and *Paludella.*

2.2 BENACRE BROAD

SUFFOLK: TM537855

Status**:** SSSI, SAC, SPA: Benacre to Easton Bavents

WETMECs: Probably mainly Type 4

Description: A coastal lagoon and reedbeds occupying the floor of a quite steeply incised, largely wooded, valley more or less at sea level, but separated from the sea by a shingle bar. Several artificial bunds have been constructed within the wetland to help maintain freshwater conditions.

Vegetation: The wetland vegetation of this site is essentially species-poor reedbeds of high value for their fauna.

Substratum: Benacre Broad is situated upon a thick (60 m) layer of Crag, which outcrops on the valley slopes. The Crag is separated from the underlying Chalk by about 70 m of Palaeocene–Eocene mudstones and siltstones. The tops of the adjoining interfluves are capped by drift (mainly sands and gravels of the Corton Formation in the east, but by Lowestoft Till further west, but within the catchment of the wetland). The valley bottom is filled with freshwater peat, but at the seaward end this is covered by estuarine alluvial deposits.

Water Supply: Little is known in detail about groundwater supply to the wetland, but groundwater from the Crag appears to discharge into the wetland, as springs and seepages, where the water table intersects the valley sides. The peats and clays of the valley bottom may help impede flow into the valley. Small streams from the north and south east, with groundwater-maintained baseflows, also provide freshwater inputs, and bunds have been constructed within the lower part of the valley to help impound freshwater and prevent brackish water incursions. The original area of freshwater, which formerly included the broad has been reduced by tidal encroachment and the bunding initiatives form part of a 'managed retreat' from rising sea levels and coastal erosion.

Conclusion: Reedbeds developed on relatively nutrient-rich peats and, locally brackish, silts, fed by freshwater derived primarily from a Crag aquifer. High freshwater levels are maintained by impeded drainage on the valley bottom, including artificial bunds, but are threatened by tidal incursions.

2.3 BERRY HALL FENS (BARTON FEN)

NORFOLK: TG3523

Status**:** SSSI: Ant Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 4

WETMECs: Type 6 (former drained area west of former embankment), Type 7 (on higher peat alongside river)

Description: A large area of fen occupying the west Ant floodplain north of Barton Broad. The R Ant once flowed through the centre of these fens, but has been diverted around the eastern upland margin, with the Hundred Stream marking its former course.

Vegetation: It appears that the fens west of the Hundred Stream were once partly drained, but have since reflooded and support (mostly rather species poor) managed sedge beds. Along much of the west margin, this vegetation grades into a drier vegetation (typically M24), sometimes *via* a band of S27, and in one place (Barton Fen) there is a particularly clear and complete zonation through *Carex lasiocarpa* vegetation, M24 to wet heath and dry heath – possibly representative of a once more common transition, since lost by agricultural improvement of the upland. The vegetation east of the Hundred Stream is more variable, but subject to considerable scrub encroachment.

Substratum and Water Supply: The distinctive vegetation zonation along the land margin of the fen has led to the recurrent assertion that this may reflect a seepage line. A short study designed to investigate this possibility (van Wirdum *et al.*, 1997), located in a small area near the fen margin, provided no evidence for groundwater input. The substratum here consisted of a thin, but very dense, low-*K* peat (this area was once partly drained) separated from the Crag by a clay layer. One discrete, apparent seepage, area near the margin turned out to be a land-drain input (from the catchwater ditch). Conditions further into the fens have not been examined, but there is no reason to suspect significant groundwater inputs.

Conclusion: Primarily fed by precipitation, with contributions from land drainage and episodic river flooding.

2.4 BROAD FEN, DILHAM

NORFOLK: TG343255

Status**:** SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 8

WETMECs: Uncertain. Either types 4 and 5 or 6 and 7 (or all of these)

Description: A quite large area of fen developed within the confluence of the R Ant (here canalised as the North Walsham & Dilham Canal) and a tributary stream coming in from Smallburgh to the west (and also part canalised). Northwards the fen is bordered by upland which (for the Ant valley) rises fairly steeply. The site contains four ponds and a series of terrestrialised turf ponds. The former Dilham Broad occupies much of the southern part of the fen. This is now completely terrestrialised and consists of a quite thick, but buoyant, vegetation mat over fluid lake muds.

Vegetation: Although there are stands of carr, much of the site supports herbaceous fen, largely species-poor beds of reed and sedge, mostly various forms of S24 and often with an abundance of *Calamagrostis canescens*. However, a few former turf ponds towards the N margin support a richer vegetation, referable to the *Peuecedano-Phragmitetum caricetosum* and similar vegetation occupies much of the surface of the overgrown broad, at the W end of the fen. Although extensive, this is not one of the best examples of the *PPc* – it does not support *Liparis loeselii* and the moss layer tends to be dominated by *Calliergon cuspidatum* rather than more characteristic brown mosses. The reason for this is not known – successional state and nutrient enrichment are both possible explanations.

Substratum and Water Supply: The fen appears to be underlain by recent alluvium, Contorted Drift and Crag, which appear to be from a single hydrogeological unit between some 15–20m thick. These appear to semi-confine the underlying Upper Chalk, though if sufficiently sandy some horizons may support groundwater flow. HSI (2000) consider that upflow from the chalk is unlikely at most times of the year. HSI (2000) suggest that some of the site may be fed by groundwater from the Contorted Drift / Crag, and consider that this may account for the low fertility, low alkalinity water which they state occurs in the ponds and drains distant from the canals. However, comparable hydrochemical conditions have been recorded in some other Broadland fens which are not obviously groundwater fed. Moreover, in contradistinction to some of the other surface waters, the sediments of the basin of the overgrown broad, which is believed to be cut down to the mineral ground, contains a considerable amount of marl. This part of the site appears to be a candidate for inputs of calcareous groundwater inputs, but access constraints in recent years mean that rather little is known about the characteristics of the site. However, some preliminary thermo-conductivity profile measurements by van Wirdum (*pers. comm.*) provided no evidence for upwelling groundwater in the former broad basin.

The importance of surface water inputs is not certain, nor is the connectivity of the former broad basin with the surface water system. The fen is regularly flooded (*c.* 30–50 cm agl) in winter, but the provenance of this water is not known. The overgrown broad is less deeply flooded than some other areas (because of its semi-floating character), but experiences some inundation. Ingress of nutrients in these episodes might account for the impoverished bryophyte layer.

Parts of the fen appear to be drier than might be expected in summer, but the reason for this is not obvious.

Conclusion: Winter flooding from the adjoining canals may provide significant inputs into the proximate parts of the fen and may cause some local enrichment. However, the solid peats that border these water courses are likely to prevent much lateral seepage of water through the peat. The site appears a likely candidate for groundwater inputs, but the significance (and source) of these remains uncertain.

2.5 BURGH COMMON

NORFOLK: TG440117

***Status*:** SSSI: Burgh Common & Muckfleet Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 12

Description: Burgh Common is an important, but rather little-studied, wetland site in Broadland. It occupies a large area of wet land, north of the Muckfleet and SW of Filby Broad, both of which it adjoins – although the Muckfleet originally flowed through the middle of part of the fen (in the western area), where the 'New Muckfleet' now provides a southern marginal drainage channel. A small remnant broad (Little Broad) occurs within the common. The north-northwestern margin of the wetland adjoins rising upland slopes.

Vegetation: The fens bordering the Muckfleet are mainly tall and herbaceous and much colonised by woody plants, but the northern part of the common is fen meadow and wet grassland, maintained by grazing. Much of this area is a form of M22 vegetation, but the upland margin is marked by a band of *Cirsio-Molinietum* (M24), mostly rather narrow but broadening in some of the western compartments. Most of the site consists of solid alluvium, but there is hydroseral vegetation associated with Filby Broad and Little Broad.

Substratum: The bedrock is Pleistocene Crag (over London Clay), overlain by a thin outcrop of Kesgrave sands and gravels on the valley sides. This is capped, on the uplands, by the Corton Formation and Lowestoft Till. The alluvial stratigraphy of the valley is not well documented. Lambert *et al.* (1960) describe only a few cores and do not provide a section. Filby Broad may have been dug in ± continuous peat (perhaps cutting through a thin layer of clay), but cores "revealed that the valley immediately below the system was filled with solid alluvium with an horizon of Upper Clay" (Lambert *et al.*, 1960). Stratigraphical data on the FENBASE database show that over much of Burgh Common there is an upper layer of herbaceous peat of about 1m depth overlaying organic silts and clays (of unknown thickness). However, in the embayment of the Nab and some other marginal areas there was no evidence of clay and, in the deeper examples, the upper herbaceous peats (about 1m depth) rested upon brushwood peat whilst in the shallower locations they were situated directly over the mineral ground. Filby Broad also appears to have been cut down to the mineral ground, at least around the edge, which in places appears to be gravel, in others a sandy clay.

Water Supply: There are very few hydrological data available for this site, so the following comments are necessarily speculative. The Kesgrave and Corton Sands are thought to be in hydraulic continuity with the underlying Crag aquifer and water from all of these probably discharges into Filby Broad. The likely water supply to the fen areas of Burgh Common is less certain, as over much of the area it is likely that the deeper peats and clays effectively confine the Crag aquifer. HSI/ECUS (1998) suggest that there may be lateral flow into the fen from the Kesgrave Sands, but the extent to which this occurs is not known – there is no obvious manifestation of flow. Flow would, presumably, be confined to the upper 1m or so of peat (*i.e.* the peat above the clay layers) and the transmissivity of this is not known. In general, the peat near the fen margins is quite solid, and often well-oxidised and amorphous, suggestive more of drainage than substantial water inflow. By contrast, away from the margins, in some of the more central areas above the organic clays, the upper peats are described as 'fresh and fibrous'. These are not thought to represent the infill of turf ponds, but may well be relatively transmissive, and it is possible that there may be some lateral flow of water from the dykes, and also from Filby Broad (summer water levels of the fen immediately

SW of this seem to remain relatively high). Nonetheless, summer water levels in parts of Burgh Common are often some 15–25 cm subsurface, and lower in some marginal locations.

The Muckfleet drains the site to the Bure and there are various connected dykes in the site. A sluice lower down the Muckfleet controls, and helps maintain, water levels in fens, but does not generally overflow in summer (though it does in winter). It is not known to what extent there is winter flooding in the fens.

Conclusion: The whole Filby–Rollesby–Ormesby broad system appears to be partly groundwater fed, and this supply – contained by the Muckfleet Sluice – helps to maintain high summer water levels in Burgh Common, especially in the vicinity of dykes and water bodies. There may also be some lateral flow of groundwater into Burgh Common from the north margin, but the importance of this to the water balance of the site is not known (but seems to be small). There are no known features of the site which are obviously related to, or dependent upon, such seepage inputs – though the water table in the Kesgrave Sands and Crag may well help support the fen water table, especially near the margins.

2.6 CATFIELD AND IRSTEAD FENS

NORFOLK: TG3620

Status**:** SSSI: Ant Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 48

WETMECs: Type 6 (recolonised turf ponds), Type 7 (undug peat).

Description: A large site, located on the west side of the Barton Broad and the R. Ant, which has been the subject of quite a lot of ecohydrological research (see Box, below). Any ecohydrological assessment of this site is complicated by the disposition of the R. Ant (which originally flowed through the fens rather than along their western margin, as now) and by the Commissioner's Rond, a bank of solid peat which divides the fen into two hydrological systems, an 'internal' system, which lacks direct connection with the river but receives some land drainage and groundwater inputs, and an 'external' system which has direct river connection. It is thought that the Commissioner's Rond was constructed to permit drainage of the internal fens, but only partial conversion of a small number of them (those directly along land eastern upland margin) seems to have been attempted. However, both the internal and external fens were subject to considerable 19th century peat extraction, and much of the surface these fens consists of shallow turf ponds in varying states of terrestrialisation. The alluvial infill is some 4–6 m deep across much of the fens. A thick layer (*c.* 4 m) of dense brushwood peat lines the entire site, but over much of the southern area this is covered by estuarine clays. These are thickest (*c.* 2m), shallowest (*c.* 0.5–1 m subsurface) and purest in the south of the site, in association with the former course of the R. Ant. Northwards they thin and become represented as *Phragmites*-clay and in the most northern compartments they are absent (but are represented by a layer of organic muds which extends laterally northwards).

Vegetation: The site has a rather complex vegetation pattern, but in essence the solid peats support various types of tall mixed fen vegetation, dominated by *Cladium mariscus, Juncus subnodulosus* and *Phragmites australis* (mostly some version of S24) and are very prone to scrub invasion when not managed. Turf ponds in the south of the complex (over clay) are mostly 'reedbeds' (*Phragmites australis* and/or *Typha angustifolia*) whereas those near the northern margin are mostly 'sedgebeds' (*Cladium mariscus*). Some of these latter are referable to the *Peucedano-Phragmitetum caricetosum* community and support nationally rare plant species. However, on-going terrestrialisation has the consequence that the vegetation of many of the turf ponds is becoming increasingly like that of the uncut surfaces and, as well as becoming more prone to scrub invasion, it is also losing some of its speciality species. In some places, areas of *Sphagnum*-dominated vegetation have established in the turf ponds.

Substratum: The site is underlain by Crag (some 35–40 m thick), which is separated from the Chalk by a fairly thin (< 5 m) layer of London Clay. The Crag also outcrops on much of the adjoining upland, though the higher ground is capped by the Corton Formation. The peat infill of the fens is separated from the Crag by a thin layer of clay, though the full extent of this is not known.

Water Supply: The 'internal' fens lack direct connection with the river and appear to receive river inundation rarely (if ever). They appear to be fed predominantly by precipitation. Land-drainage inputs are directed into the dyke system. A consequence of this is that the surfaces of some of the fens – especially, but not exclusively, undug surfaces – seem to receive little input of bases or nutrients[1] and may become quite dry during the summer. Gilvear *et al.* (1989) suggest that groundwater inputs may occur into the internal fens, through clay windows, but the magnitude of this effect is not really known – though it is clear that, if it occurs at all, it has no obvious impact upon the ecology of the fens. It is likely that some groundwater discharges into the dyke system, around the perimeter and in some of deeper marginal dykes, but the ecohydrological significance of this is not known. Various workers have reported more base-rich conditions in the marginal dykes than in most of the internal system dykes, but these seem to be largely confined to locations where the Crag is exposed in the dykes, with a rather abrupt lateral change to the dystrophic conditions of most of the internal dykes off the Crag (the significance of this is discussed further below). Connection with the external system is regulated by a sluice.

The 'external' system is connected to the river and is partly irrigated by this, by episodic flooding and, in the case of turf ponds closely attached to the dyke system, probably by subsurface flow during the summer. Much of the southern part has thick accumulations of estuarine clay, which are likely to prevent upward water movement in this area, but these clays thin and disappear towards the N margin, where communities with 'seepage indicator species' occur. However, piezometric investigations close to the N margin provide no reason to suspect groundwater inputs. This area is, however, in (tortuous) connection with Barton Broad *via* an overgrown dyke, though the degree (and direction) of flow is not well established. The external fens also receive some water inputs from the internal fens, mainly through a sluice cut through the Commissioner's Rond between Sedge Marshes and Great Fen.

Conclusion: Precipitation appears to be the main water source for much of the fen, supplemented by some land-drainage in the internal system and important river inputs in the external system. Groundwater inputs into the fen compartments *per se* appear to be small – inputs into the marginal dykes may be more significant, but this needs to be established.

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[1]Note that this process of base-depletion does *not* correspond with the process of *Sphagnum* invasion, which is observed in various parts of the fens, including locations quite close to the river. *Sphagnum* colonisation is a more localised process, associated with acidification of buoyant fen mats over terrestrialising turf ponds. The base depletion in the internal fens is a much more pervasive process and is not associated with *Sphagnum* establishment.

Ecohydrological Investigations at Catfield Fens

The Catfield fens have been the focus of a number of 'ecohydrological' investigations, more so than any other site in Broadland. Studies in which a significant number of field measurements have been made include the following:

- Jennings (1951) published some peat stratigraphical sections from across the fens.
- Wheeler (1975) made numerous vegetation records. Giller (1982) and Wheeler & Giller (1982a) produced a vegetation map, recorded a number of stratigraphical sections, examined aspects of the plant ecology and made some simple water level measurements. Aspects of the work have been published (Wheeler & Giller, 1982b; Giller & Wheeler, 1986a, 1986b, 1988).
- The University of Birmingham made some detailed hydrological and hydrochemical investigations, including measurements of topography, hydraulic conductivity and piezometric head. This has been reported by Collins (1988) and Gilvear *et al.* (1989) and aspects of the work were subsequently published (Gilvear *et al.* 1994, 1997).
- Parmenter (1995) made a comprehensive vegetation survey and map (herbaceous communities only) as part of the *Broadland Fen Resource Study.*
- Environment Agency installed 5 piezometers and 3 gauge boards (HSI, 1996). Data from these have been collated and interpreted by Montgomery Watson (1999).
- van Wirdum *et al.* (1997) reported some preliminary hydrological investigations in part of the fens, with particular reference to the peat layers (mainly determinations of hydraulic conductivity, piezometric head and thermal-conductivity profiles).
- Wells & Wheeler (1999) analysed the developmental history of the fens over the last 2000 years, based on detailed macrofossil analyses of peat cores. This showed *inter alia* the changing importance of river flooding to the wetland.

Despite these studies, some aspects of the ecohydrology of the Catfield fens remain inconclusive. This is partly because sufficiently detailed studies have not been made of salient issues, but it is also because of errors in recording and inconsistencies in reporting.

Main Water Sources

Wheeler & Giller (1986b), Gilvear *et al*. (1989) and Williams *et al.* (1995) all concluded that precipitation is the dominant component determining the hydrodynamics of this site. However, as with all broad generalisations, consideration needs to be given to the detail. There are some hydrochemical differences between adjoining parts of the external and internal system, which may possibly reflect differences in water sources. The University of Birmingham study was particularly concerned with the internal system, and it seems quite possible that these studies may have underestimated surface water inputs from the R Ant into the external system. This is not least because the relationship between water levels in the external system and the river does not yet seem to have been established consistently or conclusively (see below).

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Topographical Relationships

It is important to know the topographical relationships and water level differences between the internal system, the external system and Barton Broad. However, the evidence available is more a source of confusion than clarification.

Wheeler & Giller (1982) presented water levels for the internal and external dykes on either side of the Sedge Marshes / Great Fen sluice for a 10-year period. This indicated that for much of the year flow was normally outwards, from the internal to the external system but that in some summers flow was inwards.

Gilvear *et al*. (1989) and Gilvear *et al.* (1997) both present data for water levels in Barton Broad and on either side of the sluice, but they are inconsistent, making interpretation difficult. For example, in Gilvear *et al.* (1997) hourly data for water levels at the sluice are in a higher range than weekly data calculated for the same period. Likewise, Broad water levels reported by Gilvear *et al*. (1989) are higher than levels reported for the same period by Gilvear *et al.* (1997). In this last paper, dyke water levels in both the external and internal systems are predominantly higher than those in the Broad, suggesting a gradient towards the Broad, but Gilvear *et al*. (1989) indicate that there is often potential for water flow from the Broad into Great Fen (external system).

The Agency gauge boards G1 (in an external system dyke), G2 and G3 (both in internal system dykes and in free hydraulic connection with each other) might be expected to resolve the issue of the direction of water flow between the internal and external systems, but they do not because they indicate about a 10 cm water level difference between G2 and G3 which almost certainly does not exist. This appears to be a consequence of a levelling error (probably of G2).

Thus, despite the work reported it is difficult to know what conclusions to draw about directions of water flow. The simple data collated by Wheeler & Giller (1982a) appear to be reliable, and indicate that flow is mainly from the internal to the external system (this is corroborated by casual observations at the sluice). However, the relationship between water levels in the external system (Great Fen) and Barton Broad does not seem to be known with confidence.

Hydraulic conductivity

There is considerable inconsistency between the peat *K* values reported by the Gilvear *et al*. (1989) study and that of van Wirdum *et al.* (1997). The former workers report mean and range values that are much higher than those recorded in the latter study. The reason for this discrepancy is not known, though it may be noted that van Wirdum *et al.* carefully located piezometer tips within well-defined and 'uniform' peat strata. It is not known to what extent Gilvear *et al*. (1989) specifically sampled a range of contrasting and 'uniform' peat strata.

Hydraulic gradients

The University of Birmingham studies show considerable inconsistency in their reporting of hydraulic gradients, especially between reports and published papers, so that the conclusions reached by Gilvear *et al.* (1994, 1997) do not appear to take account of the full complexity of the results presented in earlier reports. For example:

- Gilvear *et al*. (1989) report, for some parts of the fen, lower heads at greater depth, giving the potential for downward movement of water.
- Collins (1988) suggests a steep downward gradient between the peat and the Crag, but these values do not seem to be used or documented by Gilvear *et al.* (1989).
- Gilvear *et al*. (1989) show a downward gradient over the clay in 1988 and a predominantly upward gradient in 1989, but neither is as steep as those recorded by Collins (1988).
- Gilvear *et al*. (1989) report small gradients within the peat, sometimes upward and sometimes downwards, yet Gilvear *et al.* (1994) only make reference to the upward gradients. Likewise, the piezometric data reported by Gilvear *et al.* (1997) suggests a complex system of upward and downward flows, which provides little convincing evidence of the predominantly upward trend subsequently emphasised by these authors in the conclusions of their 1997 paper.

The reasons for these discrepancies are not known to us.

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Groundwater Supply
Gilvear *et al.* (1997) suggests a clear over-pressure in the Crag. This agrees with other piezometric observations. Gilvear *et al.* also conclude that groundwater forms only a minor component of the water balance of the fen, but may be important in providing a saturated base to the system. van Wirdum *et al.* (1997) broadly concur with this conclusion (insofar as they found little evidence for upwelling water feeding the fen). However, Gilvear *et al.* (1997) go further and, on the basis of hydrological modelling, conclude that a drop in the Crag water level would cause drying of the fen. This conclusion, however, is open to some challenge:

- the contribution made by the Crag appears to have been overestimated (and needs to be better determined by further research).
- vertical drainage of water from the peat into the Crag depends not just on head values, but also on *K* values of the peat and clay. In the model used, the *K* values used are high (compared with those measured by van Wirdum *et al*) and may overestimate rates of vertical water transfer.
- little account is taken of the potential for replenishment of water from surface water sources (particularly relevant to the external system).

Groundwater and Fen Ecology
The *Peucedano-Phragmitetum caricetosum* community that occurs in Great Fen is characterised by a number of species that are also found in soligenous fens. The occurrence of these so-called 'seepage indicator species' has led to the recurrent suggestion that the distinctive compositional characteristics of Great Fen occur because this area receives groundwater inputs. There is, in fact, no evidence for this. Neither Giller (1982), using simple thermal measurements, nor van Wirdum *et al.* (1997), using a combination of thermal-conductivity profiles and piezometry, were able to find indications of groundwater inputs.

One feature that distinguishes Great Fen from the internal system fens is that it is slightly more base-rich (see Fig 1–11 in R&D Report W6-068/TR). The origin of this is not known – it could reflect 'fossil' bases deposited when the R Ant formerly flowed close to this part of the fen and probably periodically flooded it, or it could be due to modern inputs from Barton Broad – though the uncertainties about the topography and water levels across the site (discussed above) leave an open question as to the extent to which broad water is likely to penetrate into Great Fen. It does, however, seem unlikely that the base-enrichment reflects localised groundwater input as the pH of the groundwaters in the nearby piezometers P1 and P2 is *less* than that measured in Great Fen. (Table CF_1).

Table CF_1. Water chemical data from samples from piezometers and dykes by gauge boards (9 April 2000)

	P1	P2	P3	P3[1]	GB3	GB2	P4	P5
pH	5.9	6.3	6.3		7.5		6.1	6.7
Conductivity ($\mu S\ cm^{-1}$)	1050	486	1672	640	679	675	964	975

[1]: sample from flooded surface water alongside P3
For more pH data from the fens near piezometers P1–3, see Figure 1–11 in R&D Technical Report W6-068/TR

In general, there has been a tendency to assume that groundwater inputs are likely to be more base rich than the fens and dykes into which they discharge (because Crag groundwaters elsewhere are often base-rich (*e.g.* Upton Fen) and because of the tendency towards acidification within most peatlands in the absence of base-rich inputs). The apparently rather low base-status of the groundwater in the Catfield piezometers is therefore of considerable interest and may have some intriguing implications. Much of the fen (and dyke) water of the internal system is rather base poor (Giller & Wheeler, 1982a, 1982b; Collins, 1988) and some of the water is little different to rainwater. van Wirdum *et al.* (1997) suggested that this reflects the present predominance of precipitation inputs coupled with the absence of the former episodic inundation by river floodwater, consequent on the construction of the Commissioner's Rond. This may still be a sufficient explanation for the base-poor conditions, but it now appears that if any inputs of base-poor groundwater do occur, they could contribute to the

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low base status of the fens, especially in the absence of inputs of bases from river flooding. If correct, this may suggest that any such groundwater inputs could be seen as ecologically and conservationally *undesirable*, because in general acidic fens have considerably smaller biodiversities than do base rich examples.

Groundwater and Dyke Ecology

As the dykes are cut into the Crag around the margins of the Catfield fens, it seems likely that they will have some exchange of water with the Crag aquifer. The general water flow from the internal dykes to the external system is also indicative of a water source within the internal system, though the proportion attributable to rainfall, land drainage and groundwater inputs is not known.

There has also been a suggestion that groundwater inputs may be responsible for determining the distribution of aquatic vegetation within the dykes. In particular, it has been suggested (C. Doarks, *pers. comm.*) that this might account for the localisation of the valued *Stratiotes*-dominated community and, moreover, that the observed decrease in extent of this community (in recent years it has become increasingly confined to the very land margins of the dykes) could reflect a diminution of groundwater inputs. This interesting suggestion merits consideration.

Wheeler & Giller (1982b) demonstrated that the *Stratiotes* community is indeed confined to the marginal dykes, and that it (then) was a good indicator of stretches of dykes cut into the Crag (as opposed to peat) (since then, the community has contracted its range so that not all Crag-based dykes support this vegetation). They also found that the waters in which it occurred were both base rich and more nutrient rich than the central dykes without *Stratiotes*[1]. They suggested that this was probably due to the influence of land-drainage inputs. This view was subsequently supported by the (independent) observations of Collins (1988) as all of the dykes which supported the former ‘best’ *Stratiotes* stands correspond exactly to her Type 3 Groundwater category, which she suggests includes water which “originates dominantly in surface run-off from the adjoining highly fertilized uplands”. Although only provisional the water chemical data from the Agency piezometers suggest that the groundwater is *less* base rich than that recorded from many of the dykes, and especially lower than the water in the *Stratiotes* dykes[2]. On this analysis (which requires further investigation), far from being the explanation of the occurrence of *Stratiotes* vegetation in base rich conditions, it could be suggested that any groundwater inputs at Catfield may in fact *decrease* the base status of the dykes and thus be detrimental to their aquatic macrophyte vegetation.

[1] The central dykes supported only a sparse macrophyte flora, dominated mainly by *Utricularia* spp.

[2] The piezometers sampled are located some distance from the ‘best’ current *Stratiotes* dykes, though in the 1970s *Stratiotes* occurred in the dyke immediately adjoining the piezometers

2.7 DECOY CARR, ACLE

NORFOLK: TG405090

Status**:** SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 2

WETMECs: Type 4 (western zone), Type 5 (between wet western zone and main drain)

Description: A large wetland area occupying a north-south side valley of the R Bure, about which rather little is known. The site is subdivided by a number of dykes, and the lower reaches of the valley (outwith the SSSI) have been partly drained. A regulated central ditch controls water levels over a quite large area of the fen. The control levels on this have been altered recently, and have resulted in increased water levels over at least part of the site, but much of the fen is still relatively dry woodland. Particularly wet conditions occur along parts of the west margin, especially in association with the former Decoy and some adjoining areas near the fen margin. It appears that this part of the fen is fed by springs and seepages, though the wet, and rather treacherous, nature of the substratum may possibly also be a consequence of former peat extraction (this requires verification).

Vegetation: The whole site is largely woodland and contains rather few uncommon plant species or communities. However, it formerly supported an area with a semi-floating mat of herbaceous vegetation, containing some rare plant species (*Eriophorum gracile, Homalothecium nitens*), which could probably be allocated to the *NVC* floristic unit M9. This appears to have been located along the west margin of the site, in the vicinity of the Decoy.

Substratum and Water Supply: The fen is underlain by Crag, separated from the Chalk by London Clay. The Crag is overlain by Contorted Drift sands and gravels and is thought to be in hydraulic continuity with these, but layers of clay both within the Crag and Drift create multi-layered, semi-confined units. The existing piezometers are located at the far NE end of the site, about 1 km from the former area of particular interest, in a rather different geological setting (capped by estuarine clay) and quite close to a drain. They may well not be representative of the site as a whole; certainly their records do not well represent conditions along parts of the west margin of the fen where the water table is thought to be close to, or at, the surface for much, or all, of the year. The source of these wet conditions is accordingly not known with certainty, but they appear to originate from discharge from the crag (and drift). The west side of the site also has a very large surface water catchment, but the rôle and contribution of rain-generated run-off to the site is not known.

Conclusion*:* In the area of former main interest, this site is a rheo-topogenous fen, fed by groundwater inputs at the west margin which percolate eastwards to the main drain, possibly *via* preferential flow paths associated with the Decoy and possible former turf ponds. It is not known to what extent the supply is primarily due to water transfer from the west margin and to what extent this is supplemented by upward flow in various places across the fen. It is reported that some of the ponds (near the margin) are spring fed.

2.8 DUCAN'S MARSH AND CARLETON BROAD

NORFOLK: TG339027

Status**:** SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 2

WETMECs: Type 2 ('seepage' slope), Type 5 (valley-bottom)

Description*:* Ducan's Marsh is situated in a side valley of the R Yare (Carleton Beck). The SSSI includes part of the gentle valley slopes and the valley floor. Parts of the slopes support seepages and there is local development of a (rather impoverished) M13-like community. The valley floor is partly drained, by dykes which discharge into the Carleton Beck, but it still retains some areas of wet grassland and fen meadow.

Substratum: The bedrock is Upper Chalk overlain by Crag which is covered by drift. The valley contains a complex sequence of alluvial deposits (25m depth of peat, sand, gravel, silt and clay) within a channel cut to the base of the Crag and underlain by chalk. The seepage slopes support almost no peat, but in the centre of the valley, peat depths of about 5 m have been recorded, with a thick (2–3 m) basal layer of solid brushwood peat.

Water Supply*:* Chalk and Crag are the main aquifers, but the degree of continuity between them is not fully known – they appear to form a single system. The chalk aquifer is artesian (0–1 m agl). The alluvium in the valley floor may act as a multi-layered aquitard which confines or partly confines the Crag and Chalk. Differential heads suggest potential for upward flow from Crag/Chalk into the overlying alluvium. Springs and seepages occur where the Crag is unconfined to the west of the site and within the site where the alluvial sequence is in continuity with the Chalk–Crag aquifer by vertical or lateral leakage. A layered drift aquifer to the west of the site may possibly contribute to the seepages. The drains and Carleton Beck may also receive support from the Chalk–Crag aquifer, or other water sources in the alluvium. However, it is clear that even the main seepages tend to become rather dry during summer (a water table of –20 cm was measured in the M13 area in 1986), but it is not clear to what extent this is due to head loss associated with the drainage system in the side valley or to other factors.

Rather little is known about water supply to the fen meadows on the valley floor, in terms of upward flow of groundwater *versus* lateral seepage from the dykes. Much of this area is, however, rather dry in summer (–40 cm was recorded in 1986), and it is possible that rainfall is the dominant component of summer water supply to the fen surface. The quite thick accumulations of brushwood peat may act here as an effective aquitard.

Conclusion*:* Intermittent seepage of Chalk / Crag water maintains the seepage slopes of the fen and may also help support the water table in the valley floor. However, water supply to the surface of this latter area is probably dominated by rainfall, at least in summer.

2.9 EAST RUSTON COMMON

NORFOLK: TG340280

***Status*: SSSI**

Key Samples: 6

WETMECs: Type 2 (margins and upper part of King's Fen); Type 4 (lower King's Fen and Mown Fen)

***Description**:* A large heathy common on sands and gravels with fen vegetation along the valley bottom, flanking a tributary stream (Hundred Stream) of R Ant. The SSSI comprises two main parts: (i) Kings Fen, north of New Bridge; and (ii) Mown Fen, south of New Bridge (both on the east side of the stream). North of New Bridge, fen also occurs on the west side of the Hundred Stream, but this area is now outwith the SSSI. The area immediately north of New Bridge (Honing Common) is alder carr. Further north is grassland which has been reclaimed from original wetland. Gently rising higher ground lies to the east and west of the site.

This site has been detrimentally affected by water abstraction and burning which, in combination, produced abnormally dry and nutrient-rich conditions over much of the site. The fen has a documented history of extensive peat extraction (Bird, 1909) and, recently, more peat has been removed over large areas, partly to reduce the high surface nutrient capital. This has also lowered the surface, whilst the rate of water abstraction has also been reduced. In combination, these changes mean that there is little residual vegetation and that the remnants are neither in equilibrium with the 'new' environment, nor do they much resemble the vegetation which occurred in the early 1970s, prior to the worst of the damage (large areas of the fen are now shallow-flooded). Rather than exclude this important site from the Framework, we will attempt to use information about the character of the site in the 1970s in relation to postulated water supply mechanisms.

***Vegetation**:* In the early 1970s, much of the lower part of King's Fen was occupied by rather nondescript mixed fen vegetation (~S24), which graded northwards into S27 vegetation at the head of the mire. Along much of the eastern margin, particularly towards the northern end, the main fen vegetation was separated from the upland by a band of acid fen, with much *Sphagnum* (~M4). This distinctive zonation was unusual in Broadland and has been attributed to water seepage. It is, however, important to notice that the acid fen was located on relatively flat ground, at the base of the rising upland slopes, and was not situated on an obviously soligenous slope. [The situation was rather similar to that found at Mrs Myhill's Marsh (Hickling Broad) where a comparable (but less well developed) juxtaposition of communities occurs.] The *Sphagnum* zone petered out towards the southern (downstream) end of King's Fen, and a comparable band of vegetation did not, apparently, occur below the (contiguous) rising slopes on the east side of Mown Fen. Much of Mown Fen was wooded, but the north end supported mown sedge beds (on old peat cuttings) with an impoverished form of *Peucedano-Phragmitetum caricetosum*, with some uncommon plant species.

Substratum: Peat depth is variable. It is less than 1 m over much of King's Fen, but typically between 1.5–2 m in Mown Fen. Both areas show evidence of extensive, old peat cutting. The Common is situated in an area of Norwich Crag covered by the loamy sands and clays of the North Sea Drift. The fen lies in a valley where the drift has been incised to reveal the underlying Crag in the valley floor. Alluvium is present near the Hundred Stream. The Crag varies from less than 10m to c. 23m thick, and overlies Upper Chalk.

Water Supply: The Chalk aquifer is generally unconfined. The Crag and Chalk are in hydraulic continuity with a small downward hydraulic gradient. Alluvium/peat overlies the Crag in the valley. Heads are difficult to specify because of the effects of water abstraction borehole. However, Binnies/ECUS (1995) suggested that prior to abstraction, Chalk water levels would have been at or above ground level throughout the year (it is not clear how this postulate relates to the former occurrence of acidic mire vegetation).

Water levels in the adjoining Hundred Stream may well help to control water levels in the fen, but do not seem to be a main source of water (except, perhaps, on rare occasions), as water movement (if any) is reported as being nearly always from the fen to the stream (drainage is increased by opening foot drains if the level is too high on the fen), but water can back up in the fen if levels are high in the Hundred Stream. This suggests that the site is primarily fed by groundwater, but it is not known to what extent this is from the Drift or the Crag–Chalk aquifer. Abstraction of water from the chalk [PWS is adjacent to the site] has undoubtedly affected water levels within the fen, but it is not yet clear whether Crag–Chalk water discharged into the fen or just supported drift water.

It seems possible that the north eastern end and eastern margin of Kings Fen may have been supplied with relatively base-poor water derived from the North Sea Drift, whilst the lower part of Kings Fen and Mown Fen may have received Crag–Chalk water. This proposition, however, requires resolution as it is possible that differences in base status could also be determined partly by the chemical character of the substratum, the proportionate contribution of precipitation and rain-generated runoff, and variation of water quality within the Crag aquifer. The Hundred Stream appears to be fed partly by seepage from the Chalk.

Conclusion: Primarily groundwater fed, but provenance of groundwater and importance of rainfall and generated runoff is not really established and may vary in different parts of the fen.

2.10 EASTON BROAD AND FROSTENDEN VALLEY

SUFFOLK: TM4979

***Status*: SSSI, SPA**: Benacre to Easton Bavents

WETMECs: Types 4 and 5

Description: An extensive, linear wetland developed for almost 4 km along the bottom of the Frostenden valley, subdivided by dykes and the axial river. The land falls from about 2.5–0.8 m OD. Easton Broad is a small, brackish lagoon at the seaward end, separated from the sea by a shingle bar.

Vegetation: In the mid 19^{th}-century, the whole valley was apparently a (freshwater ?) estuary, open to the sea, but by 1884 had been almost completely drained and converted to grazing levels. Subsequent deterioration of drainage structures led to re-flooding, and by 1952 the valley was mostly reedbed. Some re-conversion to grazing marsh occurred subsequent to this, but some of this has since reverted to reedbeds. Today there are some areas of grazing marsh, but much of the valley is occupied by species-poor reedbeds, showing a transition from brackish to freshwater conditions upstream, and including some of the largest stands of reed in the UK. In the upper parts of the complex, fen meadow (M22) vegetation occurs at the drier edge of the reedbed and there are also areas of alder carr.

Substratum: The valley and broad is situated upon a thick (50 m) layer of Crag, which outcrops on the valley slopes. The Crag is separated from the underlying Chalk by about 50 m of Palaeocene – Eocene mudstones and siltstones. The tops of the adjoining interfluves are capped by drift (mainly by very localised sands and gravels of the Corton Formation in the east, but by extensive Lowestoft Till further west, but within the catchment of the wetland). The valley bottom is filled with freshwater peat, but at the very seaward end this appears to be capped by estuarine alluvial deposits.

Water Supply: Little is known in detail about groundwater supply to the wetland, but groundwater from the Crag appears to discharge into the wetland, as springs and seepages, where the water table intersects the valley sides. The peats and silts of the valley bottom may help impede flow into the valley. Small side streams, with groundwater-maintained baseflows, also provide freshwater inputs, and a sewage works upstream at Wrentham provides a small contribution of freshwater flow. HSI–ECUS (1999) estimated that groundwater contributes some 40% of the mean water inflow into Easton Broad. The site has a number of water control structures, designed to regulate water levels in the grazing levels and the reedbeds, and to reduce upstream incursions of brackish water. Easton Broad was formerly freshwater, but the shingle bank is now breached by seawater about once a year.

Conclusion: Floodplain wetland fed by surface flow and groundwater plus saline incursions (in the lower reaches). In the main reedbed areas, high water levels are maintained by control structures which help produce surface inundations.

2.11 HALL FARM FEN (HEMSBY COMMON)

NORFOLK: TG481170

Status**:** SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 3

WETMECs: Type 2 (slope), Type 5 (flatter area near Ormesby Broad)

Description: An area of fen meadow and wet grassland, crossed by dykes, forming part of the head of the Ormesby Broad valley. The broad adjoins the lower (western), more-or-less flat, part of the 'fen'. Eastwards, towards the head of the valley, the fen is slightly sloping and grades out into grassland.

Vegetation: Fen vegetation is not particularly well developed at this site, and consists mainly of a rather poor example of M22 fen meadow, though with some species of local importance (*e.g. Anagallis tenella, Menyanthes trifoliata*). The dykes have greater biological 'interest' (HSI/ECUS, 1998).

Substratum*:* The site is underlain by, and adjoined by, the Corton Formation. This is about 2–3 m thick beneath the site and overlies Crag deposits (Norwich Crag). These are about 60 m thick and form the main relevant aquifer to the site (they are separated from underlying Chalk by a 40–50 m thick layer of London Clay). The Crag aquifer is mainly unconfined, and in hydraulic continuity with the Corton Formation (though clayey facies may cause local confinement). It is likely that the fen is, in part, irrigated by groundwater discharge from this.

Water Supply: There is some water flow through the (partly groundwater-fed) dykes, ultimately into Ormesby Broad. However, a plug in the dyke system (a metal plate) and occlusion of dykes in the vicinity of the broad, may mean that there is rather little flow through these, at least in summer. The plug may also prevent substantial reverse flow, when levels in Ormesby Broad are high. The dyke levels may help control water levels within the fen but the details of their relationship with the fen water table is not known[1]. On the slope, the dykes may help reduce seepage supply to the fen surface: dyke water levels are generally lower than the water table.

Conclusion: A fluctuating water table, subsurface for much of year, intercepted and partly controlled by dykes (ditches).

2.12 HICKLING BROAD MARSHES

NORFOLK: TG4021

Status**:** SSSI: Upper Thurne Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 24

WETMECs: Type 6 (turf ponds and broad margin); Type 7 (undug peat)

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[1] HSI/ECUS (1998) report for AMP3 suggests that dyke water levels behave in a similar way to groundwater levels, but it is not known how either dyke water levels or groundwater levels relate to phreatic water levels measured in the fen.

Description: Hickling Broad occupies a shallow, gently sloping embayment within the upland, an offshoot of the main Thurne valley. Towards the eastern end it is adjoined by partly-drained levels (part of the SSSI but excluded from consideration here) and is contained by embankments located at, or close to, the edge of the alluvium. The valley is shallow and peat has been removed from much of it, apparently down to the mineral floor over large areas towards the shallow margins. The site extends westwards (Catfield Common) and south-westwards (Mrs Myhill's Marsh) along shallow valleys.

Vegetation: Much of the fens around the broad are hydroseral reed and sedge beds. In some places – especially towards the SW margin – there are small areas of semi-floating *Sphagnum* (with *Dryopteris cristata*). There is some scrub invasion and both Catfield Common and Mrs Myhill's Marsh are particularly heavily invaded. However, Catfield Common has some sedge beds over relatively deep and solid peat whilst a clearing towards the W end of Mrs Myhill's Marsh, effectively at the edge of the wetland, supports a small area of acidic fen over very shallow (25 cm) peat (upon clay).

Substratum and Water Supply: Hickling Broad is situated over Crag (perhaps some 60 m thick), separated from the underlying Chalk by London Clay and Reading Beds. There is evidence that the broad itself has been cut down to the Crag and 'gravel' is exposed over quite large parts of the bottom of the broad basin, which may make it a candidate site for water exchange with the Crag. However, all of the peat cores for Hickling Broad on FENBASE show the underlying mineral ground deposit (Crag ?) to be smeared with clay (*e.g.* Table HB_1), though of course all of these were necessarily made near the edge of broad (where fen has re-developed). Little seems to be known about the possible importance of such clay layers. Holman *et al.* (1999), discussing the Thurne valley, indicate that "In the marsh area, surface water bodies, including the River Thurne, have water levels that are higher than found in the Crag aquifer" and consider that they may recharge the Crag. It is not certain to what extent this applies specifically to Hickling Broad and the nature of water flow between the Crag and the Broad may require clarification.

It is possible that groundwater discharge may be of some local importance in some locations adjoining the upland margin, *e.g.* Mrs Myhill's Marsh, but there is no known evidence for this and the underling clay may act as an effective aquitard (Table HB_2).

Table HB_1. FenBASE Sample 12/114004: Peat profile, S side of Hickling Broad, TG418208

Depth (cm)	
0–40	Very loose, light brown peat with *Phragmites*
40–110	Brown, organic clayish material, rather uniform
110–140	More clayey than above
140–145	Thin band of blue grey clay, grading down into organic clay
145+	Gravelly material

Table HB_2. FenBASE Sample 12/114007: Peat profile, Mrs Myhill's Marsh, TG403213

Depth (cm)	
0–20	Loose, peaty material, amorphous and sloppy
20–55	Humified, granular peat, crumbly and firm
55–75	Stiff, gritty clay
75+	Mineral material, apparently gravelly but not penetrated

The surface water system (the broad and river) is tidal and is subject to regular winter flooding, usually with at least one high water episode during the summer. It also receives considerable pump-drainage water discharge. Much of surrounding fen is hydroseral and has a loose peat infill, which may facilitate transfer of broad water into the adjoining fen.

Conclusion: Primarily a surface-water fed system. The Broad may recharge the underlying Crag but may possibly also receive some groundwater inputs at certain times of the year (summer). Some marginal fen locations may also receive localised groundwater inputs, but the importance of this is not known. The water is slightly brackish.

2.13 HULVER GROUND (HORNING)

NORFOLK: TG360178

***Status*:** No statutory designation

Key Samples: 5

WETMECs: Type 6 (former turf ponds), Type 7 (uncut peat)

Description: A small area of fen adjoining R Ant, north of Ludham Bridge and embanked above the adjacent farmland.

Vegetation: The vegetation is mainly sedge beds (S24) and reedbeds (S4), in various states of management, and with invasive carr. Much of the area is reflooded, revegetated turf ponds, and patches of *Sphagnum* vegetation (with *Dryopteris cristata*) are associated with some of these.

Substratum: The valley infill here is quite deep (*c.* 6 m), much of which is composed of Romano-British clay upon a highly compressed brushwood peat. Estuarine clay (Romano-British transgression) extends beneath the entire site, thinning towards the W margin, and forms the bottom to the turf ponds. It is likely to be an effective aquiclude.

Water Supply: The R Ant seems to be the principal source of telluric water, with ingress into the fen being partly by sub-irrigation through revegetated turf ponds.

Conclusion: Fed by river water, mainly subirrigation into transmissive peats plus episodic overbank flooding

2.14 LIMPENHOE MEADOWS

NORFOLK: TG398032

Status**:** SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 2

WETMEC: Type 5

Description: A small area of wetland at the landward edge of the drained levels of the R Yare floodplain, at the base of the rising upland slope, but situated on fairly deep (> 1.5m) peat.

Vegetation: The vegetation is rather fragmented and does not provide particularly good examples of *NVC* units, but the lower, wetter parts are a species-rich form of M22 whilst the higher fragments are a form of M24. Patches of this latter have considerable cover of *Sphagnum* species.

Substratum: The site is located at the bottom of a Crag slope, largely covered by North Sea Drift on the upland and by alluvium in the river valley. The Crag is the main aquifer, and is unconfined to semi-confined. The alluvial/peat deposits form a thin phreatic unit, with water levels close to the ground surface. Where the Crag water table intersects the surface topography, groundwater discharges as seepages (although these may be masked by drainage). The Chalk (main regional aquifer) is not considered to be of hydraulic relevance to the site. London Clay forms the basal aquiclude to the Crag and the alluvial/peat phreatic unit, and the confining aquiclude to the Chalk.

Water Supply: The site is entirely bounded by 2m-wide drains and a network of drains cross the site, most of which contain standing or slow-moving water. Drainage is to the south, and water is eventually pumped into the R. Yare. Springs emerge within the meadows close to the base of the valley slope, but wet conditions are very localised.

The surface water catchment extends northeast of the site, but drains from outside converge with the boundary drains at the north and east corners of the site. Any run-off may be largely intercepted by a drain running parallel to the NE boundary. The possible contribution from the Yare (which is embanked at a higher elevation) is not clear – there may be some leakage through the banks & bed plus some flooding (the site is also separated from the River by a railway embankment), It is not known to what extent any flooding might influence the meadows, but it seems unlikely to be of any importance with regard to normal summer conditions.

Conclusion*:* Intermittent seepage system, fed primarily by lateral groundwater flow from an unconfined / semi-confined Crag aquifer.

2.15 POPLAR FARM MEADOWS

NORFOLK: TG369022

Status**:** SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 2

WETMEC: Type 5

Description: An area of wet grassland and fen, close to the west edge of the Yare floodplain. The site lies in an area of a dense drainage system, discharging eastwards and pumped into the tidal R. Yare. Drains form the site boundaries on three sides, and the western boundary adjoins the upland margin, close to the main road. The adjoining parcels are drained fen and support grassland.

Vegetation: The vegetation is mainly a form of fen meadow (M22, M24). However, a small depression contains a number of species that are often associated with groundwater seepage, and has some obvious affinities with a degenerate form of M13.

Substratum: The substratum comprises 4–6 m of peat, underlain by 5–10 m Pleistocene Kesgrave formation (sands with clay layers); then 5–10 m Crag, over 30–40 m London Clay, upon Upper Chalk (at a depth of c. 45 m bgl). Eastwards in the valley the peat becomes compressed beneath a deposit of estuarine clay/silt.

Water Supply: The main regional aquifer (Chalk) is confined by London Clay, and presumably not relevant. Crag and overlying Kesgrave sands form aquifers which are semi-confined by clay layers and peat. The Crag and Kesgrave Sands rise to form the interfluve SW/W of the site, capped by sandy clays of the Corton Formation and then Lowestoft Till. There is some uncertainty about the importance of groundwater to the site and its mechanism of delivery (direct discharge *versus* lateral seepage from groundwater-fed dykes). Piezometric data indicate an upward potential for groundwater flow, but there is little reason to suppose that this normally reaches the surface of the peatland component of the wetland.

HSI (Hydrological Report) consider that vertical flow upwards from the Crag does not reach the surface because of the confining effect of the peat, and they consider that "the wetland is dependent on rainfall whilst the dykes depend on groundwater contributions from the underlying aquifers". Montgomery Watson (1999) conclude that "it is ... not yet possible to determine whether the groundwater levels in the Peat and the site wetland conditions in general are sustained by the Crag Formation, by rainfall or a combination of the two". As far as peat surface *conditions are concerned, the HSI view is probably correct: the summer water table in the main wetland areas is often quite low (–40 cm was measured in the 'wettest' area (a slight depression) in 1986) and the peat surface probably is fed exclusively by rainfall in the summer. This does not exclude the possibility that the 'wet' conditions of the site are supported by a localised groundwater upwelling within the peat, which comes close to the surface. The peat (in the vicinity of the main area of wetland interest) has been described as 'fresh and rather sloppy' beneath a surface (60 cm) layer of rather solid, oxidised peat (B.D. Wheeler, field notes, 1986) and although K values are not available for this site, it seems likely that the lower peats may be rather more transmissive than is often the case for the peat infill in the Broadland valleys.*

Taking a more empirical view, it may be noted that the main wetland areas appear to be located towards the centre of the fen compartments, away from the dykes, suggesting that these do not have an important supply function (at least in summer). Such conditions could, perhaps, be attributed to impeded drainage of rainfall, but it is believed that similarly wet conditions are not found towards the middle of adjoining compartments. The highly localised character of this wetland remnant suggests that it may be a product of equally localised hydrological conditions, such as local groundwater upwelling. If this is the case, available information does not indicate the basis for a localised discharge.

On balance, it seems unlikely that the telluric water supplies to the fen component of this wetland site are derived via groundwater input into the dyke system and some form of more direct groundwater input seems more probable.

Conclusion: Both fen and dykes are probably fed by direct groundwater discharge, but the fen surface is primarily fed by precipitation.

2.16 REEDHAM MARSHES

NORFOLK: TG3619

***Status*:** SSSI: Ant Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 9

WETMECs: Type 6 (Turf ponds and reflooded drained marshes), Type 7 (ronds and areas of undug peat)

Description: A large area of fen occupying much of the floodplain west of the R Ant. The hydro-ecology of this site has been complicated by diversion of the R Ant along the upland margin at the east side of the site and by embankment and drainage of the marshes on the west side of the former course of the Ant (which is now marked by the Hundred Stream). Some of these drained levels have since been reflooded.

Vegetation: Much of the 'undrained' area has been dug for peat and consists of shallow, reflooded turf ponds, which have recolonised with (fairly species-poor) reed and sedge beds. Many of these are still regularly mown, but there is some scrub invasion. Some of this is by birch and is associated with small buoyant islands of *Sphagnum* within the fen. The turf ponds are separated from the Ant by a rond of solid peat, which essentially supports a derelict litter fen with a good deal of invasive scrub.

Substratum: The valley is fairly flat-bottomed, with a typical depth of some 6–7 m of peat and clay, deepest along the W side of the fen (the former course of the Ant). Most of the site is underlain by a thick and wide deposit of estuarine clay, some 50 cm subsurface, over compressed brushwood peat. Again this is thickest near the Hundred Stream and thinnest near the present course of the Ant.

Water Supply: There have been few investigations of the hydrodynamics of this site, but the thick and extensive deposit of estuarine clay suggests the likelihood that the site must be primarily irrigated by river water (rather than upwelling groundwater). Examination of the uncut rond along the W side of the river reveals low *K* values and modelled results (van Wirdum *et al.*, 1997 – for details, see Part 3, Section 3.7) suggest that there is unlikely to be any significant transmission of water *through* this material into (or out of) the fen interior – which is unsurprising as the main reason for leaving a rond of uncut peat seems to have been to facilitate digging of peat further into the fens. Currently, river-connected dykes have direct contact with the loose infill of the turf ponds and are probably critical in maintaining summer water levels in these. By contrast, the solid peats tend to become rather summer-dry – which may well point to the 'natural' summer water level over much of the fen before peat extraction. There is some possible evidence for upward movement of water into the rond alongside the river (this is actually at the land margin and the estuarine clay thins considerably here); however, if this occurs it is likely to be unimportant to either the water balance or the ecology of the fens (van Wirdum *et al.*, 1997).

Conclusion: River water fed, mainly subirrigation into transmissive peats plus episodic overbank flooding

2.17 SMALLBURGH FEN

NORFOLK: TG327246

Status**:** SSSI; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples 3

WETMECs: Main seepage area is intermediate in character between Type 1 and Type 4. Most of the valley appears to be Type 2.

Description: A narrow, long fen on very gentle slopes along the bottom of the shallow valley of a tributary stream of the R Ant, on the south side of the stream. The area of wetland is considerably larger than the SSSI.

Vegetation: A strip of carr and wet woodland extends a considerable distance (3 km) along the valley, but the main 'interest' (and the SSSI) is in an area near the east end, on the south side of the stream, where the wetland broadens slightly and where there is herbaceous vegetation. This includes fen meadow (M22) and tall fen, stands of *Schoeno-Juncetum* (M13)) and, locally, patches of *Sphagnum* in acidifying areas. The herbaceous fen is surrounded by carr and is separated from the stream to the north by a broad band of birch / willow carr.

In 1972, when the herbaceous fen area received only limited management, there was a fairly clear vegetation pattern: the [M13] 'stands' were irregular and encompassed a few rather small areas of open *Schoenus* fen with a well developed moss carpet, within a matrix of taller *Juncus subnodulosus* fen meadow [~M22]; some of the notable species appeared to be restricted to one low-growing area; some small 'runnels[1]' formed narrow zones of similar low-growing vegetation within the fen meadow, some of which connected to the main flushed patches; and some acidophiles were associated with tussocks and old tree stumps etc. (B.D. Wheeler, field notes, 1972). Since then, vegetation management has blurred the fairly clear physiognomic distinction between the M13 and M22 stands noted in 1972 and has resulted in an apparent increase in the area of M13, by reducing the dominance of *Juncus subnodulosus* and permitting either a real or apparent expansion of the M13 characteristic species that were present in the 'M22' stands in 1972. The distinction noted in 1972 is still more-or-less evident, however, as patches of *Schoenus* dominance are still fairly localised and much of the rest of the vegetation has less *Schoenus* and is often less species-rich. In some locations it is a moot point whether the less rich areas are actually M13 or M22; in others they are clearly referable to M22[2].

The area of apparent 'M13' seems to have increased since the 1970s, apparently in response to management, but there has also been some species loss from the site. Some species (*Carex limosa*, *Liparis loeselii*, *Homalothecium nitens*) seem to have disappeared by the 1950s, but there has also been apparent loss since 1972 (*e.g. Carex dioica*, *Dactylorhiza traunsteineri* and *Philonotis calcarea*). The reason for this is not really known. These species were recorded from a low-growing patch of M13 that appears to have been damaged in consequence of its selection as a bonfire site in the early 1980's – though it is possible that they had disappeared from this patch before this event. The view has also been expressed that the fen has become drier, but it is not known if this is actually the case, nor is it easy to separate the possible effects of drying from other causes of damage (bonfire sites and dereliction). It may, however, be noted that the fen retains a considerable, locally abundant,

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1 These were not actual 'runnels', more sinuous strips of low-growing vegetation within the fen meadow

2 A recent *NVC* survey by Norfolk Wildlife Services did not apparently record any M22 and allocated the herbaceous vegetation to either M13 or S25. We consider this to be an inaccurate reflection of the floristic character of the vegetation.

population of *Drepanocladus intermedius*[1], an uncommon bryophyte which is generally considered to be sensitive to drying.

Substratum: The stratigraphy of this fen has not been described in detail, but it is situated on peat, some 2 m deep in the main herbaceous area and about 3 to 4 m deep near to the stream. A layer of silty clay, some 20-30 cm thick, occurs at about 60-70 cm bgl across much of the fen, from the herbaceous area to the IDB stream, and there are thinner bands of calcareous silt at deeper layers closer to the stream. In the main M13 areas the substratum is locally quaking and here the peat, above the silty layer, is rather loose and either detrital in character or rich in hypnoid moss remains. Below the silt layer, the peat here is a rather soft and loose but with substantial remains of hypnoid mosses. Closer to the stream, the lower peat is also rather soft, but tends to be amorphous and without many moss remains; wood fragments occur here, but they do not form a 'brushwood peat'. There are also some thin bands of sandy silt. The peat infill is generally underlain by a sandy clay with stones (thickness uncertain, but at least 80 cm thick in places). There is rather little evidence for marl layers in the peat – it seems likely that the marl layers reported by Parmenter (1996) correspond to the horizons considered here to be 'silty clay' or 'sandy clay'[2].

Parmenter also suggests that peat cutting has occurred at this site. The evidence for this is not known, but some former excavation does seems probable and might account for the slightly quaking surfaces found in parts of the site. However, preliminary peat profiles in the M13 area, including the quaking patches, (B.D. Wheeler, unpublished data) have not revealed a turf pond stratigraphy such as is typical of much of Broadland, suggesting that either this community is not located over an old peat working or, if it is, then the turf pond was of different character to those found elsewhere. It is possible that quaking areas within the herbaceous fen *may* represent zones of strong water discharge rather than terrestrialised peat diggings, but this requires further investigation and there is currently no evidence for this.

Water Supply: The fen is located over a semi-confined Chalk/Crag aquifer, with a piezometric head well above ground level (mean = 1.2 m agl). The herbaceous fen area is believed to be groundwater fed, probably from Crag or Chalk rather than Drift. Discharge conditions appear to be very localised, presumably associated with upward leakage through a small area of transmissive material (much of the underlying substratum is clay-rich). Lateral to the main discharge area, the fen appears to be an elongated area of intermittent seepage, possibly fed partly by lateral flow from the Crag/Drift, but little is known about this site away from the SSSI.

The SSSI is bordered on three sides by ditches, which presumably help control the water level in parts of the fen and which appear to receive water from the fen. The mechanism of water supply to the herbaceous fen surface is not very clear. The patches of low-growing M13 noted in 1972 were reminiscent of the vegetation associated with springs and strong seepages in

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1 This species (or any other *Drepanocladus* species) was not recorded in a recent (2000) *NVC* survey of the fen by Norfolk Wildlife Services but it is, in fact, quite widespread in parts of the herbaceous fen. Other uncommon species that still occur in the fen (*e.g. Calliergon giganteum*) also do not appear to have been noted in this survey, and it cannot be considered to provide a comprehensive record of the current floristic composition.

2 Parmenter (1996) states that "The substrate beneath the fen is striking in that there are large quantities of shell marl which have been deposited in bands, presumably in the shallow water of the terrestrialising peat workings. There appear to be two distinct bands present, although additional stratigraphical work will be required to confirm this. The uppermost lies at between 50 and 80 cm beneath the fen surface, and is typically approximately 25 cm thick. The second layer of marl lies just above the sand layer at the peat-sand interface in the central fen area. Discontinuous marl deposits occur throughout the central and northern parts of the fen, and to within about 30 metres of the IDB drain." [Parmenter J (1996) *Smallburgh Fen Management Plan. 1996-2001*. Report to Norfolk Wildlife Trust, Norwich]. Our own stratigraphical investigations, although preliminary, have found little clear evidence either for terrestrialising peat workings or for large quanitities of shell marl. The upper 'marl' layer recorded by Parmenter appears to be a fluvial silty clay, the lower to be a sandy clay underlying the main peat infill. The provenance of the fluvial silty clay is not known, but could conceivably have originated during a freshwater flooding episode contemporary with the Romano-British marine transgression lower down the Ant valley.

other valleyhead fens, but there was no surface flow of water from them then, nor does there appear to be now, calling into question their actual status and reason for localisation. It is assumed that there is flow of groundwater into the SSSI and it is possible that the main *Schoenus* patches may be located in areas where there is particularly strong upward flow, but there seems to be no definitive evidence for this, nor even for the presumption that the fen is fed by upward flow (lateral flow from the upland margin could perhaps occur).

Conclusion: Main area of conservation importance appears to be a permanent seepage face, apparently sourced from a Chalk/Crag aquifer.

2.18 STRUMPSHAW AND BRADESTON MARSH

NORFOLK: TG3306

Status**:** SSSI: Yare Broads & Marshes ; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 4

WETMECs: Until recently, probably Type 6 and Type 7, but recent conservation management has reduced surface water inflows.

Description: A large area of fen and water on the broad (0.5–1 km width) north floodplain of the R Yare. The site includes Strumpshaw Broad (now with considerably less open water than its medieval basin) and there is at least one turf pond area in the fen, but much of the substratum has not been excavated. The site is divided into a series of compartments by dykes, with two larger channels which cross the fen from edge to river. These are the Lackford Run, which separates Bradeston Marsh to the NW from Strumpshaw Fen to the SE, and the broad channel that connects Strumpshaw Broad to the river. The Lackford Run retains its river connection, but that to Strumpshaw Broad has been blocked. South-east of Strumpshaw Broad an embankment separates the wetland of Strumpshaw Fen from the drained grazing levels of Strumpshaw Common further to the south-east. These levels are not as thoroughly drained as other examples further down the valley, and support some residual fen species, but they are essentially wet grassland rather than fen and are not further considered here. The dykes within the Common retain a rich aquatic flora.

Substratum: The adjoining upland rises rather steeply above the fen, and the mineral ground beneath the site falls away from the margin equally steeply, so that rather deep peat (*c.* 5 m) occurs close to the upland edge. However, the valley profile flattens quite rapidly (the break of slope corresponding approximately to the line of the railway) to give a rather flat-bottomed valley, dipping to a maximum depth of about 9m in the vicinity of the river. In the landward half of the valley, the lower 4–5 m of peat is a solid brushwood peat, but towards the river (corresponding more-or-less with the extent of overlying estuarine clay), the basal layer of brushwood peat is thinner and is covered by a quite thick accumulation of mainly herbaceous mixed fen peat with conspicuous bryophyte remains. This material is capped by a layer of estuarine clay (Romano-British transgression), which reaches inland about as far as the riverward limit of the Strumpshaw Broad basin. The clay is about 1 m thick across much of the fen, though it rapidly deepens in proximity to the river. It is capped by about 1m depth of mostly rather oxidised peat, which extends across to the edge of the fen.

The site is situated upon some 20 m of Crag, directly underlain by Upper Chalk, c. 25–30 m bgl., but the hill to the north of the fen is composed mostly of drift (Lowestoft Till / Corton Formation / Kesgrave Formation). The semi-confined Chalk aquifer is in hydraulic continuity with the Crag aquifer, and this with the Kesgrave sands and gravels. The alluvial multi-layered hydro-geological unit, comprising peat aquifers and a clay aquitard, is thought to be in some hydraulic continuity with the underlying Crag and indirectly with the Chalk.

Water Supply: The natural position of the chalk water table in the vicinity of the site is uncertain, as it is has been modified by nearby abstractions, but chalk water flow converges on the valley and it is thought that chalk water levels were formerly probably close to, or above, ground level and artesian[1], and may have discharged at least at the margins of the fen. However, piezometric observations suggest that there is now potential for downward leakage from the peat aquifer.

Since 1978 a water management regime developed by RSPB has included attempts to isolate the fen from surface water supply from the R Yare, on the basis that these were considered to be too polluted and nutrient rich for their conservation objectives. Embankments have been constructed alongside the river and Lackford Run, to exclude river water (though they are sometimes breached in flooding episodes). The reduction in water supply has been compensated partly by artificial introduction of groundwater into the dykes.

Although there can be little doubt that any former groundwater contributions to the site have decreased, or ceased, the former importance of groundwater is difficult to assess. It is likely to have fed some of dykes, but the probable balance between groundwater and river water in these, before their river connection was blocked, is not known (it may be noted that it is believed that at Wheatfen (*q.v.*), on the opposite side of the river, which also has artesian chalk water, the dykes are thought to be primarily tidally-fed). It is even less certain what importance groundwater is likely to have had upon the fen water tables. Given the depth and character of the peat, substantial upward leakage of groundwater across the fen as a whole seems rather unlikely, even in those areas without a clay aquitard layer, and any peripheral groundwater inputs may have had only a localised effect. It may be suggested that the excavation of the fairly deep Strumpshaw Broad may have been possible only because there was little lateral transmission of water, of whatever source – river or groundwater, through the peat at this location.

Conclusion*:* Until recently, this site was primarily fed by surface inputs from the river, perhaps supplemented with some groundwater inputs. Recent attempts to prevent penetration of river water mean that the site is now dependent upon precipitation for its summer water supply, though the dykes are artificially supplied with groundwater and no longer have the ‘natural’ character as seen, for example, at Wheatfen.

2.19 SUTTON BROAD

NORFOLK: TG3723

Status**:** SSSI: Ant Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 31

WETMECs: Type 6, possibly transitional to Type 4 near upland margins.

Description: A quite large area of fen, swamp and water occupying a side arm of the R Ant valley, over the site of the former Sutton Broad. This has now largely terrestrialised and is represented by a central water course flanked by largely hydroseral wetland.

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[1] As in currently the case at Wheatfen on the opposite side of the river.

Vegetation: The broad has almost entirely re-vegetated, to leave a central navigable channel, and unlike many broads has not shown catastrophic loss of swamp during the last few decades, though the channel has undoubtedly widened in recent years. Almost all of the vegetation is hydroseral and either semi-floating, or buoyant, with a loose surface infill of mud and rhizomes.

Sutton Broad is also rather unusual in Broadland in showing a particularly clear zonation of plant communities from swamp at the river (broad) margin to fen at the landward edge; this occurs along most of the length of the broad and is repeated on both sides, though the zones are wider on the south side (at least locally). The vegetation near the land margin mostly contains 'seepage indicator species' (*Peucedano-Phragmitetum caricetosum*) and groundwater discharge has been suspected, particularly as the broad was dug down close to the bedrock along its margins.

Substratum: The valley is rather shallow, with a maximum peat depth of about 2–4 m for most of its length, though deepening slightly towards its confluence with the Ant. The basal peat, in the deeper sections, is a solid brushwood peat, but almost all of the surface peat has been excavated, with the deep (*c.* 2–2.5 m) Medieval broad being extended laterally by peripheral, shallower 19th century turf ponds. Towards the sides of the valley, peat cutting has apparently exposed the underlying mineral substratum.

Water Supply: Very little is known about the hydrodynamics of this site, but a small number of preliminary thermo-conductivity profile probes on the south side of the broad (van Wirdum, unpublished) provided no evidence for groundwater inputs. It is possible that, like the adjoining Sutton Fens, a layer of clay separates the Crag from the peat. Chemical measurements show declining concentrations with distance from the river (see Figure 3–9 in R&D Technical Report W6-068/TR), but it is not known to what extent this reflects modification of the chemical composition of river water by the peat and rhizome mat or the mixing of water from different sources of contrasting chemical composition. Much more needs to be known about this important site. On the basis of the sparse existing evidence it seems reasonable to suggest that the principal supply of water for much, perhaps all, of the site is from the river, by flow beneath (and episodically above) the peat raft. However, it is possible that the landward zones receive some groundwater inputs.

The Broad receives some land drainage water inputs from the east, but the importance of these *versus* inputs from the Ant is not known.

Conclusion: Hydroseral fens are mainly fed by subirrigation with river water. Possible rôle of groundwater needs further examination, but may be important to some marginal zones.

2.20 SUTTON FENS

NORFOLK: TG370230

Status: SSSI: Ant Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 6

WETMECs: almost entirely Type 6, but with local strips of Type 7.

Description: This is a large, but poorly known, area of fen which occupies a broad floodplain on the east side of the R Ant, extending southeast of the junction of the Ant with the Sutton Broad valley into a short side valley south-east of this. The site has two unusual features for Broadland: (a) a very sparse system of dykes, which are more sinuous and natural-looking than in most Broadland fens; (b) a very extensive, semi-rafted surface, which may possibly be the product of old peat extraction, but which mostly (completely ?) lacks the narrow baulks and remnants of solid peat which occur in most turf pond complexes in Broadland.

Substratum: The valley bottom is fairly flat, but contains up to about 8 m depth of peat (towards the south end). Much of this (below about 1–1.5 m depth) is a solid brushwood peat. This gently slopes upwards to the east margin, where it meets the gently-shelving upland with a quite broad band of rather shallow peat. These marginal locations appeared to be candidate sites for groundwater input and piezometric studies were made to examine this in one place (Little Bog) (Baird *et al.*, 1998). This provided no evidence of upward flow into the peat, probably because the thin fen peat was separated from the Crag by a quite thick (*c.* 1m) layer of clay. However, this study did show that water levels in the fen in this area (which was close to a river-connected dyke) were very responsive to changes in river water levels, probably because the semi-raft like structure provides a transmissive system for sub-surface flow at low water levels (the surface is inundated at high levels). The behaviour of the rest of the system has not been examined. It is, however, known that the central areas of the fen, away from the dykes, tend to become rather dry in the summer (this is reflected in the species composition of the vegetation) and it seems likely that the sparse system of dykes is insufficient to recharge the evapotranspirative losses of the central fens in summer, despite the apparently transmissive substratum.

Conclusion: Mainly fed by subirrigation and flooding with river water.

2.21 UPTON FEN AND DOLES

NORFOLK: TG390137

Status**:** SSSI: Upton Broad & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 15

WETMECs: Type 4 (near broads and land margin), Type 5 (towards marsh wall)

Description: Upton Fen occupies a slight embayment within the upland margin of the Bure valley. The fen is separated from the R Bure by drained levels (*c.* 1 km), into which the fen water drains. The site contains two medieval broad basins, both of which have been extended by 18/19th century turf ponds. Turf ponds occur quite widely over much of the site, and are especially prominent in an area to the northeast of the broads, known as the Doles (Wheeler, 1985). There is also another, largely overgrown, pond towards the W of the fen, often referred to as the Flight Pond, but the origin of this excavation does not seem to be known (it is considerably deeper than typical turf ponds).

Vegetation: The vegetation pattern of the site is complex, with a range of fen and carr communities. The north-east and north sector of the fen, near to the marsh wall, is relatively dry and supports rather species-poor tall fen communities (with invasive scrub) (and, formerly, a poplar plantation). Much of the turf pond area nearer the broads, where not tree invaded, consists of sedge beds. Most of these are rather derelict and species poor, but annually-mown paths through them can be species rich (where not damaged by heavy trampling) and this sort of vegetation was once widespread in the terrestrialised turf ponds. Extensive examples of it still occur on a buoyant fen surface in the Flight pond area. It is a form of *Peucedano-Phragmitetum caricetosum*, but with stronger floristic affinities to M13 than is usually the case. Pools within the community often show evidence of marl precipitation, but another distinctive feature of this vegetation at Upton is that it is very readily colonised by *Sphagnum* (especially *S. subnitens*). Fragments of this vegetation still occur around both of the broads, but were once more extensive. Herbaceous conditions are still maintained (by mowing) around much of the Little Broad, but in many places around the Great Broad fen woodland ± directly abuts upon open water, in consequence of destruction of earlier hydroseral stages.

Substratum: The depth of peat beneath the fen at the marsh wall is about 9 m, but more typical depths over much of the fen area are about 4 m. North of the marsh wall, the drained levels contain a thick accumulation of estuarine clay. This penetrates into the undrained fen, rapidly wedging-out into a layer of *Phragmites* clay, but does not extend as far as the broads. The main areas of floristic interest in this site correspond to locations distal to the clay. The Great Broad is *c*. 3m deep and is reported to be floored by 'gravel' along its landward margin.

Water Supply: Upton Fen is underlain by some 30–40 m of Crag sands and clays. These are separated from the Upper Chalk (50–60 m bgl) by about 10 m of London Clay. The hills to the south of the fen appear largely to be formed from drift (Contorted Drift, capped by chalky boulder clay). It is presumed that the Chalk aquifer is confined by the London Clay aquiclude, but the semi-confined Crag aquifer has a head higher than the surface water system and has the potential to feed the fen by upward leakage. The hydrological importance of the (apparently substantial) drift deposits adjoining the site is not known. Piezometric data suggest that there is some hydraulic connectivity between the drift and Crag, but the clay layers in the Crag may result in some locally-important contribution from the drift. It is at least possible that the drift may be of particular relevance to the springs which occur on the lower slopes of the adjoining upland, somewhat above the level of the fen.

Unlike most Broadland fens, there can be no doubt that Upton Fen is not fed by river water as the river connection is severed. Both springs and field drains discharge down to the site on the S side, but much of their water appears to enter a catchwater ditch (though in at least one place this leaks into the fen in high water conditions). Flow within the fen is complex, and some dykes are seasonally bi-directional, but in low water conditions dyke flow appears to emanate from the Broads (in all directions[1]) and it has been suggested that these may be the main source of entry of groundwater into the system (perhaps because they intersect with the Crag). The possibility that there may be other upwellings into the peat cannot be discounted, but there is currently no evidence for this. The fen has a quite wide distribution of communities with 'seepage indicator species' (these were formerly much more extensive, but have become derelict), but in the main area which retains such vegetation (the Flight Ponds) there is no piezometric evidence for direct upwelling of groundwater (van Wirdum *et al*, 1997). This is not surprising as the peat deposits here are separated from the Crag by a quite thick (1 m) layer of soft, blue-grey clay[2]. There is some evidence that during the summer water from the Great Broad flows into the Flight Ponds area, through the surface water system (dykes) and thence beneath the semi-floating vegetation mat and into the fen. It is not known if this flow is driven primarily by evapotranspiration or if it is part of a broader flow pattern through the site to the main discharge point (a sluice) in the marsh wall. The height of the

[1] For example, on various occasions there has been visible evidence of surface water flow from the Little Broad into the catchwater ditch along the upland margin. The water level in the catchwater drain is now maintained at a high level by a series of weirs and this has apparently resulted in higher summer water levels in the Little Broad (J. Wells, *pers. comm.*).

[2] It may be noted that corings have shown that in some places this layer of clay is capped by a thin layer of gravel, immediately below the peat. Thus, reports of 'gravel' at the base of peat cores do not necessarily indicate hydraulic continuity between the peat and the underlying Crag. Detection of the presence of a clay layer clearly requires quite detailed boring below the peat, rather than simple estimates of resistance to penetration by a corer.

discharge point undoubtedly helps control water levels in the fen, though the marsh wall is known to be leaky elsewhere.

Water flows northwards from the Great Broad towards the sluice through a well-maintained dyke and in winter there is strong flow through this, pointing to substantial water inputs. In recent years attempts have been made to retain water in the broads and southern part of the fen by installation of a series of weirs in this dyke; the northwestern part of the fen has also been made wetter to support a reedbed. It is difficult to assess the likely impact of these changes, but they may well help to induce water stagnation in the southern part of the fen, thus reducing – or locally removing – its percolating character. Of course, the rheotrophic condition of the site has almost certainly been accentuated by its severance from the river and drainage of the intervening levels, steepening the hydraulic gradient. However, these are the conditions under which the current conservation interest has developed, and reduction of flow could prove to be damaging to this. In parts of the site, extensive development of rather impoverished *Sphagnum* vegetation has already occurred, as a seral replacement for more species-rich *Peucedano-Phragmitetum caricetosum* communities on buoyant surfaces, probably because of the absence of surface flooding; this trend may be expected to be encouraged by blockage of drainage (Beltman & Rouwenhorst, 1991).

The source of the groundwater is not known with certainty, but is presumed to be primarily from Crag. The chalk aquifer is reported to be confined beneath the fen, but the fen water is considerably more calcareous than in most Broadland sites, and Upton is one of the few Broadland sites in which fen pools contain calcite. pH and conductivity measured on water samples from piezometers 1 and 2 are similar to values from some surface water samples and point to particularly base-rich conditions (Table UP_1). Holman *et al.* (1999) observe that (in the vicinity of Hickling Broad) "The Crag groundwaters are all saturated with respect to calcite" and this appears to be the case at Upton, though it contrasts with observations in some other sites (*e.g.* Catfield Fen, *q.v.*).

Conclusion: Groundwater fed with a small land-drainage contribution in wet weather.

Table UP_1. Upton Broad: pH and conductivity data from some water samples (9-April-2000)

	P1	P2	GB1	Broad	P3
Conductivity (μS cm^{-1})	713	726	695	628	
pH	7.6	7.4	7.95		6.7

2.22 WALBERSWICK (WESTWOOD AND DINGLE MARSHES)

SUFFOLK: TM47506450

***Status*:** SSSI, SAC, SPA, Ramsar: Minsmere to Walberswick Heaths & Marshes

WETMECs: Type 1 and 2 (seepage margins); Type 4 (main valley bottom)

Description: A large area of coastal marsh south of Walberswick. Westwood Marshes occupy a blind embayment within the upland. There are no real feeder streams for much of this area but there are deep ditches within the wetland. Near the eastern end, the wetland extends southwards along the coast as a unit known as Dingle Marshes, separated from the sea by a shingle bar. The R. Dunwich flows through these and across the eastern end of Westwood Marshes to discharge into the R Blyth at Walberswick.

Vegetation: The area was pump-drained grazing marsh before the 2nd World War, but was flooded as a wartime defence measure in 1940. Reedbeds interspersed with shallow pools occupy much of the site, but there are some narrow marginal areas of fen meadow and fen woodland. Some 'reedbed' areas are summer mown to enhance botanical diversity. The reedbed in Westwood Marshes is subdivided into four main compartments, by bunds with sluices. These permit independent water regulation and enable very high water levels to be maintained. They also help to isolate the reedbed from the effects of the sea, though there is some penetration of brackish water

Substratum: The wetland is situated upon a thick (30 m) layer of Crag, which outcrops on the valley slopes. The Crag is separated from the underlying Chalk by about 30 m of Palaeocene – Eocene mudstones and siltstones. The tops of the adjoining interfluves are capped by sand and gravel drift alongside the wetland and by extensive deposits Lowestoft Till further west, but within the catchment. The valley bottom is filled with estuarine alluvium.

Water Supply: Little is known in detail about groundwater supply to the wetland. The Crag aquifer is largely unconfined around the wetland, but upward flow is probably largely prevented by the alluvial deposits. Groundwater from the Crag appears to discharge into the wetland around the margins, as springs and seepages, where the water table intersects the valley sides. Westwood Marsh (which has few obvious surface water point sources) is reported to have strong groundwater inflow, which can reflood the western reedbed within 1–2 weeks after drawdown for reed harvesting. The dykes in Dingle Marshes are also reported to be fed by groundwater, but this area is also fed by the Dunwich River. Sea water incursions occur periodically when the shingle bar is breached, but the bunds that have been constructed help reduce brackish inputs into large parts of the reedbeds.

Conclusion: Floodplain wetland fed by surface flow and groundwater plus saline incursions (in the lower reaches). In the main reedbed areas, high water levels are maintained by control structures which help produce surface inundations.

2.23 WHEATFEN

NORFOLK: TG3205

Status**:** SSSI: Yare Broads & Marshes ; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 23

WETMECs: Type 6 (locally around broads); mainly Type 7, but with groundwater possibly of some importance near the margins.

Description: Wheatfen is part of the extensive Surlingham–Rockland fen complex on the SW side of the R. Yare, more or less opposite Strumpshaw Marshes. It contains a deep, fairly well terrestrialised, medieval broad (Wheatfen Broad), which connects southwards to the much larger Rockland Broad, and thence to the R Yare. There is at least one turf pond area in the fen, but much of the substratum has not been excavated.

Vegetation: The herbaceous vegetation of the solid peat surfaces consists primarily of reedbeds and tall herb fen, marking a fertility and productivity gradient declining from river to upland margin, though this is disrupted locally by bands of elevated fertility associated with the proximity of dykes. Much of the solid peat surface has become colonised by carr. Wheatfen Broad is mainly surrounded by floating mats of hydroseral *Glyceria maxima*, which is well able to accommodate the significant tidally-induced fluctuations in water level.

Substratum: The peat infill of much of the area is relatively shallow (3–4 m), but deepens to about 7 m in the vicinity of the R. Yare. Brushwood peat underlies most of the deposit, but is sometimes only about 1–2 m thick and Wheatfen Broad appears to be have been dug down to the mineral ground, at least in places. There is a deposit of estuarine clay in the upper part of the profile close to the river (*c.* 1–1.5 m subsurface), but this forms only a narrow band along the course of the Yare – though *Phragmites* silts and muds extend laterally from this further into the fens. The surface peats near the river contain an obvious (but unquantified) silt fraction which declines landwards. The surface layer of all the solid peats is well oxidised, but beneath this the bulk of the various peats which cover the brushwood peat are fairly fresh. Their transmissivity is not known, but may well be higher than the sedge peats of the northern Broadland valleys.

Substratum & Water Supply: Little is known in detail about the hydrodynamics of the system, but it is regularly flooded by river water, primarily in the winter (January–February and sometimes November–December), and the open dykes conduct river water into, and beneath, the *Glyceria* rafts around the broad (Clarke & Baker, 1995). The dykes are tidal, including the land boundary dyke (*fide* P. Ellis), though this is also reported to receive land drainage water and groundwater. The solid peats normally become rather dry during the summer, especially in the riverward compartments. There is, however, no reason to suspect any progressive drying of the site over the last few decades – indeed P. Ellis considers that the site has become generally wetter in recent times, which she attributes to higher tides in the Yare.

Wheatfen is situated upon some 20m of Crag, directly underlain by Upper Chalk, c. 20–35m bgl. The rising upland to the west of the fen is composed of Crag overlain upslope by sand and gravel of the Keswick Formation and then sandy clay of the Corton Formation. A surface band of shallow river terrace sands and gravels separates the foot of the slope from the main wetland area. The Chalk aquifer is in hydraulic continuity with the Crag aquifer, and semi-confined by it whilst the alluvial multi-layered hydro-geological unit, comprising peat aquifers and a clay aquitard, is thought to be in some hydraulic continuity with the underlying Crag and indirectly with the Chalk. The River Terrace Gravels form a minor aquifer, in contact with the peat of the valley bottom and the Crag in the valley side.

The importance of groundwater to these fens is not known, and is generally assumed to be small or non-existent. Chalk water flow converges on the valley and in the vicinity the fen is known to have been artesian. Water from a deep well dug into the Chalk at Wheatfen in the early 1970s originally spurted some 10′ into the air, but has much reduced since, apparently particularly after 1995 ("A definite fall has taken place since 1995. It no longer spurts in the air when uncovered but still has a strong flow. A shallower (12′) well "rises and falls with the tides. Water flows from the west (upland) and never fails even when pumping takes place for 24 hrs +". (*P. Ellis, in litt.*). Although the peat stratigraphy is quite well known, there is little information on potential aquitards *beneath* the peat (*e.g.* clay layers). It seems quite possible that Wheatfen Broad, which may have been cut down to the mineral ground along its landward edge, could receive inputs from water-bearing layers in the underlying mineral ground, but we know of no evidence suggestive of this – the broad appears primarily to be tidally-fed with river water (Clarke & Baker, 1995). Hence, even if the broad does receive groundwater inputs, these appear to be insufficient to influence surface water quality materially. Some marginal fens (*e.g.* Alder Carr Marsh) appear to remain wetter during the summer than do more riverward compartments, which could possibly indicate groundwater inputs (or seepage of surface water from the adjoining landspring drain), but critical evidence is lacking. There is no obvious flow in the dykes away from the land margins.

***Conclusion**:* A tidal floodplain system, with regular inundation by Yare floodwater, coupled with some lateral penetration of river water through dykes into, and beneath, high permeability peats associated with Wheatfen Broad. Other areas tend to become summer dry. There may be some groundwater / land-drainage water support in some marginal locations, but this appears to be of little consequence to the ecohydrology of the fen, except perhaps locally.

2.24 WOODBASTWICK FENS AND MARSHES

NORFOLK: TG3316

***Status*:** SSSI: Bure Broads & Marshes; SAC: The Broads; SPA: Broadland; Ramsar site: Broadland

Key Samples: 17

WETMECs: Type 6 (turf ponds and broad margins), Type 7 (solid peat)

Description: A large fen complex formed on the Bure floodplain, S of the river. The western limit is effectively set by a bend in the river – which brings the river almost to the upland margin, but eastwards fen is continuous for some 4 km, into the Ranworth complex (and its subdivision into discrete 'sites' is largely arbitrary). The Woodbastwick fens were extensively dug for peat in the 18–19th centuries, somewhat earlier than many of the 19th century excavations. Most of the excavations were in the northern part of the fen, coming close to the river, and reflooded to form a large lagoon referred to as 'Broad Waters'. This is separated from Decoy Broad (to the W) – a deeper, medieval peat working – and from the upland margin by solid peat. The fens are crossed by a system of dykes, which are particularly sinuous in the Broad Waters area. Most of them are not connected to the river.

Vegetation: The site supports a mixture of herbaceous fen – mainly M22 and S24 – and fen woodland. Some patches of more buoyant fen – over former turf ponds – support vegetation with affinities to M9 (*Peucedano-Phragmitetum caricetosum* of Wheeler (1980a)) and which contains some so-called 'seepage indicator species'.

Substratum: There is a quite thick peat infill across the valley, typically about 6 m depth, but deepening to some 12 m in the vicinity of the R Bure. Brushwood peat forms the basal deposit across the valley, with a typical depth of 4 m, and is separated from the underlying Crag by clay deposits (at least in places). The Romano-British marine transgression is represented in the upper parts of the profile, but mainly as organic silts and muds. Clay is confined to a narrow band ± following the course of the Bure, and across part of the S of the fen (marking a former cut-off channel).

Water Supply:

The site is underlain by Crag, which is exposed on the valley sides, underlain by Upper Chalk (surface between –30 and –26 m OD). The Crag and Chalk are though to be in hydraulic continuity and piezometric levels in the Chalk appear to be very similar to those in the Crag. Groundwater converges towards the R. Bure in this area, indicating discharge to the river and possibly to the marshes. However, the actual contribution of groundwater to the fen is not known. The combination of deep peat and clay upon the Crag suggests that there is likely to be rather little, if any, upward flow into the peat over much of the site, and any such inputs are clearly insufficient to maintain high summer water tables in the areas of solid peat[1].

[1] There appears to be no information about the presence or absence of a clay layer separating the peat from the Crag at this site.

Whilst little is known in detail about the hydrodynamics of this site, observations by R Southwood (EN) indicate that most of the site is shallow flooded during the winter (probably by a combination of rainfall and river flooding). Summer flooding does not normally occur and the summer water tables in the centre of solid peat compartments are independent of dyke water levels and are usually rather low (< 30–40 cm), whereas the water table in the turf pond sites is usually near to the surface[1]. It seems likely that there is direct ingress of river water into the former Broad Waters turf ponds, though entry points have yet to identified. The importance of river flooding to the character of the dykes and to the solid peat fens is not really known. However, most of the dykes on this site are dystrophic and support *Utricularia* (bladderwort) – a genus thought to associated with oligotrophic conditions. If this association is correct, it may provide evidence that rather little nutrient (or base) enrichment occurs in much of this site.

There is a small amount of land drainage input (into some dykes), especially in winter. However, the land margin dykes are dug into mineral ground and it is possible that groundwater may discharge into these, along the southern boundary of the site. However, there is no evidence of flow through the dykes away from the upland edge and, as is the case at Catfield (*q.v.*) (but in contrast to the situation at Upton (*q.v.*)), the dykes are not supplied with particularly calcareous water, from whatever source.

Conclusion: fed by a combination of river water and precipitation inputs. The Broad Waters area is mainly fed by subirrigation and flooding with river water whereas, in summer, rainfall appears to be the main water source to the solid peat areas away from the dykes.

[1] Note that this does not imply that the absolute level of the water table is higher in the turf ponds than in the solid peat. The higher water levels relative to the peat surface may be a consequence of vertical buoyancy of the vegetation mat.

3. EAST ANGLIAN VALLEYHEAD FENS

3.1 BADLEY MOOR

NORFOLK: TG009115

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 4

WETMECs: Type 1 (tufa mounds), Type 2 (peripheral seepages), Type 8 (main valley bottom)

Description and Vegetation: Badley Moor is an extensive area of poorly-drained land on the north side of R Tud east of Dumpling Green. Much of the area is wet grassland, with overgrown ditches and wet hollows sustaining a variety of fen plants, but in the northwest corner, at the junction with the rising valley slopes, there are substantial tufa mounds supporting species-rich fen vegetation. This is mainly *Schoeno-Juncetum* {~M13} with some fen meadow and with a small patch of *Acrocladio-Caricetum* {~M9} in a sump formed by an overgrown drain on top of a mound. The mounds are adjoined by some fen meadow and taller fen on the valley bottom but much of the flat land alongside the Tud is wet grassland rather than fen.

Substratum and Water Supply: This site has been the subject of some detailed hydrological studies, reported by Collins (1988), Gilvear *et al.* (1989) and Gilvear *et al.* (1994). Thick (> 20 m) glacial deposits (Lowestoft Till) overlie the Upper Chalk, but do not completely confine it and the tufa mounds appear to be fed from a chalk aquifer in hydraulic continuity with an overlying sand / gravel aquifer. Piezometric head is about 4 m agl. Adjoining areas receive some surface flow of groundwater from the springs. It is likely that there may be some (intermittent ?) upward leakage of groundwater into some peripheral areas, but overall the main discharge area seems to be highly localised. A phreatic sand and gravel aquifer may discharge laterally into the R Tas and underlie much of the site, but water levels in this are not sufficiently high to support true fen vegetation. There is no evidence for significant surface water inputs, though the lower-lying areas of wet grassland may receive episodic flooding from the R. Tud. There are a few drains through this area, discharging into the Tud.

Conclusion: Area of primary interest is a permanent seepage face fed by artesian chalk water, and groundwater run-off from this locally recharges the adjoining phreatic sand/gravel aquifer to support fairly fertile fen. However, the bulk of the site has lower summer water levels and is not really fen.

3.2 BARNHAM BROOM FEN

NORFOLK: TG070070

Status**:** Former SSSI

Key Samples: 4

WETMECs: Type 1 (springs), Type 2 (marginal seepages), Type 8 (main valley bottom)

Description and Vegetation: A quite large, partly spring-fed fen on the R. Yare flood-plain, south of the river and immediately east of a small tributary stream flowing in from the south. It mostly supports thick and tangled herbaceous vegetation, with patchy scrub and larger areas of carr, but there are some remnant areas of fen meadow (M22), especially associated with seepages towards the west end of the site.

At one time fen originally occupied a substantial portion of the R. Yare valley in this general vicinity, at least from Hardingham Mill at the SW to Rust's Green at the NE and on both sides of the valley (*i.e.* including the area currently recognised as Coston Fen (*q.v.*)). At least part of the westernmost end (Runhall Common) was reclaimed in the 1950's and by 1973 the meadows north of the Yare in the eastern area were also regarded as having little biological interest, so that the area designated as Runhall Common SSSI was reduced to the eastern part south of the river, *i.e.* Barnham Broom Fen. However, it has become clear that there is still some fen meadow vegetation north of the river in the western part of the site and the fairly recent rediscovery of Coston Fen (*q.v.*) indicates that habitat loss north of the river was not as complete as was once supposed. A further area of fen vegetation occurs outside of the SSSI on the NW side of the Yare, north of Barnham Broom village. This has been referred to as 'White House Meadows' (TG 077089).

Substratum: The main surface deposit is Lowestoft Till, which has been incised by the R Yare to produce a valley lined with alluvium and river gravels. The till beneath the river is about 5 m thick and is underlain by Upper Chalk.

Water Supply: Rather little is known about the hydrogeology this site. It is undoubtedly partly irrigated by discrete springs and probably by more general seepage. However, the lower parts are on the flat floor of the Yare valley, where there is poor drainage. Some dykes connect parts of the site to the river and together these are likely to influence fen water levels as well as provide inputs, at least in flood conditions. The alluvial sands and valley sands and gravels form a discontinuous minor aquifer in the Yare valley, perched on Boulder Clay and/or putty chalk. The Boulder Clay, however, is sufficiently permeable, particularly where sandy, to be water-bearing. The Chalk water table appears to be artesian at the site, but its degree of confinement in the vicinity of the fen does not seem to be known and hence it is not clear to what extent seepages within the site represent upward flow from the Chalk *via* the thin Boulder Clay or from lateral flow through the Boulder Clay aquitard from the south. It may be noted that all soil samples from this site, including those from the springs and seepages, are highly fertile – much more so that is generally the case with chalk-water fed sites (and much higher than the chalk-fed Coston Fen on the opposite side of the river). This suggests either that chalk water is not the primary constituent of the seepage water at Barnham Broom Fen, *or* that the chalk water discharge is onto a eutrophic alluvial substratum.

Conclusions: The seepage areas appear to be fed by groundwater discharge from a leaky aquifer, and their permanence is probably a reflection of local topography and, perhaps, top-layer conditions. The main valley bottom area appears to be fed by episodic flooding from the R Yare. It also receives water from the marginal seepages and may also be fed by some upward groundwater flow. However, water inputs are insufficient to maintain the valley bottom in a surface-wet state during the summer.

3.3 BEETLEY MEADOW

NORFOLK: TF982174

Status**:** SSSI

Key Samples: 2

WETMECs: Type 1 (main seepage area), Type 2 (adjoining slopes)

Description and Vegetation: Beetley Meadow supports a fairly small, sloping area of wetland, developed around and beneath seepages, in the middle of a field on the north slope of a tributary stream of the R. Wensum. A particularly strongly flushed area is surrounded by fen meadow (which occupies much of the seepage area) and thence by moist grassland. More acidic grassland occurs near the top of the meadow and a distinctive feature of this site is that the main flushed area also supports some plant species which tend to be associated with more acidic fens (in East Anglia) (e.g. *Carex demissa, Juncus bulbosus, Pedicularis sylvatica*). These are not found in most of the more base-rich sites, but do also occur, for example, in some of the marginal flushes at Swannington Upgate Common.

Water Supply: The main aquifer is Upper Chalk, semi-confined or confined beneath the site, covered by a boulder clay aquiclude / aquitard which is capped by locally semi-confined glacial sands and gravels. Although detailed topographical data are unavailable, the water level in a shallow piezometer (P2), screened in a phreatic sand aquifer, is consistently above the level of the main springs and seepages and it is presumed that this provides the telluric water to the site. The source of water to this aquifer is uncertain and the possible rôle of different sources in maintaining groundwater levels and flows is not really known. However, whilst the lower ground of the southern part of the site may be fed by upward leakage of artesian chalk water, it is unlikely that there are direct inputs of chalk water into the main seepages. HSI (Site Monitoring Report) suggest that the source of water to the sand and gravel aquifer is from rainfall at the higher ground to the north of the site, and this is compatible with the acidophilic character of the vegetation. Conversely, whilst it is possible that there may be come connection between the drift and the chalk at some distance from the site, a significant chalk water contribution to the water supply is not compatible with the observed character of the vegetation.

Conclusion: Seepage / spring-fed fen with a permanent seepage face fed from a locally semi-confined drift (sand and gravel) aquifer. Surrounded by zones of reduced / intermittent seepage, perhaps associated by top-layer clays and silts.

3.4 BOOTON COMMON

NORFOLK: TG113230

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 7

WETMECs: Type 1 (main seepage areas), Type 2 (adjoining slopes)

Description and Vegetation: Booton Common is an elongated mire developed on a narrow seepage slope above a small tributary stream of the R. Wensum. There are two main ecohydrological facets to the site: (i) near the west end there is a small, sloping permanent seepage face, occupying and adjoining a shallow, flushed gully, which supports the primary conservation interest (M13); (ii) east of this, and ± continuous with it, are various types of less rich fen vegetation (mainly fen meadow and tall herb fen) in locations where – for the most part – the water table scarcely reaches the surface, or does so only intermittently. A small patch of *Acrocladio-Caricetum* {~M9} once occurred in a small sump in a seepage area towards the E end of the fen, but its current status seems uncertain.

Substratum: The site is in an area dominated by chalky boulder clay (Lowestoft Till) on the higher ground but exposing glacial sands and the sandy clays of the North Sea Drift on the valley slopes and floor. The main aquifer is the Upper Chalk which within the site is semi-confined and artesian. The overlying Drift hydrogeological unit is multi-layered, comprising sand aquifers and silt-clay aquitards. The Chalk and Drift units are in hydraulic continuity – there is probably a localised hydraulic connection between the chalk and surface, *via* sands and gravels deposited in the buried glacial valley. At the site, differential heads between Drift sand layers, and the Drift and the Chalk indicate that vertical groundwater flow is upward. Lateral flow converges into the valley of Booton Common. Seepages within the site represent both lateral and vertical groundwater flow from the Drift hydrogeological unit supported by the Chalk aquifer below.

Water Supply: Both the HSI and Montgomery-Watson reports propose that groundwater discharge, at least in the vicinity of the piezometers near the W end of the fen, is likely to be artesian chalk water. It is, however, notable that chemical analyses of the discharge waters of the M13 areas indicate alkalinities and pH values that are somewhat lower, and Fe concentrations that are somewhat higher, than those found in some other chalk-fed sites. This is reflected in the sparsity of calcite precipitation at the surface of the permanent seepage face and may indicate some mixing of chalk water with groundwater of other provenance, or some other effect of passage through the drift.

Also unresolved is the water source to the intermittent seepages which comprise the bulk of the fen east of the M13 area. It is possible that these may be fed by some upward leakage of chalk water, and that these seepages differ from the M13 seepage in small topographical characteristics (slightly more elevated) or in being capped by a less permeable material, but an alternative explanation could be that they are fed from a drift aquifer rather than the chalk. It may be noted that in both piezometers P3 and P4, which are situated in the eastern seepage area, water levels fall up to 20 cm subsurface.

Field drainage is channelled across the fen to the main stream at three points, but probably has little relevance to the fen water balance. The stream is IDB-managed, with a water level *c.* 1m below bank height, and does not normally flood the site.

***Conclusion**:* Western permanent seepage area is fed by artesian water from a semi-confined Upper Chalk aquifer, possibly mixed with drift water. Water source to eastern intermittent seepages is uncertain: may be chalk water or of other provenance.

3.5 BUNWELL COMMON (ASLACTON PARISH LAND)

NORFOLK: TM154918

Status**:** SSSI

Key Samples: 1

WETMECs: Type 2

Description: A small spring-fed fen developed on valley slopes alongside the upper reaches of R. Tas (south side). It supports rather dry fen meadow and moist grassland vegetation, and a small area of alder carr. There is a quite large, but no longer active, spring mound with coarse, grassy fen meadow. This contains layers of marl and tufa[1] capped by a rather solid, oxidised silty peat. It is crossed by several (partly occluded) drains. The slope is relatively steep, falling from 35m to 28m OD within about 200m.

Water Supply: HSI (1996) identified three hydrogeological units: an upper aquitard, up to 10m thick (clays and silty sands); a sand and gravel aquifer, c. 20m thick (semi-confined by the clay above and in hydraulic continuity with the Upper Chalk below); and the Chalk, which is the regional aquifer. Rate of upward flow would vary within the site depending on the nature of the Drift – where the aquitard contains a higher proportion of sand, as is probably the case in the main seepage area, the flow may be significant. A drift piezometer (P3), located in one of the wetter areas of the seepage zone (but peripheral to the main spring mound) and screened at 2–4.5 m bgl in silty sand beneath the surface peat had a head slightly (up to 50 cm) above the surface for much of 1998 and 1999, but was subsurface for much of 1996 and 1997. However, it must be recognised that this site tends to be dry, certainly during the summer. This includes the former spring mound, where in 1985 a summer water table of –26cm was recorded – a value compatible with the composition of its vegetation, which contains some fen species (including much *Epipactis palustris*) mixed with coarse grassland species and disturbance species such as *Cirsium arvense* to produce an assemblage that is rather typical of drying-out fens. Winter water tables also appear to be subsurface. For example, in February 2000 the fen water table close to piezometer P3 was *c.* 0.25 m bgl, whilst that in P3 was 0.32 m agl (Table APL_1). However, the accumulations of calcite here suggests that this was once, at least in part, a permanent seepage face. The reasons for drying are not known: possibilities include direct drainage (various ditches drain into the Tas, some of which have been partly blocked, apparently in the early 1980s), reduction of supply and deepening of the Tas, but on the balance of the evidence available it seems likely that these changes are of long standing (in the order of decades, perhaps pre-20th century).

Surface runoff is thought to be unimportant to this site.

Conclusion: Area of primary interest was formerly a permanent seepage face fed by artesian chalk water, but now has summer water tables well below the surface. Principal interest probably now resides in wet(-ish), mesotrophic grassland vegetation, peripheral to the primary seepage area.

Table APL_1. Aslacton Parish Lands. Water table records, 6th February 2000

[1] In 1985 a deep layer (*c.* 1.5 m) deposit of marl/tufa was recorded, beneath a stand of *Epipactis palustris*. It was not possible to relocate this during December 1999. A series of cores made then revealed some shallow layers of marl, but not the deep marl recorded in 1985. It is presumed that this latter represented a very localised deposit, perhaps at the main site of (former) groundwater discharge.

Piezometer	P1	P2	P3	dipwell	P4
Ground level (maOD)	33.65	33.8	31.49	[~31.5[1]]	33.61
Water level (m)	-0.434	-0.466	+0.322	-0.25	-1.012

[1] The ground level associated with the temporary dipwells has not been measured accurately. However, the dipwells were located within 2m of P3 in positions which were estimated to be level with the base of P3.

3.6 BUXTON HEATH

NORFOLK: TG175218

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 8

WETMECs: Type 1, Type 2

Description and Vegetation: A small valleyhead fen site within heathland forming the headwaters of a small tributary stream of the Camping Beck. Seepage slopes occur on both sides of the stream, but those on the south side are of particular interest, both because of their species composition and the occurrence of a particularly clear and distinct zonation from base-rich fen near the valley bottom to acidic grassland and heath. A similar zonation is found in some other Norfolk sites (*e.g.* Roydon Common) and it gives Buxton Heath high ecological interest. A narrow zone of quite productive fen meadow occurs alongside the stream and grades into base-rich seepages. These lead up into *Molinia* grassland {~M24}, wet heathland and thence dry heath upslope, locally interrupted by rather base-rich flushes. The base-rich seepages close to the stream are very species rich, and have obvious affinities to M13 vegetation, but they contain considerably more acidophilic species than do normal examples of this vegetation.

The 'base-rich' flushes on the lower seepage slopes at Buxton Heath are of relatively low pH (6.3), which is significantly ($p < 0.001$) lower than the mean pH value associated with M13 vegetation in East Anglia (6.9 ± 0.001 (se)). Likewise, titrated alkalinity (144 mg l^{-1} HCO_3) is also much lower than the mean M13 value (443 mg l^{-1} HCO_3) (data from FENBASE database). These values probably help account for the presence of a number of calcifuge species in the 'base-rich' seepages at Buxton, including the local prominence of *Sphagnum* species (mainly *Sphagnum palustre*, *S. subnitens* and *S. recurvum*). Nonetheless the seepages still support the majority of calcicole species that are typical of M13 (including the rare liverwort *Leiocolea rutheana*), and the combination of the calcifuge and calcicole species results in a particularly diverse vegetation.

Substratum: The wetland is developed upon North Sea Drift upon Crag and Upper Chalk. Upper areas are occupied by sands, with boulder clays downslope. Sand and gravel is found west of the site. The Drift deposits consist of Boulder Clay, Sand & Gravel and Contorted Drift. The Crag wedges out a few hundred metres to the southwest [HSI, 1996]. There are 3 hydrogeological aquifer units: (1) thin phreatic unit comprising alluvial sands and peat; (2) a semi-confined multi-layered minor aquifer consisting of sand layers in between thin clay aquitards; (3) an Upper Chalk aquifer, thought to be in hydraulic continuity with the minor sand aquifers above. The Upper Chalk is the main aquifer, semi-confined by clay layers within the Crag and Drift. Water levels are close to the surface. The regional direction of groundwater flow in the Chalk is to the east, convergent on the River Bure valley. The Crag/Drift is a multi-layered minor aquifer comprising sand layers semi-confined by relatively thin clays, and provides the main water supply to the wetland. A near-surface phreatic sand unit is perched upon a clay layer. Groundwater in the Crag/Drift and the phreatic unit moves to the east. It discharges into the tributary stream and forms seepages along its valley. The Chalk/Crag and Drift are hydraulically connected, but clay layers within the Crag/Drift impede somewhat groundwater flow between the Chalk and sand layers. Agency piezometric data in February 1996 suggest downward movement of groundwater from the phreatic unit into the Crag sands and into Chalk. This condition may change (i.e. there may be upward flow from the Chalk into the Crag/Drift) in the summer-autumn or during periods of drought, but hydrometric data provide little evidence for this. Interestingly, a quite deep (7.2 m) piezometer installed in the lower part of the fen by Boeye *et al.* (1997), and screened in clay showed a strong artesian pressure (some 1.2 m above the head in the associated shallow piezometer). It is not clear how this observation relates to the claims of downward flow into, and connectivity with, the chalk aquifer.

Water Supply: The water at the bottom of the valley is more base-rich than that of the upper seepage slopes, and it has been suggested that this may be derived from the Chalk (Boeye *et al.* 1997 suggest that upward flow from the Chalk / Crag aquifer may contribute some 20% of inflow to the site, but the origin of this water is not certain – these authors do not have conclusive evidence that it is derived from the Chalk (D. Boeye, *pers. comm.*)). Water quality is very different from that of fens more clearly irrigated with chalk water, which suggests either considerable mixing of chalk water with water from a less calcareous aquifer, or no significant surface egress of chalk water. The hydrometric data suggest the latter is the more likely alternative. It may, however, be noted that the view has been expressed that the calcicolous bryophyte species in the lower base-rich seepages have declined in favour of *Sphagnum.* If correct, this observation could suggest a decline of the contribution base-rich water to the seepage, though there are other possible explanations.

An axial stream collects water from the seepages, but run-off is not an important water source. The stream is, however, quite N rich (for reason that are unclear) and may have a eutrophicating influence upon bordering mesotrophic habitats, perhaps including the lower base-rich seepages. It may be noted that at least one seepage, isolated from the stream, has rather high fertility and N concentrations, suggestive of enrichment of the supplying groundwater.

The water table in the lower seepages is fairly high, even in dry conditions, with values of about 3 cm bgl being typical. Further upslope, in the area of *Molinia* grassland and wet heath, the water table is not only generally further below the surface, but also much more variable. Boeye *et al.* (1997) attribute the high variability of head measured in piezometers screened in sand layers below the wet heath to “The absence of the stabilizing influence of a large reservoir [which] causes a strong response to climatic variation. This means that there is no important discharge from the southern deposit of Glacial Sands into the upper sandy deposits of the southern slope.” The water here is considerable more acidic than that which feeds the lower seepages. Interestingly, the slope north of the stream is generally wetter than that on the south side, but sustains considerable less ecological interest.

Conclusion: The base-rich fen on lower slopes is on a permanent seepage face, probably fed by a multi-layered drift aquifer. Above this are intermittent, more base-poor seepages, possibly sourced from an upper phreatic unit.

3.7 CAVENHAM–ICKLINGHAM HEATHS

SUFFOLK TL755733

***Status*:** SSSI

Key Samples: 3

WETMECs: Type 8 (main floodplain), Type 2 (side valleys)

Description: This is primarily a heathland site, but it contains some fen interest (i) where springs and streams emerge(d) in side valleys in the heathland (e.g. Ash Plantation, Cavenham Heath (TL 765725); 'SW ('Sphagnum') valley', Tuddenham Heath (TL 745727)); and (ii) along the flood-plain of the R Lark, which passes through the heathland complex. The Lark floodplain marshes encompass sites in varying degrees of reclamation. There are (a) some extensive areas of improved and semi-improved neutral grassland; (b) areas that were formerly partly reclaimed and grazed, but which have since become derelict; and (c) areas of unreclaimed (Poor's) fen. Currently the sites in categories (b) and (c) are also rather dry, because of a lowering of water levels. The three main Poor's Fen sites within the NNR are Cavenham Poor's Fen, Icklingham Poor's Fen and Tuddenham Turf Fen.

Vegetation: The fen vegetation of this site is mostly impoverished. Much of the Lark floodplain consists of dry, eutrophic reedbeds (mainly S26 – *Phragmites-Urtica dioica*), locally with tall herb fen (M27) (especially in the west part of the floodplain) and small patches of species poor fen meadow (M22). There are also areas of fen carr, most notably a rather dry stand of W2 at Ash Plantation (still with *Thelypteris palustris*) and at Tuddenham Turf Fen and in the Tuddenham Heath side valley. The latter retains some *Sphagnum squarrosum* and is adjoined by a small stand of M22. Part of the Lark floodplain is grazed and supports wet grassland.

Although now very impoverished, the fens in this area were once very species rich, with individual records suggesting the former occurrence of M9 or M13 communities (or both). Nineteenth century records for ‘Tuddenham’ include: *Anagallis tenella, Blysmus compressus, Carex diandra, Carex dioica, C. echinata, C. elata, C. hostiana, C. lepidocarpa, C. pulicaris, C. rostrata, Cicuta virosa, Cladium mariscus, Drosera anglica, D. intermedia, D. rotundifolia, Eleocharis quinqueflora, Epipactis palustri*s, *Eriophorum angustifolium, E. latifolium, Gymnadenia conopsea, Hypericum elodes, Lathyrus palustris, Liparis loeselii, Lycopodium inundatum, Menyanthes trifoliata, Oenanthe lachenalii, Parnassia palustris. Pedicularis palustris, Pinguicula vulgaris, Potentilla palustris, Sagina nodosa, Schoenus nigricans*, *Stellaria palustris, Utricularia minor, Cinclidium stygium*, *Calliergon cordifolium, Calliergon giganteum*, *Campylium polygamum, Cephalozia bicuspidata, C. connivens, Cinclidium stygium, Cratoneuron commutatum, Drepanocladus aduncus, Drepanocladus exannulatus, D. revolvens, D. sendtneri, Philonotis fontana Riccardia multifida*, *Scorpidium scorpioides, Sphagnum acutifolium, S. cymbifolium, S. papillosum, S. compactum.* Most of these species no longer occur. Their former location is uncertain; records may conceivably refer to Tuddenham Turf Fen, Tuddenham Heath, or a possibly separate Tuddenham Mill Stream Fen, near to Tuddenham village. The suggestion that Tuddenham Turf Fen may formerly have supported many of them does not conform well with the view of Haslam (1965) that Tuddenham Turf Fen is a characteristic ‘valley fen’ and thus, by implication, intrinsically rather species-poor – a view which is supported by the apparent presence of a rather impoverished tall herb community (~ S25) in 1961. However, reviewing the options, Wheeler & Shaw (1992) concluded that the Turf Fen provides the most likely former site for many of the records, subject to the presumption that they came from now-disappeared seepages on the rising upland slopes or – and probably more likely – from a spring-fed topogenous zone along the valley bottom (*cf* Blo’ Norton Fen and Thelnetham Fens). This view is shared by F Rose (*in litt.*). Nonetheless, there is no doubt that the seepages in the west stream valley at Tuddenham Heath were also once considerably more species rich than the current impoverished remnants (Wheeler & Shaw, 1992), and these may have provided the sites for some of the more acid-preferring species, such as *Carex echinata* and *Drosera rotundifolia.*

Substratum and Water Supply: The main aquifer is Chalk overlain by sands and gravels (10–30 m thick), both unconfined and in good hydraulic continuity. Two main springs areas are known, at Ash Plantation and in the west stream valley at Tuddenham Heath, but at neither location are there now regular spring flows. Groundwater flow is to the northwest along the River Lark valley, and a component of this supports the base flow of the river. Historically, the Lark floodplain has been subject to seasonal inundation by river flooding, but this has effectively ceased since the 1940s in consequence of river dredging and the construction of effective embankments against flooding. Little appears to be known about the nature of the wetland substratum at this site. Haslam (1965) considers valley fens to be subject to silt deposition, but the presence of former Turf Fens points to the occurrence of significant accumulations of peat.

Conclusions: This site is primarily groundwater fed, from the chalk and overlying sands and gravels, but over most of the site groundwater levels are usually sub-surface, even in the side valleys which were almost certainly once groundwater dependent. Reduced groundwater levels appear to be a consequence of river deepening and, possibly, quarrying activities south of the site. The former importance of groundwater to the Lark floodplain is not known, but it seems likely that groundwater was once important for maintaining high summer water levels, perhaps even with some marginal percolating zones. However, the nature of the interaction between groundwater and the wetland substratum is not known, nor the relative importance of former river flooding.

3.8 CHIPPENHAM FEN

CAMBRIDGESHIRE TL642692

Status**:** SSSI; SAC: Fenland

Key Samples: 12

WETMECs: Type 2 (North Meadow), Type 5 (much of fen)

Description: Chippenham Fen is situated in a shallow river valley which is surrounded by farmland. This is considerably higher to the north-west and south-east, but of a similar level to the fen to the north-east and southern sides. The site is drained by a tributary of the River Snail, which has been canalised through the site. There is an extensive network of drains, dividing the site into compartments, some of which are cut for sedge.

Vegetation: The fen comprises a large area of open fen and woodland (much planted), but supports only a fairly restricted range of herbaceous fen communities, primarily M22 and M24. The main sedge beds are mostly floristically more closely allied to M24 vegetation than to true fen communities, perhaps reflecting their summer-dry character. This may also be responsible for the abundance of the nationally-rare species *Selinum carvifolia* (a *Molinia* grassland species in much of mainland Europe).

Substratum: Chippenham Fen 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 'dry' chalky material, between 0.6 and 2m depth, 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 clays and peats. The peat cover varies in depth from a few cm to 2m (6'), and in places there are peats both below and above the clay. Mason suggests that the clay is a lacustrine deposit [Kassas (1951) had previously referred to it as 'boulder clay'].

Water Supply: Springs have been reported at the site, primarily associated with the Totternhoe Stone, but these seem to be mainly in the bottom of dykes that have been dug through the Head into the chalk – over much of the fen, the chalk and peat are apparently separated by Head and clay. Discharge may be as discrete pools in the Chalk (known as "spring-holes" locally), measuring approximately 1 m in diameter, or as areas of groundwater seepage. The extent to which upward leakage of chalk water into the peat occurs is not really known. Mason makes the point that, if this occurs at all, it is likely to be associated primarily with the ring of Totternhoe Stone outcropping on site, but he 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 report that dipwells in the area of Totternhoe Stone were not distinguished by distinctive waters tables and hydrographs. However, there are reports of one (former ?) spring-fed patch of fen. Uncertainty also attaches to the moist grassland on the sloping North Meadow (not investigated by Mason), above the influence of the Chippenham River. Here some upward water seepage seems the only possible source of telluric water.

Fen water tables are usually near the surface in winter (typically *c.* 5 cm bgl), but they drop considerably, and rapidly, during spring and summer (Mason reports up to 1m 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 (1951), Mason (1990) and White *et al.* (1996) all provide evidence that the behaviour of the water table in the fen is partly independent of the dyke water levels, except in close proximity (< 25m) 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. Available evidence, including the response of fen water tables to manipulation of dyke water levels, suggests that any such seepage may be limited to the vicinity of the dykes – though it should be appreciated that the peat is very shallow over much of the fen, and dyke levels may often be below this, so that any seepage could be constrained by the underlying mineral deposits. However, White *et al.* (1996) point out that, except for relatively short drought periods, "in terms of water level elevation (m.aOD.) there is a hydraulic gradient from the fen to the dykes for most of the year, water levels in the fen only rarely falling below those in the dykes.", though they also consider that the behaviour of the water table in the dykes is not suggestive of inflow of water from the fen and accordingly suspect "some form of error in the data". One possible source of error is in the levelled OD of the monitoring structures – some of them have been re-surveyed with different results (White *et al.*). However, if the fen water table really is normally higher than dyke levels, except in very dry periods, this again raises at least the possibility of some groundwater upwelling. It may be notable that White *et al.* found a strong and significant correlation between water tables in the dipwells and the principal spring; there was a weaker (but still significant) correlation between water tables in the dipwells and the dyke levels (as measured by the gauge boards).

Mason concluded that this site is not substantially fed by direct groundwater discharge, and that the localised seepage which occurs is into the dykes (and may be partly a product of their excavation). On this analysis, the dyke water could be seen as a substitute for the chalk water which once regularly flooded the fen, and permitted lake clays to be deposited and peat to accumulate, when the site was once part of the headwater complex of the Chippenham River before drainage near the start of the 19th century reputedly lowered water levels by about 1.5m. 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 support for this.

Conclusion*:* The fen surface is fed primarily by rainfall (at least in summer) with some localised seepage of chalk water inwards from dykes and, in places, periodic summer flooding. The possibility of direct chalk water inputs is uncertain – even if these occur, the water table is (on average) well subsurface during the growing period. Rain fed surfaces probably remain base-rich on account of a highly calcareous peat and underlying clays (and perhaps because of episodic flooding).

3.9 CORNARD MERE

SUFFOLK: TL888389

Status**:** SSSI

Key Samples: 5

WETMECs: Type 5 (most of basin), Type 2 (marginal slopes)

Description: Cornard Mere occupies a basin embedded within the alluvial deposits at the edge of the Stour floodplain, immediately south of Little Cornard. The NE part of the mire has been reclaimed, to produce a particularly irregular shape. The mere is thought to be a remnant of a former channel (ox bow) of the R Stour.

Vegetation: Much of the vegetation is rank and impoverished, composed of species-poor vegetation dominated by *Glyceria maxima* and of *Phragmites-Urtica* vegetation. Small, wet depressions (associated with the central drain and the former mere) support greater wetland interest, with such species as *Carex rostrata* and *Menyanthes trifoliata* suggesting floristic resemblances with S27 vegetation. Much of the northern part of the site (along with the margins of the southern part), consists of rank grassland (MG1), rather than wetland, but (rather impoverished) stands of M22 also occur in the northern area.

Substratum and Water Supply: The site contains a deep (> 5 m) accumulation of peat, in places over lacustrine deposits (which include shell marls). The area is shown as open water on 18th century maps, but by 1880 it has been drained. However, it is not clear if the 18th century 'mere' represents a remnant of the original lake or a temporarily flooded area (there is 0.5 m of peat over lake deposits in the location of the mere). Prior to drainage, it is likely that the Cornard Brook once flowed into the mere. Now there is no inflow, nor surface water outflows, and the upper peat is dry and oxidised across much of the site and (judged from the character of the vegetation) appears to be nutrient rich, perhaps on account of mineralisation.

Cornard Mere is located within river terrace deposits occupying a valley within Upper Chalk. The chalk does not outcrop but is covered on either side of the Stour by drift, in some places away from the valley separated from the Chalk by Tertiary deposits (Thanet Sands, Woolwich & Reading Beds and London Clay). The Terrace Gravels are in hydraulic continuity with the Chalk. The Chalk piezometric surface is within the gravels, with values some 2–3 m bgl in the vicinity of the mere recorded during the summer of 1994. However, the relationship of this to peat water levels does not seem to be known. Shaw (1991) reported that water levels in the central, lowest part of the wetland were about 20 cm bgl, but in other (continuous peat) cores, it was lower in the profile (1–1.75 m bgl). Although topographical data are not available for the cores, it seems unlikely that this difference in water level is just a consequence of topographic variation.

Robertson (1994) suggests that "the wetland maintenance is mainly due to the presence of high groundwater levels together with seasonal flooding which inundates the lower-lying parts of the site following periods of high run-off in late winter and early spring". The presence of shell marls in the lake deposits may suggest that the lake was originally fed by base-rich, probably chalk, water and the peats are also of high pH (Shaw, 1991).

Conclusions: A terrestrialising lake, formerly fed by stream inputs and a high groundwater table, now rather dry on account of diversion of stream input, drainage and groundwater abstraction.

3.10 COSTON FEN

NORFOLK: TG060067

Status**:** SSSI; SAC: Norfolk Valley Fens

WETMECs: Type 1 (seepage slope), Type 2 (adjoining seepage slope), Type 8 (valley bottom)

Description and Vegetation: Coston Fen lies on the northern slope of the Yare valley and its southern boundary is marked by the River Yare. The site includes an area of marshy grassland with comparatively extensive base-rich flushes developed below seepages (~M13 – the feature of primary conservation interest) developed on the valley slope and separated from the river by improved grassland.

Substratum and Water Supply: Glacial deposits (Lowestoft Till) overlie the Upper Chalk and the aquifer of primary hydrological significance to the site is the Chalk, which is semi-confined by the Boulder Clay aquitard and locally by putty chalk, and is artesian at the site. Alluvial sands and valley sands and gravels form a discontinuous minor aquifer in the Yare valley, perched on Boulder Clay and/or putty chalk. The Boulder Clay, however, is sufficiently permeable, particularly where sandy, to be water-bearing. The water-table is dictated by topography and therefore the direction of groundwater flow is towards the valley of the River Yare. Slope seepages within the site represent upward flow from the Chalk via the thin Boulder Clay and also some lateral flow through the Boulder Clay aquitard from the north. The groundwater is intercepted by drainage ditches and is not associated with wetland development on the alluvial flat, where the ditches control the near surface water-table. The lowest parts of the site may receive occasional flooding from the R. Yare, but this is of little relevance to the main features of conservation interest.

Conclusion: Area of primary interest is a sloping permanent seepage face fed by artesian chalk water.

3.11 CRANBERRY ROUGH (HOCKHAM MERE)

NORFOLK: TL936937

Status**:** SSSI

Key Samples: 10

WETMECs: Type 6

Description: A basin wetland developed on the former site of Hockham Mere, situated at the head of the valley of an easterly draining tributary of the River Thet and surrounded by higher ground to the north, south and west. The site has been partly drained and is subdivided into a number of compartments by dykes and a main sluice-regulated IDB drain crosses the site from W to E. However, much of the site is very wet and treacherous.

Vegetation: Much of the herbaceous vegetation is referable to swamp and wet fen types, mostly *Potentillo-Caricetum* and some *Peucedano-Phragmitetum*, which have retained their essential floristic identity despite extensive colonisation by sallows. There are also extensive alder-sallow woods, with occasional oaks and areas of birch in the firmer and drier examples. Some of these latter have extensive *Sphagnum* carpets. The southernmost compartments (which adjoin a large conifer plantation) were excluded from the original SSSI, but this was subsequently extended to include them. Several rarities occur, including *Calamagrostis stricta.*

Substratum and Water Supply: The lake basin contains some 8–10 m depth of lake muds covered by a fairly thin (1 m), but rather uniform, layer of sedge peat, locally covered by shallow (*c.* 80 cm) accumulations of *Sphagnum* peat. Almost all of these deposits are capped by a thin layer of oxidised wood peat. This is probably a legacy of drainage[1]; it is not known to what extent the peat layer is a product of natural terrestrialisation processes or has been partly produced by lake level changes induced by drainage. In the western part of the site (near the former Thetford-Swaffham railway and peripheral to the main lake), peat depths of *c.* 5 m have been recorded.

The bedrock is Upper Chalk, with local putty Chalk on the upper surface, overlain by some 5–35 m of drift. The drift includes lacustrine deposits, with sand and occasional clay and gravel. This is underlain by boulder clay, *i.e.* chalky clay with local layers of sands and gravels, which is thought to confine the Chalk aquifer. Glacial sands and gravels form a ridge immediately southwest of the site, but are not thought to extend beneath it. This may provide a minor aquifer feeding the site, but it appears that the major source of water is rainfall and generated runoff, from a large, superficial groundwater / surface water catchment. The surface water catchment is estimated at 4.76 km^2.

The IDB drain brings in water from the west of the site, and may contribute to the water balance of the fen in flooding episodes. It may also have a drainage function, though a (leaky) sluice on the main drain, at the eastern (downstream) edge of the fen helps maintain water levels and these are high for much of the year, with winter flooding across large areas of the site (including fen woodland), and with more local swampy conditions during the summer. At one stage (1960s), the drain was apparently deliberately breached to flood part of the fen (for shooting).

Conclusion: A badly drained basin supplied primarily by rainfall and generated runoff from a large, superficial groundwater / surface water catchment, with some contribution from drift.

3.12 DERNFORD FEN

CAMBS: TL474503

Status**:** SSSI

Key Samples: 2

WETMECs: Type 2; Type 3 (ground hollow)

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[1] In Tudor times (and before) much of this site was a large mere (*c.* 280 acres). By 1737 the lake was considerably overgrown to 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 1750-1790 and a second, more effective scheme, between 1795-1798. 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 3'. The Forestry Commission started drainage operations in 1933 and, aided by summer droughts, by 1935 the water table was lowered by about 3' and land was being grazed which had been under water 3 years before, and it was possible to walk dryshod over the area. The original depth of the mere may have been some 8' above the level of 1932. This was gradually followed by drainage dereliction and currently the site is extremely wet, year round in some years.

Description: A small fen remnant at the edge of the Cam valley at the base of rising chalk slopes. Apparently once adjoining the river, it is now separated from this by some 600m, with an intervening railway and drained land. The surface has some small ground depressions. The site is bounded by a deep perimeter drain.

Vegetation: Much of this site is now rather dry, with grassland and scrub and with fen mainly confined to the shallow depressions (of uncertain origin), containing *Juncus subnodulosus* fen meadow, reedbed and alder carr. Areas of open pools within the site, together with ditches and the chalk stream enhance the diversity. *Gymnadenia conopsea, Epipactis palustris* and *Cladium mariscus* occur on the site.

Substratum & Water Supply: Rather little is known about the geology of this site as there are no local boreholes, but it appears to be situated upon Lower Chalk (probably only 1–3 m bgl) overlain by alluvial deposits of the River Cam floodplain. The aquifer at the site is the Chalk, unconfined other than by local occurrences of silty alluvium. Groundwater discharges close to the site at Nine Wells Spring. The perimeter ditch intercepts a proportion of groundwater flow which would otherwise reach the wetland, along with any surface drainage. The fen water table is variable, with some shallow flooding of the depressions (mainly winter) but subsurface in summer. Piezometric data are not available for this site, but it seems likely that the fen water table may track water level changes in the Chalk, though there may be some measure of 'internal' control – it seems likely that the rather silty deposits that line the fen basins may help retard vertical water exchange.

Conclusion: Intermittent seepage basins associated with fluctuations of water level of the unconfined Chalk aquifer.

3.13 DERSINGHAM BOG

NORFOLK: TF675289

Status: SSSI; SAC: Roydon Common and Dersingham Bog

Key Samples: 5

WETMECs: Type 1 and Type 2

Description: "Dersingham Bog SSSI" includes two contiguous wetland areas known as Dersingham Fen and Wolferton Fen. Mire and acidic grassland vegetation also continues beyond the N boundary of the SSSI as an area that is referred to as 'Dersingham Meadows'. Together, these parcels form an extensive site on flat ground below a steep, indented Greensand scarp slope, reputedly representing a former coastline. The (abandoned) railway from Kings Lynn to Hunstanton effectively forms the western limit to the site, but the fen probably once extended further seawards, grading into saltmarsh.

Vegetation: The main area of this mire is acidic and contains various types of poor-fen vegetation, with varying amounts of *Sphagnum.* The 'best' areas contain *Sphagnum*-rich M21 (*Narthecium ossifragum-Sphagnum papillosum* valley fen), with some *Sphagnum cuspidatum* pools, both of which are most uncommon in eastern England. There are also extensive surfaces dominated by *Eriophorum angustifolium.* Within the mire and, particularly adjoining it, are areas of wet heath and species-poor, acidic marshy grassland (M25). Scrub and young trees are encroaching on the bog in many places. Along the base of the escarpment is an upslope gradation from wet to dry heath, which in turn grades into woodland.

Substratum: Most of the mire lies on alluvium, with saltmarsh and blown sand deposits, up to *c.* 2m depth, overlying Sandringham Sands. The adjoining escarpment is formed of the Dersingham Beds and underlying Sandringham Sands. These are underlain by Kimmeridge Clay.

Water Supply: The site seems to derive most of its water supply from the water-table in the Greensand, this reaching the surface on the coastal flat below the cliff. Groundwater inflows are from the Sandringham Sands (Lower Greensand) aquifer (acting as a single unit with the overlying Dersingham Beds), flowing in from the south and east, maintaining a shallow water table across the site. The base of the aquifer is formed by the underlying Kimmeridge Clay aquiclude. The Sandringham Sands appear to be in hydraulic continuity with the overlying deposits (peat & recent Drift) over most of the site. It is not known to what extent water is primarily derived by lateral flow from discharges along the base of the escarpment as opposed to vertical upwellings across the valley bottom.

Two small streams enter the area just south of Dersingham, but the water from these passes directly into the drainage ditches before reaching the main part of the mire. Surface runoff from the heath may play a minor part in the water supply of the margins of the mire. Drainage from the site collects in a ditch running along the base of the railway embankment, which prevents water draining freely from the site. There are two piped culverts under the embankment, which can be used to manage water levels on the site, but their effect is considered to be localised and not extensive (P. Holms, *pers. comm*.). Surface water from the fields west of the embankment does not enter the mire.

Water level is subsurface for much of the year, but quite high (within c. 20cm of the surface) and seasonally relatively stable, on account of the high storativity of the aquifer (and on-site water regulation ?). Shallow, temporary pools form locally after heavy rain. Most run-off from the mire occurs in response to high winter rainfall and summer rainfall is also considered important in maintaining water levels (P. Holms, *pers. comm.*).

***Conclusion**:* A groundwater-fed mire, primarily from an unconfined Greensand aquifer.

3.14 EAST WALTON COMMON

NORFOLK: TF7316

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 14

WETMECs: Type 1 (seepages near main spring); Type 2 (seepage areas in unconfined basins); Type 3 (shallow, higher basins); Type 4 (deeper ground hollows)

Description: This complex site consists primarily of a set of small basin-shaped ground depressions, separated by chalky ridges, (apparently collapsed pingos with well-developed ramparts), which contain standing water and swamp and wet fen communities. The depressions vary greatly in size and level. Intermixed with them are areas which are less obviously basins, though in some cases perhaps created by the coalescence of adjoining basins. These support winter-wet fen, grading into wet and dry grassland, depending on the topography. A complex of seepages with a strong spring occurs in the north-east part of the site and feeds a stream that runs through the western part of the common. Low-lying areas alongside this support quite extensive areas of fen. The nature and origin of the depressions has been described and discussed by Sparks, Williams & Bell (1972).

Vegetation: The wet depressions are surrounded by calcareous grassland in the open area (some depressions also occur in the adjoining woodlands). The pools are in various states of wetness (in some cases terrestrialisation) and some show a clear zonation, but only a few hollows contain open water. They mostly contain a range of fen vegetation-types ranging from *Carex elata*, *Cladium mariscus* or *Phragmites* swamp and fen through *Potentillo-Caricetum* {~S27} and *Acrocladio-Caricetum* {~M9} stands to examples of rich-fen meadow. Some have become colonised by scrub (which in some instances has been removed recently). Some stands of rather impoverished *Schoenus* vegetation occur in the drier, more open basins, but these are more fen meadow (M22) with *Schoenus* than examples of M13. They grade into drier *Molinia* {~M24}(and other) grassland. The rare fen orchid (*Liparis loeselii*) has been recorded from one depression (apparently with M9 vegetation).

Substratum: Most of the site is situated upon Lower Chalk, at the western edge of this deposit, truncated westwards by a N-SW deep buried channel filled with sand and gravel and overlain by alluvium and apparently plugged downstream of the site with till, marine alluvium and clays (Adams *et al.*, 1994). The chalk is covered by calcareous alluvial sands, of varying depth but often rather thin (1–2 m). Much of the drift appears to be considerably more calcareous than in some other Norfolk sites and dry areas support vegetation reminiscent of chalk grassland. The chalk is considered to be in hydraulic continuity with the overlying sands, but deep putty chalk has been recorded and it is not clear to what extent this partly confines the Chalk water. The chalk is underlain by a Gault aquiclude, and wedges out westwards. Groundwater flow in the Chalk is from east to west, and it discharges into the ground depressions and seepages. Adams *et al.* (1994) consider that downstream plugging of the buried channel suggests that there is "little opportunity for underflow at East Walton, and the majority of the groundwater supplied by the groundwater catchment will come to the surface at the wetland site".

Water Supply: In the NNE part of the Common there is an extensive seepage complex, located within woodland. One particularly strong main spring (outside of the SSSI) feeds a stream that runs down the west side of the Common (it is also used for domestic water supply). A central, deep, steep-sided and open pool contains clear water which apparently shows rather little seasonal change in level. It appears to be a sort of well, though its origin is not known (a solution hollow rather than a pingo ?); it feeds a small stream. Drift and chalk piezometers, located in the NE corner of the site, show rather similar fluctuations (of some 50+ cm between wet and dry periods), but there is a tendency for the water level in the drift piezometer to be slightly higher than that of the chalk in wet periods and lower during dry periods, suggesting some upward flow from the chalk. In 1997 and 1998, gauge board records from a pond at the E end of the common were similar to those in the piezometers (greater fluctuations in 1999 appear to be recording errors). Montgomery-Watson point out that (from the piezometric data) there is evidence for hydraulic connection between the gauged pond and the near-surface alluvium, but the evidence for a connection between the pond and the chalk is inconclusive. However, there is evidence for hydraulic continuity between the chalk and the sandy alluvium.

The numerous pingos occur in close juxtaposition, but often at different levels. The shallower, higher-level depressions may be older (Zone I) than the deeper examples (Zone III) and may have been partly infilled by sandy drift and cryoturbation material (Sparks *et al.*, 1972). Some depressions have clearly coalesced, but others are more-or-less discrete basins, though the majority of these latter have drainage outfalls, and many of the pingos appear to form part of a drainage chain flowing broadly east–west. In some instances the outfalls appear artificial and in some of the bigger pingos (complexes) ditches may bypass the deeper parts of the depressions. Water levels across the Common have not been measured, but it is clear that pingos in close proximity can have very different water levels (1 m or more difference). This, and the occurrence of drainage outfalls, points to constraints upon free flow of water between at least some of the pingos. Sparks *et al.* (1972) report that cemented layers of fine chalk rubble, sand and flints occur in some of the ramparts. Preliminary corings suggest that in some of the drier, higher level depressions, there appear to be low permeability layers (silts and clays), both beneath the depression infill and in the separating walls. These may serve both to impede groundwater inflow and to retard drainage (depending on the groundwater table height) and it is believed that these hollows become rather dry during dry periods. By contrast, preliminary cores from some deeper, lower-lying hollows with a semi-floating vegetation raft point to a deep layer of sandy muds beneath the bottoms of basins, with no obvious impedance layers. The depth and lateral extent of this deposit is not known, but its occurrence raises the possibility that not only are the permanently wet pingos deeper than the shallow examples, and thus more likely to experience high water tables, but they may also have better connection with groundwater inflows. Water pH and conductivity in the pingos (and in the central well and the main spring complex) appear to be more similar to values recorded in the shallow piezometer (P2) than in water from the deep chalk piezometer (P1) (see Table EW_1).

Conclusion: The lack of detailed topographical data, and the preliminary nature of all observations made, makes it difficult to draw clear conclusions about water supply mechanisms for this site, but the following suggestions are made. The site is primarily fed by groundwater discharge through the superficial sandy alluvium. Some pingos are quite deep, may have good hydraulic connection with the drift, and may be fed by strong groundwater flow from underlying sands, but constraints on lateral outflow (because of cemented layers in the ramparts *etc.*) mean that the depth of water in them may be fixed primarily by the height of a surface outfall. Those basins in which the outfall is below the normal lowest groundwater head have very stable water levels (and semi-floating vegetation mats). Other (often shallower and higher, and perhaps older) depressions have some constraints on water inflow and outflow (and in the case of the higher examples, may be situated above the normal lowest groundwater level) and function as intermittent seepage basins. The exact source of the groundwater is not known with certainty. It seems likely to be chalkwater transmitted through the superficial sands, but perhaps not derived from the same horizon as that in which piezometer P1 is screened. Surface inflow is limited to generated run-off, which is probably unimportant in maintaining wet conditions in summer.

Table EW_1. pH, conductivity and alkalinity in water samples from parts of East Walton Common

	pH	Conductivity µS cm^{-1}	Alkalinity mg l^{-1}	Location	Date
EW_P1	7.5	565		Agency piezometer P1	9 April 2000
EW_P2	7.55	660		Agency piezometer P2	9 April 2000
EW_S		675		Main spring (sample from water supply point)	9 April 2000
EW1a	7.4	664	331.5		Dec 1999
EW1b	7.45	666	325	Main well pool in centre of site	Dec 1999
EW1c		665			9 April 2000
EW2a	7.2	829	520	Pingo with *Carex elata* floating raft (near W fence)	Dec 1999
EW2b	7.3	836	513.5		Dec 1999
EW3	7.45	621	396.5	Pingo with trees recently removed (near W fence)	Dec 1999
EW4	7.3	701	448.5	Pingo with small *Chara* pool (E side of Common)	Dec 1999

3.15 FLORDON COMMON

NORFOLK: TM182973

***Status*: SSSI; SAC: Norfolk Valley Fens**

Key Samples: 3

WETMECs: Type 1 (local on valley bottom); Type 2 (much of valley bottom and slopes)

Description and Vegetation: A medium-sized groundwater-fed fen in the upper reaches of a tributary valley of the R. Tas. The uppermost part (west of the road that crosses the fen) has been considerably damaged; the eastern portion has also been partly drained, but retains good quality seepage communities (~M13). These mainly occur on the flattish valley floor, on either side of the southernmost E–W drain. Elsewhere the valley floor supports fen meadow (M22), *Molinia* fen grassland (M24) and patches of tall herb fen, along with drier grassland types.

Substratum and Water Supply: This site has not been much investigated. Coring reveals shallow peat and marl deposits quite widely on the valley floor and up the (now dry) slopes, as well as in the extant M13 areas, suggesting that discharges were once considerably more widespread than now. In one place on the slope there is a dry spring mound. It is not known to what extent this drying is a consequence of the drains along the valley floor. There is still a small pond embedded within the valley slope, apparently on the site of an active spring.

The site lies in an area of Upper Chalk which is predominantly covered by a thick (10-30 m) deposit of Lowestoft Till. This consists of boulder clay interdigitated with layers of glacial sand and gravel. At Flordon, sandy deposits are exposed on the lower slopes of the alluvium-floored valley. These overly the chalk and appear to be in hydraulic continuity with this, though it is not known to what extent this may be reduced by putty chalk. The overlying boulder clay acts as an aquitard, semi-confining both the Chalk and Drift aquifer units. In the absence of piezometric data for the site, HSI (2000) estimate that Chalkwater levels may be around 26 m OD in the vicinity of Flordon Common, which is above ground level for much of the site (22–29 m OD). It thus seems likely that this site is fed by chalk water through the overlying sands, gravels and alluvium. Shallow throughflow in the sand and gravel, rainfall and generated runoff, may contribute minor water inputs.

The main stream is well below the main level of valley floor and it may have a drainage function. It is separated from the main seepage zone by a narrow, and surprisingly dry, wooded slope. It is not certain whether this results from a drainage effect of the stream or whether this zone helps impedes lateral drainage from the seepage areas.

Conclusion: Lower part of the valley has a permanent seepage face maintained by a semi-confined chalk aquifer.

3.16 FORNCETT MEADOWS

NORFOLK: TM166927

***Status*:** SSSI

WETMECs: Type 2 (seepage slope), Type 8 (valley bottom)

Description and Vegetation: Two meadows on sloping ground on either side of the upper reaches of R. Tas, with some fen interest in the southern meadow, where there is *Carex acutiformis*- and *Juncus subnodulosus*-dominated fen meadow (M22). Much of the area is a form of rough, wet grassland, differing in character between the valley bottom and slope, but the slopes also support fairly localised seepages, with fen meadow. An artificial channel extends along the length of the base of the slope and discharges into the Tas (though it is now plugged). There is visual evidence for seepage into the gravel bottom of this.

Substratum: The site occurs on drift (Lowestoft Till) upon Upper Chalk. Most of the till of the area is boulder clay, with sands exposed on some of the lower valley slopes, but the semi-confined sand and gravel unit appears to be absent within the site, which consists of alluvial clays, sandy clays and boulder clay upon chalk. The site is situated in an area of a "chalk high", where the Chalk occurs at shallow depth (5 m bgl), but its upper 2-3m consists of putty chalk which, in conjunction with the boulder clay, may act as an aquitard.

Water Supply: The chalk water table is slightly artesian. HSI suggest that water in the sand lenses in the drift are perched upon clay layers and putty chalk. However, they consider that the site "is sustained primarily by groundwater seepage originating from upward flow from the underlying Chalk and lateral flow from the [nearby] sand and gravel unit". They further suggest that "Because water levels are only mildly artesian, seepages can decrease or cease altogether for only marginal (1–2 m) falls in water levels." In addition, the most distinct seepage area on the southern slope is capped with a layer of 'clay' which is likely to provide upward resistance to water flow. S. Tolhurst (*in litt.*) considers that "the site is badly affected by water abstractions as it is notable that as soon as summer irrigation starts on arable land, water levels in the ditch can drop by several inches. On the northern part of the SSSI the ditch suddenly empties in early summer".

Several parallel drains run down through the S field and discharge into the R. Tas. Episodic flooding from the Tas occurs. "Flooding of the valley bottom occurs most years during winter. The river is very flashy, rising quickly after heavy rainfall and staying up only for 24/48 hours. About one in ten years, flooding reaches the valley sides (*i.e.* the ditch) and the water on the valley bottom can come to the top of waders" (S. Tolhurst, *in litt.*) but in general there is little reason to suppose that surface water makes any ecologically important contribution to the water balance of the site or to summer conditions (no summer flooding is known). There appear to be some surface run-off inputs into the fen, from adjoining arable land, during the winter.

Conclusion: Seepage surfaces are fed by intermittent upward seepage of chalk water, with some contribution from the drift, which discharges through and onto a clay-rich substratum. Groundwater discharge helps maintain a fairly high water table in the valley bottom, but this is subsurface for much of the year.

3.17 FOULDEN & GOODERSTONE COMMONS

NORFOLK: TF7600

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 15

WETMECs: Type 1 (part of Gooderstone Common), Type 2 (much of Foulden and Gooderstone Commons), Type 3 (ground depressions in Foulden Common)

Description: A large fen site at the headwaters of a small tributary stream of the R. Wissey. Foulden Common, south of the stream, has long been rather 'dry' (certainly since 1970, probably before then). It contains numerous depressions[1] of varying depth and integrity, with the most discrete examples east of the road across the fen. There are some large, flatter areas of fen (Talents Fen), though this also contains a number of shallow depressions (which generally support the wettest examples of fen vegetation here). Talents Fen is bounded by a deep ditch on the south and west edges, though in recent years water has been retained in this at a high level, whilst a second drainage ditch has been dug parallel to this outside of the Common.

Gooderstone Fen (north of the stream) also contains some slight depressions, but primarily provides a rather even surface, sloping down to the stream. An artificial channel fed by strong spring flow crosses Gooderstone Fen diagonally. It is also fed by small seepages from the adjoining fen (primarily on the N side) and much of this part of the fen comprises a large seepage system, with particularly active seeps draining into the channel and – further west – into the main drainage stream. Apart from the main spring channel, and some small attempts at surface drainage, Gooderstone Fen seems to have been little-drained.

Vegetation: The commons corporately form a large, flattish, complex area of grassland, fen and woodland. In Foulden Common, west of the road, the substratum is calcareous and the stream is bordered by a band of alder carr and rather fragmented *Cladium*-dominated fen. However, the main area of *Cladium* fen occurs in Talents Fen to the south of this, separated from the stream-side fens by a slightly elevated band of grassland. In the higher parts of the fen, and at the margins, there is most often a *Cladio-Molinietum* community, but there is also some dry (and impoverished) *Schoenus* fen (former M13 ?), grading out into *Cirsio-Molinietum* {~M24} or drier grassland. Near the stream there are several small ground ice depressions, some of which coalesce with the streamside fens, supporting species-poor *Cladium* or *Carex elata* 'swamp', but the main area with distinct pingos is in the north-east arm of the Common, east of the road. Here, on a dry sandy, and rather acidic, drift there is much birch, and the smaller pingos are almost completely shaded and dystrophic.

The hollows contain varying amounts of water and vegetation. Some support aquatic species (*Utricularia vulgaris, Potamogeton coloratus*), but this site is not as important for aquatic plants as, say, Thompson Common.

Much of Gooderstone Common has been reclaimed for agriculture, but Gooderstone Fen, towards the west of the Common, has some well developed springs and seepages with good base-rich mire vegetation {~M13}, grading out into *Cirsio-Molinietum* {~M24}, fen meadow {~M22} and drier grassland.

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[1] The depressions are often referred to as pingos but, unlike the structures at East Walton Common, they do not have very obvious ramparts.

Substratum and Water Supply: The bedrock is Chalk, covered by deposits of sands and sandy silts of varying depth – in some places Chalk appears to be ± uncovered. The main aquifer is unconfined Middle Chalk, in hydraulic continuity with the drift, and over much of the area the wetness of the ground is essentially determined by the intersection of the topography with the water table, though in wet periods there may be temporarily perched conditions within the drift, especially where this is silty. Upward flow from the chalk may be retarded by putty Chalk, which may mean that hydraulic continuity is indirect. The piezometers in the main fen areas of Foulden Common indicate a fluctuating water table consistently below ground level at the piezometer, though the absence of topographical data makes it difficult to relate this to typical fen water levels. Water levels in the shallow (drift) piezometers tend to be slightly below chalk water levels in dry conditions and higher during wet periods. Gauge board 151, in one of the pingos, indicates particularly strong fluctuations in water level, though this may be due to recording errors There is some evidence that two of the pingos east of the road contain water of lower pH and considerably lower alkalinity than examples west of the road (Table FG_1). This may be because the drift is deeper here and the depressions are fed just by drift water. There is some anecdotal evidence that the east pingos retain water in the summer better than examples in the chalk which, if correct, may reflect greater storativity of the drift.

Table FG_1. Hydrochemical data from three depressions (December 1999)

	pH	Conductivity μS cm^{-1}	Alkalinity mg l^{-1}	Location
F1a	7.7	832	552.5	*Cladium* pingo, W of car park [chalk fed ?]
F1b	7.8	835	559	
F2a	6.85	238	97.5	*Phragmites/Typha* pingo, E of road [drift fed ?]
F2a	6.8	233	91	
F3a	6.4	238	71.5	*Carex elata* / *J. effusus* pingo, E of road [drift fed ?]
F3b	6.45	236	65	

The rather low, fluctuating water table is reflected in the measured water tables in much of the fen, and the pingos (at least those W of the road) undoubtedly experience strongly fluctuating water tables, and range from being swamp (mainly winter) to 'dry' (mainly summer). It should, however, be noted that this condition is of some long standing. It is possible that at one time 'better' plant communities may have occurred at this site and that a long-term lowering of the water table has produced the present assemblages from a former richer state. However, the degree to which there has been a reduction of water tables is difficult to assess, as it seems likely that this site may always have experienced quite a large water table fluctuation. Reasons for suspecting this include the thin layers of peat present across much of the site. Another difficulty in assessing changes in Foulden Common is provided by the adjoining Gooderstone Common, which undoubtedly had the best seepage communities in the early 1970s – the problem being that past botanical recorders may not always have distinguished clearly between the two parts of the site.

Although (arguably) the more important of the two sites (in terms of fen vegetation), Gooderstone Fen has received less hydrological examination and monitoring. It is unfortunate that the main piezometers installed at this site are located at some distance from the main seepages. Its differences in character from Foulden Common appear to be a consequence of particularly strong and reliable spring flow, possibly associated with discharge from a fissured chalk horizon (Melbourne Rock or an analogous layer ?), though the spread of this across the site is not really known.

***Conclusion**:* Foulden Common is fed by a fluctuating water table in a largely unconfined chalk aquifer and overlying drift. The water table is frequently subsurface in much of the fen, and some of the pingos often have subsurface water tables in summer. The pingos in the east of the common are located in deeper drift and may not be fed directly by chalk water. Some of these, at least, seem to retain higher water tables in summer. Gooderstone Fen has ± permanent seepages associated with discharge from strong chalk springs and adjoining areas of less wet fen.

3.18 GREAT CRESSINGHAM FEN

NORFOLK: TF848022

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 4

WETMECs: Type 1 (seepage area at NE), Type 2 (other marginal seepages), Type 4 (wetter parts of basin), Type 5 (drier, central basin)

Description: Great Cressingham Fen is unusual in an East Anglian context, in that the short side valley off the R Wissey which it occupies is configured as a small, but quite steep-sided (former lake) basin, the base of which is considerably lower than river levels.

Vegetation: The central parts of this site are occupied by stands of tall reed and derelict fen meadow with some willow invasion. Around the margins there are quite large areas of lower-growing vegetation, probably maintained by grazing. Much of the SW margin was covered by a quaking mat of *Acrocladio-Caricetum* {~M9} in 1985 but this now appears to be mainly a form of fen meadow. In the NE corner there is some development of *Schoeno-Juncetum* {~M13} on seepage slopes leading down to the fen.

Water Supply: This site is primarily groundwater fed, from a series of discrete springs and seepages along the west and northwest margins. There are no known drains feeding the site, nor does the nearby River Wissey apparently flood the fen (though it probably helps determine the groundwater table). Water levels are probably much controlled by the outfall dyke in the south east corner of the site. They are very responsive to heavy rainfall and surface flooding can occur, both in winter and sometimes in summer, presumably in response to generated run-off.

The conceptual groundwater model of the site is that the main aquifer is the Upper Chalk, overlain by thin drift and alluvial deposits with which it is in hydraulic continuity, although layers of putty chalk and clay may impede vertical flow, at least locally (these are particularly thick near the southern boundary). The main basin contains a quite deep accumulation of lake marl, which probably forms an effective aquitard, so that groundwater inputs may enter the site primarily through near-surface discharges. Chalk water flow is from NE to SW and there is a series of springs and seepages along the west and north west sides of the wetland, including a small (and not very species-rich) example of M13 vegetation in the northern corner of the site. The provenance of the spring and seepage water is a matter of considerable interest. Based on an analysis of borehole monitoring (Saul, 1998 (unpublished report)), Saul (2000, *in litt.*) "suggests that the deeper Chalk layers do not contribute or control the springs to any measurable extent. The drift and weathered chalk layer does and is the main source of water to the fen. The weather zone does not usually extend to more than 5 m below the surface of the chalk.". This suggestion is compatible with the known ecological characteristics of the site and with the observation that the chemical composition of the fen water in the M13 area has considerably smaller concentrations of Ca and alkalinity than those found in many chalk-fed Norfolk examples of M13.

Although there are no detailed topographical data, or water levels, for the fen itself, the chalk water head in piezometers on the north side of the fen is above the fen water table, but that in the drift on the S side of the fen fluctuates around the levels of the apparent fen water table. In 1985 lowest water levels (relative to the soil surface) were measured in 'solid' peat in the north-central part of the fen. This is east of the small pond and surrounded by dykes and may well receive little if any direct groundwater inputs (it is not know to what extent the dykes help to drain or recharge this central area). At this time (1985) some of the wettest conditions (semi-floating semi-swamp) on-site occurred in the southwest corner, extending some distance eastwards along the south side of the fen. As these water level measurements were made relative to the peat surface they may, of course, largely reflect variations in the height of the peat surface rather than in the height of the fen water table, but it is nonetheless clear that the biggest hydrological change observed on the site since 1985 has been the apparent drying of the vegetation surface in the SW/S corner, the loss of the semi-floating mat and strong reduction in many of its characteristic species. The reason for this is not known but, as well as being an unfortunate development in its own right, it may have repercussions on the ecohydrology of other parts of the site as it seems likely that the semi-floating mat probably provided a preferential sub-surface flow path for spring water from the north of the fen.

River levels, and the nature and altitude of the outfall into the Wissey, potentially exert an important influence upon fen water levels. It would be of considerable interest to know to what extent summer water levels in the fen are critically dependent upon groundwater levels and to what extent they could be controlled by regulation of the outfall.

Conclusion: Apparently chalk water fed from a largely unconfined aquifer, perhaps primarily from the drift and the topmost weathered chalk layer (which appear to act as a single hydrological unit), but fen water levels probably also regulated by the topogenous character of the site. An example of a rheo-topogenous mire, but evidence for low (post 1985) water levels especially in the SW/S part of the fen.

3.19 HOLLY FARM MEADOW (WENDLING POOR'S FEN)

NORFOLK: TF935131

Status**:** SSSI; (Deleted from Norfolk Valley Fens SAC)

Key Samples: 2

WETMECs: Type 2.

Description and Vegetation: This small site consists mainly of moist and marshy grassland, but a tiny area has some affinities to true fen, occupying a shallow, ditch-drained depression in the western part of the site. This latter supports a small amount of *Schoenus nigricans,* but it is not really M13 vegetation, except perhaps in a very degraded form. The whole site occupies a gentle south-facing slope, truncated at the southern end by a shallow cutting associated with the A47 road (which here follows the course of the former Swaffham-Dereham railway).

Substratum and Water Supply: The broad geology of the area of the site is Upper Chalk overlain typically by a considerable depth of Lowestoft Till, but in the vicinity of the site a boss of chalk, capped by sands and gravels, is separated from the surface by only a thin (2-3m) layer of boulder clay. HSI suggest that this layer weakly confines the Chalk aquifer, and the available piezometric data also suggest that the surface deposits are in hydraulic continuity with the chalk. Lack of topographical data, coupled with the undoubted considerable topographical variation of this sloping site make it difficult to relate the piezometric data to surface conditions, but summer water levels are known to be subsurface over much of this site, and even the small flushed area had subsurface water levels when measured in 1985 (water level was then below the base of the peat) and it has been reported as 'dry' on several occasions since then. As there is still some 30 cm of peat, the seepage area must once have been considerably wetter than it is now. The present dryness may be a consequence of the small drain and draw-down associated with the A47/railway cutting. However, if the sparsity of past botanical records of uncommon fen species can be taken as a guide, there is little reason to suppose that this site was ever a known and notable fen to past naturalists. From this point of view, it may also be noted that, as 'Wendling Fuel Allotment' this site has had a long history of exploitation. For example, the Norfolk Charities Commissioners report (1838) "Turf has been cut without restriction and is now almost exhausted. Herbage is let."

Conclusion: Small intermittent seepage slope adjoined by marshy grassland with permanently sub-surface water levels, fed by upward leakage of semi-confined chalk water. Low water levels may partly be a consequence of drainage and railway / road construction.

3.20 HOLT LOWES

NORFOLK: TG088374

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 3

WETMECs: Type 1 (slopes and valley bottom of SW valley), Type 2 (peripheral parts of SW valley and main Glaven valley bottom)

Description and Vegetation: A large site, primarily dry heath, but with fen developed both alongside the R Glaven and in small tributary valleys. Greatest floristic interest attaches to the southwestern tributary valley (considered here), where there is a close juxtaposition of base-poor and base-rich fen. The small, and intergrading character of these communities means that they are not easy to categorise, but some of the acidic mire can be allocated to M21, and the more base-rich examples to M14, grading into M13. These are adjoined by patches of fen meadow (M22) and acid wet grassland (M25). This latter occurs elsewhere on the site, in some cases much colonised by birch. The lower parts of the Glaven valley contain some tall herb fen.

Substratum and Water Supply: The Lowes is a plateau of glacial sands and gravels overlying approximately 30m of boulder clay (Lowestoft Till), which forms the bed of the Glaven. It is underlain by Upper Chalk. There is a near surface phreatic sand aquifer of limited extent, perched upon a low-permeability Boulder Clay aquitard. Groundwater discharges into the tributary valley in the form of seepages (and also sustains the water supply to ponds within the valley). The Boulder Clay confines the underlying Crag/Chalk aquifer The rest Chalk water level lies mostly within the boulder clay, although there is at least the possibility of some upward leakage in the eastern part of the site, where piezometric elevations are at or above ground level. However, in terms of explaining the observed ecological features, it should be noted that the clearest zonation of base-poor to base-rich conditions occurs in the southwestern valley, where – at one point at least – base-rich seepages discharge onto the valley slopes *above* the level of the base-poor fen (Table HL_1). Moreover, the water pH values and, especially, alkalinities recorded here are much lower than are typically associated with chalk water, even for the most base-rich parts of the SW valley. Such considerations make chalk influence seem unlikely and argue in favour of contrasting water sources within the drift. HSI (1996) consider that "the main source of water to the site is from the shallow, phreatic sand" and the University of Birmingham site dossier proposes that "the modest degree of base enrichment encountered may well reflect a contribution from the boulder clay than from chalk". This explanation would be compatible with mechanisms that appear to apply at Buxton Heath, and which may occur at Roydon Common (both of which sites also support this unusual base-poor – base-rich zonation), and it seems to be probable. It is, of course, possible that parts of the Glaven valley, in the E of the site, receive some upward leakage of chalk water, but we have no evidence for this.

Conclusion: Main area of interest is a permanent seepage face supplied from a drift aquifer, probably with local variation in water quality.

Table HL_1. Some hydrochemical data from the SW valley at Holt Lowes (December 1999)

	pH	Conductivity µS cm^{-1}	Alkalinity mg l^{-1}	Location
HL1a	6.65	555	65	*Juncus subnodulosus* spring on valley side
HL1b	6.45	658	78	[above HL2 and 3]
HL2a	6.9	792	58.5	*Schoenus nigricans* area along valley bottom
HL2b	6.85	786	65	[down-valley of HL3]
HL3a	4.35	295	26	*Sphagnum magellanicum* area near head of valley
HL3b	4.65	287	19.5	

3.21 HOPTON FEN

SUFFOLK: TL991798

***Status*: SSSI**

Key Samples: 7

WETMECs: Type 2 (slopes in SE corner), Type 5 (main area of fen).

Description: A fairly large fen site, alongside a small tributary stream draining into the River L. Ouse. Weston Fen (*q.v.*) is higher up this stream, but unlike this site, Hopton Fen – located near the junction with the Ouse flood plain – is not obviously sloping. Rather, it appears to occupy a half-basin, adjoining the stream.

Vegetation: The vegetation shows a very broad zonation (of increasing rankness and decreasing 'interest') from the southeast corner northwest-wards, with 'eutrophic' vegetation (S25) occupying much of the site and grading northwards into a peripheral band of S26. In the southeast corner there are patches of M24 (*Molinia-Cirsium dissectum* fen meadow). There are also small reedbeds, marginal scrub and, towards the SE corner, a shallow scrape with swamp and some aquatic plants. A broadly similar pattern of low-productivity fen in the SE to taller, coarse fen in the NW was observed in 1972 [BDW] but at this time there were stands of *Schoenus* vegetation scattered quite widely in the southeast corner, though these were not particularly species-rich, nor did they have some of the bryophytes and small forbs (*e.g. Pinguicula vulgaris*) that characterise the 'best' examples of *Schoenus* fen (M13). At this stage they could have been considered to be a degraded form of M13, though the abundance of *Carex lasiocarpa* in some samples raises the alternative possibility of a dry form of M9. At that time, this sort of vegetation was not restricted to the SE corner, but also occurred northwest of the concrete path – though some of these latter examples had a strange species mix, with *Epilobium hirsutum, Eriophorum angustifolium* and *Schoenus* growing together.

Substratum and Water Supply: The bedrock is chalk, overlain by some drift and various alluvial deposits, including sands and gravel and clay. Although peat digging has occurred at this site, the surface peat deposit is quite deep, with up to 2 m of peat resting upon sand. The main aquifer is chalk, mostly unconfined and in hydraulic continuity with the overlying sands and gravels. A sand/gravel drift covers the valley side to the east and south of the site and provide some lateral inputs of shallow groundwater. A sandy clay is reported from the south of the site, which may restrict upward flow, but most of the apparent seepages (and wettest fen conditions) seem to occur in this area. Further NW there is generally a reduction in the fen water table (to give rather dry summer conditions) and even in the south of the site the peat surface may be some 25-30 cm above the summer water table.

The head of water in both chalk and drift piezometers on the E margin of the fen is well above the average fen surface level, but summer water levels are substantially subsurface in most of the fen (a shallow scrape towards the SE corner may retain a small depth of water) and apparently drier than when visited in 1972. It is not clear whether this is a consequence of an overall reduction of piezometric pressure or improved drainage in the Ouse valley (or both), but rainfall events may now be particularly important in determining summer wetness over much of the site. Mapped chalk piezometric heads decline NW-wards across the site.

The Hopton Brook periodically floods small parts of the site, but is not an important source of summer water. It is not clear to what extent it regulates the fen water table. There appears to be a water table gradient from the SE corner westwards to the brook.

Conclusion: A rheo-topogenous fen, irrigated mainly from an unconfined chalk aquifer, probably mainly from seepages at the SE end. Now rather dry, for reasons that are not clear, but which appear to relate primarily to low water tables and low rainfall.

3.22 KENNINGHALL & BANHAM FENS

NORFOLK: TM041875

Status**:** SSSI

WETMECs: Type 2 (marginal seepage slopes; Type 5 (main basin); Type 6 (margins of mere)

Description and Vegetation: A quite large fen site, near the headwaters of the R. Whittle, but mostly occupying a former lake basin (Quidenham Mere). The mere is largely surrounded by fen carr, including wet ash wood and wetter alder carr, but both Banham Great Fen (to the N and NW of the mere) and Kenninghall Fen (to the SE) are substantially herbaceous. Kenninghall Fen is obviously partly a spring/seepage fen, supporting extensive areas of fen meadow with smaller patches of *Schoeno-Juncetum* {~M13}, with patches of *Carex elata* "swamp" and some *Cladium* and *Phragmites* dominance. By contrast, Banham Great Fen, to the north of the mere has extensive, rather dry, beds of sedge (*Cladio-Molinietum*) and reed, with some marginal *Cirsio-Molinietum*.

Substratum and Water Supply: The easternmost margin of Kenninghall Fen is sloping and peripheral to the lake basin, with very shallow peaty soils (10–30 cm), but most of the site is based on peat (of varying depth, but typically between 1–1.7 m) upon deep lake marls (note that these are referred as 'silts' in the HSI Hydrological Monitoring report). A number of drains cross the site, some of them focussing on Quidenham Mere, which was formerly partly bypassed on the E side. There is also a catchwater drain alongside the land margin of Banham Great Fen. The R. Whittle level is below that of the fen (at least during the summer) and probably serves to reduce water levels both in the lake and the adjoining fen. The marl deposits of the lake suggest that this was fed by highly calcareous water, and chalk water is thought to flow to the site from the N, E and S. However, it is much less clear to what extent this directly irrigates the fen. HSI suggest that the alluvial silts (*i.e.* marl) and peat may act as an aquitard, reducing upward flow and perhaps preventing this reaching the surface (we would strongly concur with this view). Putty chalk (*c.* 1 m depth has been recorded) may also retard vertical flow. However, along the sloping E edge of Kenninghall Fen, lateral groundwater inputs from the unconfined chalk aquifer support seepages, some of which discharge into drains and enter the surface water system. Seepages have also been claimed for Banham Great Fen, but we have seen no evidence of these.

Ultimately the whole site is dependent on chalk water inputs, which feed the R Whittle and hence supply the mere, and may directly feed some of the marginal drains. However, the characteristics of Banham Great Fen suggest that the vegetation of this area is probably little fed by direct groundwater discharge but depends upon lateral seepage of water from the surface water system (including the marginal catchwater drain) through the peat as the main telluric water supply (we do not know if the area floods). It is likely that such seepage is rather limited, especially at low dyke water levels, as the peat is dense and well-humified, and it is to be expected that much of Banham Great Fen, away from the dykes, is likely to become rather dry in summer. It is possible that rainfall is the predominant source of water to much of this area of fen. The low water levels in this area in summer presumably reflect low surface water levels, consequent upon reduced chalk flow and channel deepening, but the humification of the peat throughout the profile suggests that this area may have naturally experienced only limited recharge during the summer. Similar comments may apply to parts of Kenninghall Fen, but here there is evidence of limited groundwater discharge, producing intermittent seepages on the valley slopes.

Conclusion: The topogenous fens at this site are fed primarily by lateral seepage from the surface water system, which is now inadequate to maintain the high water levels which once permitted peat to accumulate. The E slopes of Kenninghall Fen support intermittent seepages supplied from a largely unconfined chalk aquifer.

3.23 MIDDLE HARLING FEN

NORFOLK TL989853

Status**:** SSSI

WETMECs: Type 2 (seepage slope in NE), Type 3 (main basin)

Description and Vegetation: A fairly long, narrow fen occupying an elongate basin at the head of a tributary valley of the R Thet. Much of the vegetation is a form of swamp (mainly *Carex elata* and *Cladium mariscus*), surrounded by damp/wet grassland, but in the NE part of the site there is some development of rather dry fen on the adjoining SW-facing slope.

Substratum and Water Supply: The bedrock is Upper Chalk, overlain by a silty sand and it is likely that the site is fed primarily from an unconfined chalk aquifer in hydraulic continuity with the overlying sands. Interpretation of piezometric data is difficult on account of the sparsity of the topographical data from the site, but it appears that the piezometric head fluctuates (quite considerably) around about the level of the fen surface (in the hollow). This may drive water level fluctuations within the fen, which range from being flooded (mainly winter) to dry (mainly late summer). However, it is premature to assume that the water table in the fen is in exact equilibrium with the chalk/drift aquifer, as it is possible that silts and peats within the basin may retard vertical water exchange, and lead to a tendency for water to be retained in the basin, regulated by the height of the outfall (not known) as well as by the position of aquifer. The strong fluctuations in the basin may explain the species-poverty of much of this vegetation. The piezometric head is slightly higher in the NE piezometer, and this may account for the development of some fenny vegetation on the slope immediately above the basin in this area. However, the water table appears normally to be well below the surface of the seepage slope here (except periodically, at the junction of the swamp), though this statement is based just on casual observations – reliable data do not seem to exist.

The higher piezometric heads at the N end of the site presumably mean that the direction of groundwater flow is counter to that of the surface water drainage of the fen. This may suggest that any lateral flow through the fen occurs in consequence of drainage rather than sustained seepage. The nature and occurrence of the surface water drainage northwards from this sites does not seem to be documented.

Conclusion: a basin site fed by an unconfined chalk aquifer. The vertical fluctuations of this are associated with periods of relative dryness and flooding in the fen. The hydrodynamics of the basin seem to be dominated by vertical water level change, not by lateral flow. There is a rather weakly-developed, intermittent seepage slope at the NE end of the site.

3.24 PAKENHAM MEADOWS

SUFFOLK: TL933682

Status**:** SSSI

Key Samples: 1

WETMECs: Type 5

Description: Pakenham Fen[1] *sensu lato* is a once quite large area of fen near to the head-waters of a small feeder stream of The Black Bourn, which is itself a tributary of the R. Little Ouse. The flow of the Black Bourne is supplemented near the source by the outfall from the Thurston Sewage Works. The area has been extensively ditched and much is now improved grassland or wood, but there are some residual pockets of unimproved wet grassland, most notably four unimproved meadows towards the southeast corner of the Fen and a group of meadows near the northeast corner of the site. These latter have been designated as Pakenham Meadows SSSI. They are located between the Pakenham Stream and the upland margin and are subdivided by a series of deep drains.

Vegetation: Much of the vegetation of the Meadows is impoverished, coarse, damp grassland (with much *Arrhenatherum elatius*) with patches of species-poor *Carex acutiformis* and *Glyceria maxima* fen, but there are also small areas of fen meadow with *Juncus subnodulosus* (M22) and a range of associates, which include *Anagallis tenella.* Both Henslow & Skepper (1860) and Hind (1889) give records for *Schoenus nigricans* from 'Pakenham', together with some species typical of M13 vegetation and it seems likely that this type of vegetation once occurred in the general area of the fen, though it is not known if it was located in the vicinity of the current SSSI.

Substratum: The meadows are situated on a quite deep (1.5–2 m) peat. Over much of the site, this is rather dry, crumbly and amorphous but in the NW (best) patch of M22 vegetation it is relatively wet and fresh below the surface oxidised layers, with patches of marl[2]. Along the eastern edge of this stand there are localised, subsurface calcite deposits (some concreted), which may mark the location of former strong chalk springs (interestingly there is little evidence of comparable material in the drier, amorphous peat *between* the M22 stand and the fen margin). It seems very likely that these may once have been associated with species-rich calcareous fen vegetation (M9 or M13).

Water Supply: The Pakenham Stream occupies a buried valley in the Chalk, filled with sands and gravels and capped with alluvium. The Chalk rises to either side of the valley and is capped by drift (Lowestoft Till). The site is probably fed by gravitational seepage of chalk water, but aquifer levels are not known (to us). Seepage inputs appear to be substantially intercepted by the deep drainage ditches that cross the site. These are piped beneath the Pakenham stream and discharge into ditches on the western side of the valley, which flow down into the Pakenham Stream downstream. Deepening of the ditches some 20 years ago may have led to increased surface drying, but drainage damage to this site is of long standing.

The water level in the Pakenham Stream is controlled by a water mill downstream and is reported to be 'very stable throughout the year and close to ground level' (Water Level Management Plan (WLMP, 1997)) (when visited in July 1999, the water level in the stream

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[1] Judging from the density of drains, there were formerly two particularly wet areas of fen at this site, one of almost 1 km length along the SE margin of the valley, the other corresponding to the current SSSI. The 1st edition 6" OS map (1882) marks the southern part of the fen as Pakenham Fen.

[2] A rather curious feature of the peat across much of the meadows is a layer of small stones about 20–30 cm subsurface

appeared to be higher than the surface of the fen). The WLMP presumes that there is 'significant seepage of river water into the site, which maintains the water levels in low level meadows in the valley bottom', but there appears to be no direct evidence for this – indeed the rather dry character of the peat between the river and main area of fen suggests that there is probably rather little lateral seepage from the river. Thus the conclusion that 'it is important that the river level be maintained at its present height in order to supply the low lying fen meadow' may be questioned.

Conclusion: A much degraded and drained, remnant wetland site, of limited biological interest. Probably formerly with a high water table maintained by chalk water springs and seepage, the remnant 'wet' areas may still be associated with localised upwelling which maintains a summer water table well below ground level.

3.25 PASHFORD POORS FEN, LAKENHEATH

SUFFOLK: TL732835

Status**:** SSSI

Key Samples: 5

WETMECs: Type 2

Description: This site lies at the bottom of Maidcross Hill on the southern margin of a small eastern embayment of Fenland (Wangford Fen), in a transition zone between Breckland to the east, and the main Fenland basin. Wangford Fen is drained, and deep ditches adjoin the north and east margins of the residual wetland.

Vegetation: The site consists of an area of unimproved, species rich mesotrophic meadow containing a number of hollows, some of which are occupied by pockets of fen and marshy grassland. There are species-poor reed areas, but in general the herbaceous hollows are composed of a form of fen meadow (S24), but with some species (*e.g. Carex elata, Cladium mariscus*) which may be remnant from a former wetter condition (some other former 'wet fen' species, *e.g. Menyanthes trifoliata*, appear to have disappeared). In places the hollows grade out into a form of *Molinia* grassland, sometimes M24 but often a less well defined community.

Substratum: Middle Chalk is at outcrop along the western edge, wedging out towards the fen basin, where the Lower Chalk is overlain by alluvium. The alluvium comprises 3-4 m of sands with gravels overlying Lower Chalk.

Water Supply: Regionally, the Middle and Lower Chalk is the main aquifer. It is mainly unconfined and in hydraulic continuity with the overlying alluvial sands where these occur within the site and in the fen basin north of the site. Chalk groundwater discharges at a spring, at the base of the Melbourn Rock, into the ditch along the western site boundary. This has been deepened and is partly bordered by a concrete pad. The spring is reported to dry up in summer. The discharge route has been redirected, deepened and lined. The drain to the west of the site is excavated into the Chalk. It intercepts throughflow, and therefore exerts an important head control over this part of the site. Water levels in the drain are an expression of aquifer levels across the site. The alluvial sands and underlying Lower Chalk have some direct hydraulic continuity, though the relationship is not fully understood. In the vicinity of the spring, the piezometric head in the Chalk is higher than in the sand deposits, but in some other drift piezometers the levels are higher than in the chalk piezometer, suggestive of a local perched aquifer

Water levels on site are controlled by the elevation of the spring, the levels of the drains and the control boards on the drains. Some attempt has been made to support fen water levels by redirection of the springflow, but the site is nonetheless summer dry.

Conclusion*:* Site fed from a largely unconfined Chalk aquifer. Ditches appear to have much modified the original spring flow, and it is hard to assess how much the residual fen vegetation in hollows receives chalk inflows near the surface.

3.26 REDGRAVE & LOPHAM FENS

SUFFOLK/NORFOLK: TM050797

Status**:** SSSI; SAC: Waveney and Little Ouse Valley Fens; Ramsar site

Key Samples: 11

WETMECs: Type 1 (former active marginal seepages), Type 2 (peripheral seepages and main valley bottom), Type 4 (reflooded turbaries)

Description: Although these once-important fens, at the head of the River Waveney, have received a considerable amount of hydrological investigation, they have not been included as major data sources for the Wetland Framework because (a) they have been subject to considerable recent hydrological and floristic change; (b) there is even less reason to suppose some equilibrium between vegetation composition and environment than is usually the case; (c) much of the present vegetation does not form ‘good’ examples of specific community-types; and (d) rather little is known about vegetation–environment relationships in those areas least subject to hydrological change (*e.g.* Lopham Great Fen).

Vegetation: Redgrave Fen once supported some excellent examples of soligenous fen (M13), at least at the margins. In places these were mixed with vegetation containing some species often associated with rather acidic conditions, both forming a marginal strip, grading into wet heath, and as islands (or small promontories) extending into the fen. In the 1970s, marginal areas mainly supported a form of *Cirsio-Molinietum* (M24) with tall herb fen (~S25) in much of the Lopham Fens. Lopham Middle and Great Fens have retained much of their 1970s character but there is evidence of drying and species loss from the margins of Little Fen and, particularly, Redgrave Fen where the former M13 stands are now much degraded (Harding, 1993).

Substratum: The general geological character of the vicinity of Redgrave & Lopham Fens consists of Upper Chalk capped by Glacial Sands & Gravels and boulder clay. These deposits are cross-cut by a deep buried channel, which is thought to be about 1 km wide in the vicinity of the fen and which appears to represent a major pre-Anglian river, draining west to east from the English Midlands (Rose, 1991). Drainage within the former east-flowing buried channel now flows both east (R. Waveney) and west (R. Little Ouse). River terrace deposits form a narrow ridge which acts as the watershed between the two river systems, and the Redgrave & Lopham Fens are located immediately east of this, flanked by river terrace margins and forming the headwaters of the Waveney.

Most of Redgrave Fen appears to be located immediately south of the southern margin of the buried river channel. The stratigraphy here consists of River Terrace Deposits upon Glacial Sands and Gravels, forming a deposit some 10 m thick, resting directly upon Upper Chalk (Aspinwall, 1992).

Most of the Lopham Fens are situated within the buried river channel. In broad terms, the channel contains fluvial deposits (between *c.* 2–12 m thickness) underlain by glacial sands of some 5–20 m in thickness which in turn rest locally on a band (< 15m) of boulder clay overlying the Upper Chalk. Along the valley to the east-north-east the thickness of both sands and boulder clay increases. The glacial sands show considerable heterogeneity and some cores show (fairly thin) layers of silt of clay. A buried sandy ridge subdivides the Lopham fens into two unequal peat basins, the smaller (western) of which corresponds roughly with the area of Little Fen. Elsewhere 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 basins are filled with a fairly shallow depth of peat (max *c.* 2m, near the river in Middle Fen), which overlies lake marls and muds over quite large areas in the deeper parts of the basins (Tallantire, 1953, 1969; ECUS, 1995). To the northwest and southeast of the buried channel the upland is mostly covered by boulder clay.

Water Supply: The Redgrave & Lopham Fens form the source of the River Waveney and there is a discrete (dug) river channel throughout their length, originating close to the head of the system. There are two main sources of surface water: (i) Worby's drain (apparently the main surface water source), which enters the fen from the north through an embanked ditch separating Lopham Little Fen and Middle Fen, and discharges into the nascent River Waveney some 0.4 km below its source; and (ii) the main drain separating Middle and Great Fens which conveys water from field drains into the Waveney. For much of the year, water levels and flow rates appear to be very small in both drains (A. Excell, *pers. comm.*). River levels are partly determined by a retention dam currently located c 1 km downstream of Worby's Drain. There is also apparently a culvert in the river, which can be regulated, just above the point at which Worby's Drain joins the Waveney, but little seems to be known about this (A. Excell, *pers. comm.*). It appears to have fallen into disrepair and may impede drainage from the western parts of Redgrave Fen and Lopham Little Fen.

Groundwater appears to be the principal water source for much of the fen. The varied deposits of the buried channel infill much complicate assessment of groundwater inputs into the fen and different locations appear to have different hydraulic relationships with the Chalk aquifer. Modifications to the fen, principally water abstraction from a Public Water Supply (PWS) borehole close to Redgrave Fen (1957) and deepening of the R Waveney within, and downstream of, the fen[1] (1960), have contributed to a lowering of water tables across much of the site, but especially close to the PWS borehole in a location which has become known as 'The Sink'. It is correspondingly difficult to assess the 'natural' water supply mechanisms. However, recently there has been a considerable rise in water level, particularly at the west end of the site, consequent upon the closing of the PWS borehole in July 1999. A. Excell (*pers. comm.*) has observed that there has been a particular rise in water levels in an arc around the south-west margins of Redgrave Fen, extending northwards along the west edge of Lopham Little Fen, suggesting that these may be particular foci of groundwater discharge.

Redgrave Fen

In parts of Redgrave Fen, south of the buried river channel, there appears to be fairly free hydraulic connection between the Chalk and Drift (although a layer of putty chalk may

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[1] The "Catchment Board" drained the river" in 1927 (G. Crompton, *notes*), though it had probably been deepened long before then. In 1960 "The Waveney was deepened from "Great Reach" downstream in order to lower the water-table in the land known as Bressingham Fen, half a mile downstream and, after consultation ... a concrete spillway was installed at G.R. 053796, which was intended to retain the water-level in the SSSI. Since 1960 this spillway has been kept by the River Authority at a height about one foot lower than the possible maximum. The dam boards appear not to be completely watertight. It is reasonable to assume that the water-table of Great Fen and the eastern ends of Redgrave and Middle Fens have been lowered by this scheme." [F.J. Bingley & D.A. White, *Management Plan, Redgrave and Lopham Fens*, 1966] [The river is thought to have been deepened by some 3–4 ft]

constrain water flow). At least part of this site, close to the (former) PWS borehole, was once substantially spring fed. In the 1950s some marginal seepages were evident on gentle mineral and peat slopes and sustained a quite well-developed runnel system (Bellamy & Rose, 1961).

PWS boreholes were constructed in 1950 and 1954 near the edge of Redgrave Fen. The pumping station was commissioned in 1957. Fillenham (1977) reports that pumping at 1.45 tcmd in 1960 increased to 3.02 tcmd in 1967, after which it has been quite constant. In 1954 the water level in the chalk was c 1 m above the general level of the fen, being confined under artesian pressure. The level dropped by *c*. 1.5 metres (*i.e*., below the level of the fen surface). In 1976 there was a water table gradient across the fen from the NW, where there seemed to be a slight spring flow, to the S edge, where there was an evident sink. This was not centred directly upon the pumping station, but was located above the best hydraulic connection between the sands and the chalk. This may well have been an important water source when the water table in the chalk was higher.

The hydraulic continuity between the drift deposits and the semi-confined artesian Upper Chalk aquifer indicates the potential for the Redgrave seepages to be chalkwater fed. However, the actual provenance of the discharging water (in particular the proportion derived from the chalk *versus* the Drift aquifer) is not really known, but there is evidence to suggest that chalkwater is not the only water source.

Compounding difficulties of interpretation of groundwater supply to the seepages studied by Bellamy & Rose at the south west end of Redgrave Fen is the juxtaposition of wet heath habitat (with calcifuge plant species) next to calcareous fen. The acidic character of part of this area suggests that it is not much fed by chalk water, but it is less clear to what extent these characteristics are suggestive of a local, base-poor water source, perhaps juxtaposed with chalkwater, or to what extent they are simply a product of topographical variation, with the calcifuge species occurring on sandy islands elevated above the normal level of base-rich flow. Bellamy & Rose (1961) assumed this latter explanation, probably correctly, though this still begs the question of the exact provenance of the base-rich water supply.

Lopham Fens

Groundwater supply to the Lopham Fens is potentially more complex than at Redgrave, on account of the variability of the buried river channel infill. 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’. ENTEC (1998) have reported piezometric heads in the Chalk as being ‘consistently and significantly above the shallow drift groundwater levels’ in Lopham Great Fen, and assume hydraulic connection. Insufficient information is available to assess these inter-relationships in detail, but it should be noted that any hydraulic connectivity may be indirect (*e.g.* by lateral connections through sand and gravel layers within the river channel). One consequence of this is that observations that groundwater levels in the Drift below the Lopham Fens are lowered in response to a reduction of Chalkwater heads (ENTEC, 1998) do not necessarily imply that that chalkwater was an important groundwater source to the fen surface, despite the relative piezometric heads. On balance, it seems likely that some surfaces (*e.g.* Lopham Little Fen) may once have received some Chalkwater inputs whereas others (*e.g.* Lopham Great Fen) may have received groundwater inputs primarily from the Drift, but this needs further investigation. Drift water levels appear to be controlled by river levels, Below the dam groundwater levels decline towards the river (*i.e.* the river is acting as a drain), but above it, in parts of Lopham Middle Fen, there is a hydraulic gradient from the impounded river water into the fen.

It is, however, noteworthy that there have long been intimations that the site was drier than it 'should be' and that the most active seepage areas were mostly at the west end (where, perhaps, they had always been)[1]. It is difficult to interpret these observations. It is possible that Ashfield's comments may reflect the occurrence of numerous reflooded turbaries, separated by patches of part-drained fen, and that the changes noted by Geldart (1901) may reflect on-going terrestrialisation within the peat ponds. However, the observations of periodic drying are also compatible with the proposition that much of the fen surface is fed mainly from a shallow, unconfined, low-gradient Drift aquifer which was rather responsive to rainfall events (ENTEC, 1998) rather than from a strongly artesian chalkwater supply. It seems possible that strong, soligenous seepages may always have been localised in the fen, perhaps to the fairly small area of Redgrave Fen where they were described by Bellamy & Rose (1961), and that much of the rest of the fen had a less consistent groundwater supply. Whilst conjectural, this suggestion is compatible with the (rather sparse) historical species records.

Conceptual Development of the Wetland:

In their 'natural' state (*i.e.* before drainage occurred at the site, or lower down the Waveney valley) Redgrave & Lopham Fens appear mainly to have comprised a wet, topogenous basin with high water levels maintained by Drift groundwater inputs, supported by a high (artesian) Chalk water table and by impeded drainage downstream, with some marginal seepages, fed by Drift and Chalk water.

In the early post-glacial period there were large, shallow, marl-precipitating lakes, but these developed hydroserally into swamp and fen which coalesced with similar non-hydroseral wetland that was developing on the wet valley floor and on seepage terraces, in the process probably helping to impede drainage further and elevate the water table. During much of their developmental history, the fens consisted mainly of a patchwork of swamp, sedge-rich (probably quaking) fen and scrub[2]. For much of this time there may well have been just a broad axial water track flowing through the fen rather than a discrete river channel, especially in the upper part of the site, and the fen was essentially a large, wet topogenous seepage complex, with both lateral and vertical flow, representing mainly a form of Seepage Percolation Fen (WETMEC 4), with localised marginal Permanent Seepages (WETMEC 1) and (perhaps more widespread) Intermittent Seepages (WETMEC 2).

Improved drainage, both direct and downstream, during and before the 19th century, caused some reduction of water levels – at least seasonally – over much of the fen basin, particularly by reducing the groundwater head in the Drift. Much of the fen then became an Intermittent Seepage system (WETMEC 2) and permanently surface-wet conditions persisted only in some badly-drained patches and in some marginal locations where there were permanent seepages (mainly parts of Redgrave Fen and, probably, Little Fen). However, turbary created

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[1] Ashfield (1861): "..a considerable tract of marshy and fenny land, in some places tolerably dry, and in others abounding in pools of water, from a few inches to several feet in depth, known by the name of Lopham Fen and situated partly in Norfolk and partly in Suffolk."

Geldart (1901): "Marshes near the source of the Waveney are the best known habitat of *Malaxis paludosa* and still yield *Liparis loeselii* - these marshes have become distinctly drier and the number of individuals of the rarer plants, although not perhaps the number of species to be found in them, has diminished within the writer's experience."

A.G. Tansley & A.S. Watt (*Site Report*, 1949): "Little Fen and Redgrave Fens are good mowing fens, but the surface was very dry (possibly due to the weather)".

E.A. Ellis (*Site Report*, 1950?) "Westward side is extremely important. Best place for *Liparis* in the county [presumably Norfolk ?]. Very rich fen. It appears to have suffered recently from lowering of water table to the detriment of the lower Redgrave Fen area in the past ten years."

[2] There is no reason to suppose that "hydroseral succession to carr woodland was prevented by the mowing of reeds and turbary" as is claimed in 'Wetland Site Dossier' (University of Birmingham)

a series of small hollows, which on abandonment effectively became shallow-flooded seepage basins, thereby recreating patches of Seepage Percolation Fen (WETMEC 4). The now-distinct river came to function primarily as a drain, but may still have sourced some occasional surface-water flooding in the lower parts of the fen. This state persisted until about the 1950s, after which further deepening of the river and groundwater abstraction caused catastrophic drying.

Conclusion:

The former M13 areas in Redgrave Fen occupied a permanent seepage face in part of the fen which had apparent direct hydraulic connection with a semi-confined, artesian chalk aquifer, though the actual contribution of chalkwater to the seepages is uncertain. Drift water may also have made a important contribution to the seepages, and is probably the main groundwater source for much of the fen. Surface water inputs may be significant, especially as a dam on the R Waveney maintains high water levels, creating the potential for flow from the river into parts of the fen, but the quantitative importance of this does not seem to be known.

3.27 ROYDON COMMON

NORFOLK: TF685225

Status**:** SSSI; SAC: Roydon Common and Dersingham Bog; Ramsar site

Key Samples: 3

WETMECs: Type 1 (lower seepage slopes and water tracks), Type 2 (upper seepage slopes)

Description: A system of shallow valleys containing acidic fen within a heathland complex. Much of this site is heathland but most of the botanical interest rests within a 'Y'-shaped valley mire, draining southwards. The main area of mire (the 'SW bog') is a flattish area below sandy slopes on the west side of the main drainage axis, just north of the track that forms the southern boundary of the site.

Vegetation: The mire shows a characteristic (though sometimes discontinuous) zonation of vegetation-types from dry heath – wet heath – valley 'bog' – more base-rich fen. This latter is represented by species-poor *Molinia–Myrica* dominated vegetation and a richer *Schoenus* community of the axial water track {~M14}; and fen carr (mostly birch-dominated). There are also areas of fen meadow with both *Juncus acutiflorus* and (more locally) *J. subnodulosus* as important species. Large areas of dry *Calluna* heath on acidic sands are also present.

Substratum and Water Supply: The mires are underlain by Sandringham Sands, upon a Kimmeridge Clay aquiclude. The aquifer is unconfined in the vicinity of the mire and it is in hydraulic continuity with overlying sand & gravel in the valley bottom, and, in the east, with the Carstone fissured aquifer. Groundwater flows southeastwards and discharges out in the low-lying southern and southwestern parts of the site.

It is not clear to what extent the fen is fed by a single water source. It is clear that the water quality of the drainage axis (M14a) is different to that of the seepage slopes (M21b):

Community	Water pH	Conductivity ($\mu S\ cm^{-1}$)	Alkalinity ($mg\ l^{-1}$)	Water Level (cm)	Soil pH	Fertility (mg phytometer)
M14a	6.52	374.5	168.36	5.2	6.78	5.31
M21b	5.24	217.53	31.6	-5.2	5.44	4.53

Possible explanations for this include:

- variation in water quality within the Sandringham Sands
- M14 represents a permanent seepage face fed by primarily by the Sandringham Sands but M21b is in an area of intermittent seepage, with precipitation having a greater ecohydrological rôle.
- water quality along the drainage axis is influenced by variation of the lithologies in parts of the substratum; these may include deposits of boulder clay which are reported to the east of the main mire and which may underlie it to some extent. [The Kimmeridge Clay appears to be too deep below the mire to influence its water chemistry.] This is possibly the most likely explanation, and one which is compatible with tentative explanations for similar conjunctions of base-rich and base-poor fen at Buxton Heath and Holt Lowes.

Conclusion*:* Permanent seepage face (valley bottom), forming a water track, and intermittent seepage (lower slopes) fed primarily from an unconfined Greensand aquifer. Some base enrichment to the lowest seepage zone, but the cause of this remains to be established.

3.28 ROYDON FEN

NORFOLK: TM102797

Status**:** Non-SSSI (SWT Reserve)

WETMECs: Type 2

Description and Vegetation: A rather 'scruffy', dry fen, developed in a small embayment in the valley slopes alongside the R. Waveney. It comprises a large area of scrub-invaded, species-poor sedge beds (in the centre and towards the east margin) with some peripheral species-poor reedbeds in areas that seem to been either disturbed or enriched. Some quite deep hollows are scattered seemingly haphazardly through the sedge beds and may represent former peat pits, though their vegetation is mostly little different to that of the adjoining, higher fen. There is a small area of quite rich *Cirsio-Molinietum* (M24) vegetation, in the southeast corner, probably associated with some degree of (subsurface) groundwater input. The site is surrounded by impoverished fen woodland, mainly of ash, alder and willow. This occupies much of the western part of the site.

Substratum: The fen lies in an area predominantly covered by the boulder clay deposits of the Lowestoft Till, on the northern slope of a valley which cuts through this chalky boulder clay cover into deposits of glacial sands, which help fill a buried valley that parallels and underlies the course of the present river. They are underlain by Upper Chalk and capped by a shallow layer of alluvium.

Water Supply: Upper Chalk and overlying sand and gravel form the main aquifer. They are unconfined, although outside the site the overlying boulder clay forms a potential aquitard. Groundwater from the Chalk, via the sand and gravel, feeds the superficial alluvial deposits. Putty chalk may impede upward flow, but it is considered that the chalk has good hydraulic connection with the sand and gravel and the surface alluvium. Observed seepages are an expression of both upward and lateral groundwater flow.

Drains connect the site with the nearby R. Waveney, and these drains, and others in the drained areas of adjoining land, may help determine the water level of the fen. It is not necessarily much fed by river water.

It is difficult to assess the current importance of chalk water to surface conditions at this site, partly because of lack of topographical data heterogeneity. It appears that the current head of chalk water may typically be subsurface – the site is summer dry. It is important to recognise that this site was once a good deal wetter than it is now, with a species complement comparable with that of such 'good' sites as Badley Moor and Scarning Fen, suggesting that the surface was once fed by strong chalk water inputs – though unlike these two sites, much of the former interest here may have been in reflooded peat workings. The existence of (former) strong spring inputs may also account for the persistence of this fen (as Poor's Land) in the middle Waveney valley – where adjoining parcels have been reclaimed. It is not clear how localised groundwater discharge would have been within this site, though there seems to be a general view that there would be more widespread upwelling of chalk water here than at, say, Redgrave Fen. There seems to be little doubt that, although smaller than Redgrave & Lopham Fen, this site once (1946) had comparable floristic diversity, but this may have been lost earlier than at Redgrave. The cause for loss is not certain – dereliction in combination with drainage seem the most likely explanations (the river is thought to have been deepened by some 3–4 ft in the early 1960s).

As at Redgrave, there are allusions to the past occurrence of more base-poor conditions, at least locally, in some of the species records. It is possible that there may once have been a zone of wet heath / poor fen along the upland margin, in much the same way as seems to have been the case at, for example, the nearby Redgrave and Lopham and Hinderclay Fens. The hydrological basis for this can only be speculated upon. As at Redgrave, one possibility is lateral flow from a local aquifer in adjoining decalcified sands and gravels, but base-poor conditions could also be produced by rain-fed sands and gravels supported by base-rich groundwater without any need to invoke an independent groundwater source.

3.29 SAWSTON HALL MEADOWS

CAMBS: TL492491

Status**:** SSSI

WETMECs: Type 2

Description: Sawston Hall Meadows SSSI is situated approximately 100 m south-east of Sawston, Cambridgeshire in the area of land between the River Cam (*c* 1.5 km distant) River Granta. The higher ground of the Chalk hills rises to the south-east of the site.

Vegetation: The site comprises a fairly small area of fen grassland in the grounds of Sawston Hall. The meadows are surrounded by woodland, some of which overlays or surrounds tall fen vegetation, especially in the SW area. There is a series of ditches extending through the site, some derelict. These contain several of the fen species recorded (*e.g. Cladium mariscus*).

Substratum and Water Supply: The site stratigraphy consists of peat over Middle Chalk (lying at only 0.5-1m bgl). The Melbourn Rock hardground lies approximately 10 m below the meadows. The Chalk aquifer is unconfined, except perhaps for slight local restrictions caused by peat and silty alluvium. As the water table fluctuates (with rainfall), groundwater underflow is intercepted by ponds and ditches within the site, and at Lady's Wash Spring, to the south. However, there seems to be little known about the hydraulic connection between the chalk aquifer and the surface peat.

There is undoubtedly spring discharge into some of the ditches through this site, but it is not known to what extent the former fen surface is fed by chalk water. As the ditches are not thought to overflow, it seems likely that the surface is primarily fed by precipitation, presumably supported by chalk water, with water tables fluctuating (rather considerably) in response to changes in the chalk water level. This raises the question as to whether the surface was ever fed by chalk water or whether the present 'meadow' water conditions are essentially those which have always occurred. There is not much evidence for this one way or the other, but the presence of oxidised peat over (at least part) of the site is suggestive of wetter conditions in the past, and it is not obvious that there are alternatives to a chalk water source. The site has strong vegetational similarities to Chippenham Fen and raises some similar questions about likely water supply mechanisms.

The former rôle of the ditches on this site is of some interest and relevance with regard to likely water supply mechanisms. Gilman (1986) considers that the ditches within the SSSI were part of an irrigation system, which once received water from a large spring (Lady's Wash, TL 493489), *via* a ditch which also supplied fishponds in the Hall grounds. This source is no longer available as a culvert connecting the ditch to the meadows is blocked. Gilman's study was made, however, without a quantitative appraisal of the relative ground levels and it is not known why he concluded that the ditches were for 'irrigation'. The use of (and need for) ditches for 'irrigation' implies that the meadows were not naturally very wet, but the occurrence of up to 50 cm of (now strongly oxidised) peat is suggestive of a formerly wet site, and raises the possibility that the 'irrigation ditches' were actually drains. It is, of course, possible that the ditches were dug primarily to feed to fishponds and did not specifically irrigate (and perhaps drained ?) the meadows through which they passed. Some simple topographical measurements at this site would be instructive.

Conclusion: Meadows fed primarily by rainfall supported by a normally sub-surface unconfined chalk water aquifer and subject to considerable water level fluctuations. Ditches are spring fed by chalk water and support most wetland interest.

3.30 SCARNING & POTTERS FEN

NORFOLK: TF983121

***Status*:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 10

WETMECs: Type 1 (seepage areas and water track), Type 2 (peripheral seepages)

Description and Vegetation: This site occupies a shallow valley bordering the southwest edge of East Dereham, alongside a small stream. Scarning Fen essentially consists of a gentle seepage slope, mainly of M13 vegetation, but grading upwards into M24 vegetation. The seepage water runs down to a swampy sump / water track. Potters Fen also supports M13 and M24 vegetation, but does not show the clear zonation of communities as does Scarning Fen. It is also more obviously disturbed by past peat cutting.

Substratum and Water Supply: The valley is floored by peats and riverine sands overlying approximately 20m of Lowestoft Till upon Upper Chalk. Chalk provides the main regional aquifer, semi-confined by overlying Boulder Clay, which acts as the regional aquitard, though it can contain water-bearing sand layers which form minor discrete aquifers. Thin, discontinuous alluvial sand / sand and gravel aquifers are perched on the Boulder Clay, but these may be only seasonally saturated (HSI-ECUS, 2000). Montgomery-Watson (1999) consider that "The thin Boulder Clay aquitard unit at the site is probably locally absent, removed by river erosion processes in the past and is therefore an ineffective aquitard layer", but this view is not shared by HSI-ECUS (1999) (who suggest low permeabilities of *c.* 10^{-3} – 10^{-4} in the vicinity of the fen) and it is not known on what evidence it is based. The chalk water head is well above the surface of the seepage slopes and Montgomery-Watson (1999) suggest that "Groundwater seepage at the site and seepage into the site stream and drains are sustained by upward flow from the Chalk", probably *via* glacial sands and gravels adjoining the site. By contrast, HSI-ECUS (1999) consider that "Chalk upward flow, though it may have a supplementary rôle, does not appear to constitute the main source of water to the wetland" – rather they suggest that "Groundwater seepages are most probably supported by lateral flow from the Boulder Clay aquitard and alluvial sands, with contributions of upward flow from the Chalk". This view is based partly on calculations of upward flow from the Chalk, which suggest that this "is insufficient to sustain the fen seepages and ponded areas". However, the results of these calculations are critically dependent on the permeability assumed for the boulder clay, but the actual values of this beneath the fen seepages are not known – the possibility of very localised high permeability pathways (as at the nearby Badley Moor, but perhaps not as transmissive) cannot be discounted. Moreover, there is evidence for a gradual increase in chalk water head from 1996 to 1999. Hydrochemically, the importance of supply from the chalk may be indicated by the abundant dispersed calcite at the surface, though rather unusually for an M13 site, these seepage slopes are also rather ferrugineous, presumably reflecting the influence of the drift. It is clear that existing data do not permit a rigorous assessment of the relative importance of Chalk water *versus* supply from the Boulder Clay and this requires re-examination. On balance, we suspect that chalk water may be the main water source, with some contribution from the drift.

The uppermost part of the main seepage area on Scarning Fen is marked by a zone of wet grassland and rather dry fen meadow, where the water table is always sub-surface or shows intermittent seepage. It is not known to what extent the characteristics of this zone depend upon periodic highs of chalk water discharge *versus* intermittent supply from the phreatic unit.

Surface water inputs are limited and seem to have little relevance to the hydrological functioning of the site. The stream flows through the site and probably has little water supply function, though it presumably provides some drainage and may cause localised flooding in winter (when it may be contaminated with sewage-enriched stormwater. The Dereham by-pass to the north of the fen appears to impede the surface drainage of the discharged groundwater.

Conclusion: Area of primary interest is a sloping permanent seepage face, probably fed by artesian chalk water, with some contribution from the drift but the relative contribution of these two sources is uncertain and unestablished.

3.31 SHERINGHAM & BEESTON COMMONS

NORFOLK: TG164424

Status: SSSI; SAC: Norfolk Valley Fens;

WETMECs: Type 1 (Seepages and water tracks), Type 2 (peripheral seepage slopes)

Description: This site comprises two contiguous commons occupying the bottom and sides of a heathy valley between Sheringham and Beeston Regis, situated approximately 1 km south of the Norfolk coastline. The commons lie between housing estates to the east and to the west; the A149 Cromer Road marks the northern boundary. Anglian Water Services' Sheringham Waterworks is located adjacent to the southwestern corner.

Vegetation: Water tracks through the site are sometimes lined with a *Schoenus* community, with flanking fen meadow (often *Juncus subnodulosus*-dominated), but in the main valley much of the main drainage axis is occupied by fen meadow (M22). There are also *Schoenus* stands on seepage slopes lateral to the water tracks. In the SW part (Sheringham Common) a small spring mound, made up from inwashed silts and sands, with some marl, forms a spur-like extension from the valley side into the mire and supports species-rich soligenous fen vegetation. There are also two areas of reed, with carr invasion. All of the wetland interest is developed on shallow (usually < 50 cm) peat. The rest of the site comprises thickets of gorse and bramble, with some birch/oak woodland, and grassy heath, with patches of bracken. The *Schoenus* stands support an interesting mix of basicolous and more acid-tolerant plant species, similar to that found at Buxton Heath and (especially) Roydon Common, but more intimately mixed here. The precise syntaxonomic status of this vegetation requires resolution. Although related to M13 vegetation, the acidophiles differentiate these stands from normal examples of this community, and it may perhaps be best regarded as intermediate between M13 and M14. With the exception of the water from the spring mound, measured alkalinity values are below those typically associated with spring-fed fens, though they are not as low as those recorded from Buxton Heath or Roydon Common.

Substratum and Water Supply: This site consists of wind-blown sands underlain by Contorted Drift, Crag and Upper Chalk. The wetland site appears to be fed by water from the sand phreatic aquifer. There are discrete springs, which often form the head of the small streams, and seepage slopes. It is considered that there is little hydraulic connection between the phreatic aquifer and the Crag/Chalk, though there may be some potential for downward leakage. Present chalk piezometry suggests that Chalk water levels are well below the surface at the site (HSI-ECUS, 1998). However, Montgomery-Watson (1999) suggest that there are also local springs from the Contorted Drift, and raise the possibility that "The Contorted Drift receives recharge from rainfall adjacent to the site, and upward leakage from the Chalk & Crag aquifer to the south of the site". The available data suggest that most, or all, of the site is unlikely to be fed with chalk water but that the water is derived from the phreatic sand aquifer and the contorted drift. The spring mound in the SW of the site is likely to be fed from the Contorted Drift, but the possibility of an indirect chalk water contribution to this cannot be discounted. The proposition of two separate water sources, one base-poor from a phreatic aquifer and one more base-rich from the Contorted Drift provides a neat explanation of the observed ecological characteristics of the site (Table SB_1).

Conclusion: Main areas of key ecological interest are permanent seepages fed from drift aquifers.

Table SB_1. Some hydrochemical data from Sheringham & Beeston Commons (December 1999)

	pH	Conductivity µS cm^{-1}	Alkalinity mg l^{-1}	Location
S1a	7.0	918	650	Spring mound in SW of site (Sheringham Common)
S1b	7.15	917	552.5	[substratum contains some marl]
B1a	7.2	747	377	M14 – axis of upper valley (Beeston Common)
B1b	7.2	756	360	
B2a	6.8	792	280	*Schoenus* area on seepage slope (E sloping side of Beeston Common)
B2b	6.75	637	208	

3.32 SOUTHREPPS COMMON

NORFOLK: TG263351

Status**:** SSSI; SAC: Norfolk Valley Fens;

Key Samples: 4

WETMECs: Type 1 (very localised), Type 2 (main seepage slopes)

Description: A small area of fen alongside the Fox's Beck (a feeder stream for the R. Ant). Fen vegetation occurs on both sides of the stream, but the best examples are on the gentle slopes on the SW side of the stream.

Vegetation: Although small, this is a surprisingly diverse site, supporting reedbeds, rough grassland, tall herb fen, fen meadow and small patches of strongly flushed vegetation, often forming a close mosaic. The taller vegetation, and patches of carr, occur mainly alongside the stream. The SE (now regularly mown) sector of the site is the most diverse and has an abundance of *Epipactis palustris* and *Gymnadenia conopsea* (including a peloric form). A small patch of very open vegetation here, with *Carex dioica* and *Eleocharis quinqueflora* (and referable to M13, but without *Schoenus nigricans*), has persisted despite past dereliction. This patch is close to rather vigorous reedbeds, the latter developed on fertile silts rather than the infertile gravels of the open patch, but the origin and basis of this rather curious juxtaposition is not known.

Substratum and Water Supply: The site is situated upon thin peat (to about 0.6 m depth) underlain by silty loams and sands, followed by sand and gravel. These overlie Contorted Drift, upon Crag and then Upper Chalk. At Borehole TG23/52, almost 1 km west of the fen, 14 m of Contorted Drift are underlain by 29m of Crag. The Contorted Drift is thought to be in hydraulic continuity with the Crag and the two deposits may act as a single hydraulic unit, semi-confining the Chalk aquifer below, and probably providing the main water source for the fen. Chalk water levels are thought to be 2 m or more bgl.

The fen is undoubtedly primarily groundwater fed, but consistently high water conditions are only known from a tiny, low growing area. An area immediately below the SSSI, which supports rather low-grade fen meadow vegetation, has numerous drains, but the SSSI itself is not obviously drained, except for the axial, channelled stream, although there is a small ditch running NE-SW on the north-east side of the beck. There are no obvious land-drainage inputs and the site is not known to be subject to flooding from the stream, except perhaps in extreme circumstances.

Conclusions: A small area of ± permanent seepage, otherwise intermittent seepage slopes, fed primarily from a combined Contorted Drift / Crag aquifer.

3.33 SWANGEY FEN

NORFOLK: TM015932

Status**:** SSSI; SAC: Norfolk Valley Fens

Key Samples: 3

WETMECs: Type 2 (upper seepage slopes), Type 7 (main sump and floodplain)

Description: Swangey Fen is situated in a shallow valley in the upper reaches of the River Thet, 3–4 km south-west of Attleborough, Norfolk. Higher ground rises to the north-east and south-west. The site includes the flood-plain area adjacent to the river, a broad sump immediately N of this, which leads up to the gentle northern slopes.

Vegetation: The northern slopes primarily support rather species-poor sedge beds (*Cladio-Molinietum*), but there are small patches of lower-growing vegetation (mainly near the top of the seepage slope). The floristic identity of these is rather difficult to assess. They are rather species-poor and are perhaps best referred to *Cirsio-Molinietum* (M24), but they may be derivative from either M13 or M9 (or both). The vegetation of the sump area is primarily *Peucedano-Phragmitetum* (S24), that nearer the Thet, and along the E margin is a coarse mix of *Angelico-Phragmitetum* {~S25}, *Peucedano-Phragmitetum*, *Glyceria maxima* sociation, *Phragmites-Urtica* fen and tall herb fen. There is also considerable scrub invasion.

Substratum and Water Supply: Upper Chalk comes close to the surface in the vicinity of the fen, covered by just a few metres of drift near the north edge, though regionally it is confined by boulder clay. A deep buried channel to the south of the site is filled with thick boulder clay, which confines the chalk. This thins northwards, but HSI-ECUS indicate that it extends beneath much of the fen and may effectively prevent upward leakage in these areas. There is, however, evidence for seepage along the N edge of the fen where thin drift sands, layers of sandy clay, and peat overlie the chalk aquifer and are in hydraulic continuity with it.

The piezometric head of chalk and drift water in the piezometers above the fen (by the car park) is well below ground level, but consistently above fen levels, but the mean head in the drift piezometer at the top of the fen (202), which seems similar to that recorded by nearby dipwells, is 33.6 cm bgl (and is considerably lower in dry periods). However, it is not known how representative 202 is of the conditions elsewhere, especially lower down, in the upper part of the fen.

The site has a large surface water catchment area which lies to the north of the site and is predominantly covered with Lowestoft Till. Runoff from this may recharge the drift aquifer. The River Thet is important in controlling summer water levels at the site and may provide some inputs through winter flooding to the riverside and, particularly, sump communities. However, anecdotal reports suggest that river flooding may be limited, but there may be substantial inputs of surface water introduced from fields to the east of the fen. Such flooding episodes can result in the lower parts of the fen being inundated (50 cm +) for much of the winter and spring.

Conclusion: Fed by chalk water seepages along the north slope. The central fen is probably fed mainly by lateral flow from these, together with substantial surface water inputs in winter. Seepage flow may be insufficient to maintain wet conditions in the lower part of the fen during the summer, and even the upper seepage zones tends to become summer-dry.

3.34 SWANNINGTON UPGATE COMMON

NORFOLK: TG149181

Status**:** SSSI

WETMECs: Type 1 (localised on upland slope); Type 2 (sloping margins and part of valley bottom); Type 3 (isolated ground depressions); Type 4 (localised, well flushed depressions on valley bottom at east end of site).

Description: A heathy site on glacial sands and gravels near the head-waters of a small tributary stream (Alderford Beck) of the R Wensum. Much of the area is scrub, bracken, rough grassland and dry heath, but at the eastern end there is an area of wet heath leading down, through seepages, to an extensive area of fen. This latter is developed on the flat valley floor and contains several extensive, and sometimes coalescing, depressions separated by narrow ridges. There are also some small, isolated depressions with pools within the heathland further west.

Vegetation: Most of the vegetation in the eastern part is a form of fen meadow, with much *Juncus subnodulosus*. Some of this tends to be rather acidic in character with patches of *Erica tetralix*, *Sphagnum* spp, *Hypericum elodes etc*. *Molinia* grassland occurs on ridges. Swampy depressions contain *Potentillo-Caricetum rostratae* (~S27) and, very locally, *Cladium* 'swamp' (S2). The adjoining slopes support some seepages, with more acidophilic species such as *Carex demissa* and, locally-extensive, *Sphagnum* mats. *Potentillo-Caricetum* also occurs (in an impoverished form) in some of the depressions towards the west of the site.

Substratum and Water Supply**:** HSI (Site Monitoring Report) suggest a site stratigraphy of chalk covered by thin superficial clays and silts. They recognise that these, together with putty chalk may impede upward flow of chalk groundwater, but nonetheless consider this to be the main source of water to the site. However, the chalk borehole (and the accompanying geological section) is located at the west end of the site and the main area of fen interest is almost 1 km east of this. The deep stratigraphy of this eastern area is not known in detail (the drift piezometer located here terminates downwards in 'firm grey clay'). Interpretation of the piezometric data, in terms of fen water conditions, is difficult on account of the absence of detailed topographical data. It seems likely that the piezometric head of chalk water measured in the west of the site is below, or only occasionally above, the surface of the main eastern fen area, whilst the head of water in the drift at the east end of the fen is well (1m +) above the fen surface. However, as the chalkwater flow is from NE–SW it is likely that head beneath the eastern fen is higher than that measured in the west. In the absence of deeper sections and chalk water measurements in the east of the site, it is impossible to conclude much about the likely sources of water here, but on the basis of (a) the absence of any demonstration of hydraulic continuity in this area; (b) the fact that various boreholes in the vicinity of the site indicate thick accumulations of clays; (c) the high head of drift water adjoining the fen; and (d) the undoubted inputs of relatively base-poor water from the drift into the fen[1] we see little evidence not to accept the proposition of the Birmingham dossier that this part of the fen is fed primarily by drift water. However, this does not exclude the possibility of some mixing with chalk water or that chalk water has an important rôle in supporting the fen water table.

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[1] The seepage slopes adjoining the main 'pan' area of fen at the eastern end support many acidophilic species (including an abundance of *Sphagnum*) and are almost certainly fed by lateral flow of base-poor water from the drift. Although it contains some acidophilic species, the floristic composition of the main pan area does not permit an unequivocal assessment of water sources. However, it supports one of the (very few) Norfolk examples of the M29 *Hypericum elodes–Potamogeton polygonifolus* soakway community (which has its headquarters in the acidic mires and heaths of the New Forest and SW England) and which is never normally associated with chalk water supply. Such considerations suggest that there is a particular need for more detailed studies at this site to determine the provenance of the irrigating water.

It may be noted that, within the main 'flat' area of the fen, vegetation composition shows only limited variation, and this is primarily in response to small topographical changes – there is little or no reason to suppose that contrasting water sources differentiate the vegetation cover in this part of the fen. However, the seepage slopes adjoining the fen are undoubtedly more base-poor than the main fen bottom. Presumably it is possible either (a) that there is very limited (if any) input of chalk water into the fen, and that the more base-rich conditions encountered in the main valley-bottom area reflect either different sources of drift water or the consequence of base-poor drift water discharging onto a comparatively base-rich valley-bottom substratum; or (b) that the chalk water helps support, or becomes much mixed with, drift water in the topogenous part of the fen.

Conclusion: The uncertainties about this site are such that it is difficult to reach any firm conclusions. The seepage slopes at the east end of the fen are almost certainly fed by drift water, but the status of the main fen area there is unresolved. It is not a foregone conclusion that this area is fed by chalk water and further investigation would be desirable.

3.35 THELNETHAM FENS (OLD FEN AND WEST (MIDDLE) FEN)

SUFFOLK: TM0178

Status**:** SSSI: Blo'Norton & Thelnetham Fens; SAC: Waveney and Little Ouse Valley Fens

Key Samples: 2

WETMECs: Type 4 (small patches near land margin); Type 5 (most of site)

Description: These fens are situated between Blo' Norton and Thelnetham near the head of the westerly flowing Little Ouse. This mire system has developed just over a mile from Redgrave–Lopham Fen but is separate from it. The Thelnetham fens lie on the south side of this shallow broad valley. They comprise two subsites: Thelnetham Old and Thelnetham West (or Middle) Fen.

Substratum and Water Supply: The fens are situated in an area of Upper Chalk predominantly covered by partially confining Lowestoft Till (boulder clay). This Till may contain sand lenses and varies in thickness from 10–50 m. Glacial Sands, river gravels and alluvium floor the east-west trending valley. Over much of the site the peat is underlain by sand/sand & gravel, but there is local confinement within the site by a boulder clay aquitard. Tallantire (1969) provided evidence for a late-glacial and post-glacial lake underlying parts of both Blo' Norton and Thelnetham Fens, crossed by the present course of the R Little Ouse. Borings showed *c.* 2m *Cladium* peat; upon 0.5m calcareous lake muds; upon a sand horizon (of variable depth); upon <4m of silty lake muds, becoming less silty below; underlain by a thin peat bed (Zone II ?). These marl lakes terrestrialised and became covered with fen peat. The peat (and marl) deposits may help reduce upward flow of groundwater.

Thelnetham West Fen is separated from the river by drained farmland (a peaty meadow) but the Old Fen extends from the upland margin to the river. In some cases, the reclaimed areas may be topographically higher than the fens, but this is not necessarily the case. It seems likely that the pattern of agricultural use may reflect the natural pattern of groundwater discharge, with the two Thelnetham Fens (and Bugg's Hole further west) being left as Poor's Land in locations subject to strong discharge and which were particularly difficult to drain.

HSI conclude that the peat is primarily fed by rainfall with a minor proportion of upward recharge, but the maximum head of chalk water recorded is now about 1 m higher than was observed at the time the piezometers were installed.

In Thelnetham West Fen it seems likely (on the basis of observed water levels across the sites) that the main input of groundwater is near the upland margin of the peat. The rate of transfer of groundwater through the peat infill towards the river is not known, but it is possible that shallow peat cuttings may have provided a preferential path for surface or subsurface flow. The point of upwelling of groundwater into the Old Fen is less clear. There are considerable depths of clay recorded from the borehole cluster near the upland margin, but it is not known how laterally extensive these are – they may not occur nearer to the river. Bellamy & Rose (1961) report that the centre of the site was (then) a floating fen mat upon a watery marl (as distinct from the shallower solid peats along the land margin and the deeper solid peats alongside the river). They interpret the floating, watery area as a product of impeded drainage consequent upon robust embankment of the river, though do not indicate how this would have prevented lateral drainage into the system of ditches and the proposition seems implausible. Wheeler & Shaw (1992) suggest an alternative explanation could be that this was a former turf pond, though with an apparent depth (in 1961) of 1.5 m it would have been deeper than most examples of these. It is possible that this area represents the main site of groundwater discharge (instead of, or additional to, the turf pond hypothesis).

Conclusion: These appear to be rheo-topogenous fens which have, in part, developed serally over former lakes. Their high water table is maintained by groundwater (including chalk water) inputs and impeded drainage. Deepening of the river, and/or drainage of intervening land may have led to a lowering of water tables, especially away from the main discharge areas, and an increased importance of precipitation inputs.

3.36 THELNETHAM FENS (BUGG'S HOLE FEN)

SUFFOLK: TM006792

***Status*: SSSI**

Key Samples: 2

WETMECs: Type 2 (southern seepage slope), Type 5 (main fen area)

Description: Bugg's Hole Fen is a rather long and thin fen unit situated along the southern edge of the shallow, broad valley of the Little Ouse River, approximately 1 km downstream of Blo' Norton and Thelnetham Fens. The fen lies at a distance of about 250 m from the river and is rather isolated from this, being separated by an agricultural field. A wide ditch along the N edge of the fen separates it from the adjoining field. Higher ground lies to the south of the area, and a short but quite abrupt, former seepage, slope leads up from the fen to the road.

Vegetation: Much of the site is rank vegetation dominated by *Cladium mariscus* and *Phragmites australis. Schoenus nigricans* occurs along the southern edge but also – and contrary to some descriptions of the site – occurs rather widely throughout the sedge beds, especially towards the eastern end, as part of a *Cladio-Molinietum* community. The slope above the southern edge of the fen is said to have once supported species-rich soligenous fen vegetation, but this no longer appears to be the case – this strip is now rather dry, coarse grassland.

Substratum and Water Supply: Rather little is known about this site. Its hydrogeological context is probably similar to that described for the Thelnetham Fens (*q.v.*) higher up the valley. At the southern edge, the peat is shallow (*c.* 30 cm) and upon sand, whilst near the northern drain it is not much deeper (*c.* 50 cm) but caps apparently thick lake marls. It seems likely that the marls may provide considerable resistance to upward flow of groundwater, and inputs may have been primarily along the southern edge, from whence past seepage has been reported.

Even the bottom part of the fen is now rather dry in summer (a water table of between 30 and 50 cm bgl was recorded in July 1999). The water table may be largely controlled by the water level in the drain adjoining the northern margin (which has recently been cleared (and deepened ?)), but it is not known if other influences have contributed to a water table reduction.

Conclusion: a partly drained, rheo-topogenous fen, which has developed in part serally over former marl lakes. A fairly high water table is maintained by groundwater (including chalk water) inputs (along the southern margin) and by impeded drainage. Deepening of the river, and/or drainage of intervening land may have led to a lowering of water tables, especially away from the main discharge areas, and an increased importance of precipitation inputs.

3.37 THRIPLOW MEADOWS

CAMBRIDGESHIRE TL438469

Key Samples: 2

WETMECs: Type 2

Description: An area of rough grassland, some marshy, developed near the head-waters of a small stream draining north from Thriplow[1] village, occupying a hummocky area of former ground ice depressions which provide a juxtaposition of marsh and freely draining soils.

Vegetation: Originally three land parcels were included within the area of interest and the SSSI. The "eastern" meadow, east of the stream, has been ploughed and reclaimed and has lost most of its wetland interest. The two meadows ("northern" and "southern") to the west of the stream have also apparently been subject to some former cultivation, but retain grassland and marsh vegetation. As its name suggests, this site is perhaps best seen as wet meadow rather than fen. It did once support a form of fen meadow (M22) vegetation, though former examples of this present in the 1960s have since been considerably replaced by tall herb vegetation and, on the drier slopes, the once relatively rich grassland has similarly become more coarse. Although apparently never of great floristic value, except in a local context, the site has supported a few uncommon fen species (e.g. *Anagallis tenella, Blysmus compressus*).

Substratum: The site is located upon chalk (Burwell Rock), capped by a layer of frost-shattered material (putty chalk), varying in thickness between about 2 and 12 m and forming a low permeability layer beneath most of the meadows. Undisturbed chalk forms the rising slopes to the east of the site. The hummocky topography is associated with considerable variation in surface conditions, with peat depth varying from negligible to about 1.5 m.

Water Supply: The main aquifer beneath the fen is chalk and investigations made in association with a proposed sub-irrigation system (Anglian Water, 1982) show a chalk water gradient from S–N/NE. The piezometric head of chalk water is shown as being slightly (*c.* 20–30 cm) subsurface in the lower-lying areas in September 1981 (considered to be slightly higher than average).

The site has been partly drained. The stream through the site was formerly situated to the west of the present, rather straight channel (dug at Enclosure) and there are remnants of ditches within the meadows. The history of cultivation points to the occurrence of at least patchy dry conditions. Water level records made in a marshy location between 1959 and 1962 indicate high (surface) water levels for most of the winter and spring, quickly declining to about 50–70 cm bgl during the summer (Crompton, 1972). Subsurface flow is east towards the stream in the southern meadow and along the former drainage channel in the northern meadow (Anglian Water, 1982).

Conclusion*:* A site with a fluctuating water table, associated with seasonal variation in rainfall and in the position of the chalk water table. Chalk Head creates both a resistance to upward flow of chalk water and impedes downward drainage. It is not clear to what extent winter surface wetness is provided by chalk water or by impeded drainage of rainfall and surface run-off.

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[1] It is important not to confuse Thriplow Meadows with Thriplow Peat Holes. The latter was a fen site apparently located along the valley bottom c. 1 km east of the Meadows (TL450475) (Crompton, 1959) and appears to have been an altogether more important botanical site, probably fed by strong springs from the Melbourne Rock and with a range of uncommon plant species (suggestive of M13-type vegetation), until part drained and afforested. There is no evidence that a similar assemblage of species ever occurred at the Meadows.

3.38 WESTON FEN

SUFFOLK: TL981787

***Status*:** SSSI; SAC: Waveney and Little Ouse Valley Fens

WETMECs: Type 1 (main seepage areas), Type 2 (peripheral zones)

Description: A quite large valleyhead fen site, situated on gentle seepage slopes alongside the Hopton Brook. There are two main seepage areas along the valley, separated by a field with wet grassland. There are also some wet depressions (natural and artificial) along the top margin of the system, but the main area of wetland conservation interest occupies the seepage slopes.

Vegetation: This site provides an example of a species rich, spring-fed valley fen with areas of fen grassland and relict heath. The central slopes support M13 vegetation, grading upwards into fen meadow (M22 and M24) and downwards into a coarser tall fen vegetation (S25). Although this is now the 'best' Suffolk valleyhead fen, it may be noted that its stands of M13 vegetation do not seem to have been as rich as those at Redgrave Fen, nor as the 'best' Norfolk sites, and a number of the rarer soligenous fen species do not seem to have been recorded from Weston Fen.

Substratum and Water Supply: This site has been investigated in some detail (Gilvear *et al.*, 1989; 1994). The main aquifer for the fen is the Upper Chalk, which is regionally confined or semi-confined by boulder clay. In the fen itself, the chalk is overlain by thin layers of sand and gravel, in hydraulic continuity, but capped (at least locally) by alluvial deposits which may provide weak confinement. The chalk water discharges in springs and seepages, where the water table intersects the topography, and there are permanent seepage faces in some parts of the fen, though elsewhere drier conditions prevail, either because they are slightly elevated or because there is a thicker capping of silts. The central part of the fen, once converted to agriculture, is generally less wet than the other parts of the site, again probably mainly reflecting different topographical and substratum characteristics. It seems likely that the main reason why this site was left as a largely unimproved unit within the valley was on account of the difficulty of draining its springs and seepages.

The Hopton Brook periodically floods onto the adjoining, lower part of the fen but has no real supply function during the summer, though it may introduce nutrients into this part of the site. Surface runoff appears unimportant as a summer supply function.

Conclusion: Permanent and intermittent seepages from the Chalk aquifer and ponds occur where the Chalk water-table intersects the ground surface, at the southern boundary slope.

3.39 WHITWELL COMMON

NORFOLK: TG087205

Status**:** SSSI

Key Samples: 8

WETMECs: Type 1 (small springheads); Type 2 (much of site); Type 4 (central depressions), Type 8 (southern 'pan')

Description: A quite large valleyhead fen alongside a tributary stream of the R Wensum, draining from Booton Common, which receives some drainage from a small number of ditches across the fen. In the north the fen is fairly narrow, but it broadens southwards into a flattish expanse of open fen, with wet hollows and with somewhat flushed slopes. A strip of raised ground, supporting dry oak woodland extends into the low areas of the southwest common. There is a very obvious depression immediately east of this, which may be a ground ice depression. At the southern end of the site, there is a quite large, flat pan-like depression. Part of the site lies at the confluence of a southerly and an easterly flowing stream and as a result the main area of adjacent higher ground is situated to the north-west of the site.

Vegetation: Much of the narrow northern part of the site is wet fen woodland, which contains some small, heavily-shaded tufaceous spring mounds. The large pan-like area in the south of the site supports coarse, tall-herb fen. Elsewhere there is much fen meadow, both in shallow sump-like depressions and on seepage slopes. In 1974 there were small patches of M9 (in one of the depressions) and species-rich vegetation with affinities to M13, but these seem to have been replaced by forms of fen meadow (which retains some of the former species complement). Fen meadow grades out into fen grassland and dry fen and there is some *Phragmites*-dominance on wetter ground. Most of the vegetation is developed on shallow peat, but the tall-herb fen in the south of the site is upon a heavy, silty clay.

Substratum: The site is situated in an area of Lowestoft Till covering the Upper Chalk. The site proper lies in a valley where the glacial cover of chalky boulder clay, glacial sands and brickearth are exposed on the valley sides. The site is underlain by Contorted Drift and Chalk, the latter with layers of putty Chalk.

Water Supply: Groundwater appears to be the main source of water. The main aquifer beneath the site is Chalk, which lies at 3-10m bgl and is semi-confined by aquitards within the drift and by layers of putty Chalk. The overlying Drift (gravel, flint, silty sand) is a multi-layered hydrogeological unit. Chalk and Drift are in hydraulic continuity, with the vertical component of flow being upward. Heads in the Chalk are probably artesian or close to the surface, and at the site are higher than levels in the Drift.

Seepages represent both lateral and vertical groundwater flows from the Drift hydrogeological unit, supported by the Chalk aquifer below.

Conclusion*:* Permanent chalk seepages in the N of the site; intermittent seepages (of uncertain provenance) in the central areas, but with depressions retaining water for longer than the slopes; probably little direct groundwater supply to the alluvial pan in the S of the site.

4. FENLAND

4.1 HOLME FEN

CAMBRIDGESHIRE: TL205895

Status: SSSI, NNR

WETMECs: Type 9

Description: A quite large area of acidic peatland near the edge of the Fenland Basin, subdivided by, and surrounded with, deep agricultural drains.

Vegetation: Holme Fen retains a small area of vegetation with *Sphagnum* (more in the character of wet heath than bog), but much of the area is rather dry woodland. A pool dug into the fen peat is base rich and surrounded by fen vegetation. The woodland at the site consists of almost pure birch with a small amount of oak. The ground flora is generally species poor and largely dominated by bracken.

Substratum and Water Supply: Holme Fen is part of the Whittlesea Mere complex and as such was one of the last parts of Fenland to be drained (in the mid-nineteenth century). Along with the nearby Woodwalton Fen, it supported, in part, an ombrogenous bog surface. Peat depth is variable, typically some 3m, and consists mainly of brushwood and herbaceous fen peats capped by *Sphagnum* peat. Much of the peat is solid and amorphous, but there are some sloppy horizons which may have high hydraulic conductivities.

Buttery clay forms a layer within the fen peat, though it has a strikingly irregular surface, thickness and distribution. The peat has developed upon Oxford Clay.

The drains adjoining the site are important for drainage of the agricultural land and drain the site rather than supply water. The site appears to be fed exclusively by precipitation, though the pool dug into the fen peat sustains quite base-rich conditions.

Conclusion: a rather dry, drained bog, irrigated exclusively by precipitation.

4.2 LAKENHEATH POORS FEN

SUFFOLK: TL703827

Status**:** SSSI

Key Samples: 2

WETMECs: Type 7

Description: A small remnant of Fenland, near the eastern margin of the basin, adjoined by deep drains and dry.

Vegetation: The vegetation is quite heterogeneous and rather difficult to classify, but is perhaps best seen as a form of fen meadow with affinities both to S24 and M24. The site has obvious floristic affinities to Wicken Fen (these were formerly stronger), of which it represents a drier, and more degraded (and much smaller), counterpart in Fenland. The vegetation contains a mixture of fen species, species of coarse grassland and disturbance-indicator species. *Lathyrus palustris* was last seen between 1988 and 1990.

Water Supply: The ditches adjoining the fen are important for drainage of the agricultural land and drain the site rather than supply water. The surface of the site appears to be fed exclusively by precipitation.

Conclusion: a drained fen, surface irrigated exclusively by precipitation.

4.3 WICKEN SEDGE FEN

CAMBRIDGESHIRE: TL553700

Status**:** SSSI; SAC: Fenland

Key Samples: 14

WETMECs: Type 7

Description: A quite large remnant of 'undrained' fen, embanked and elevated above the surrounding agricultural land. The Wicken Lode runs along the western fen margin and a series of dykes extend from this into the fen.

Vegetation: The site supports a range of characteristic fenland communities and is notable for its diverse fauna and flora, in particular the invertebrate fauna and the relic fen flora. The peat fen to the north supports communities of carr, sedge and litter. Much of the herbaceous vegetation of the site can be classified as S24 and M24. However, the nominate species of S24 (*Peucedanum palustre*) does not grow well at the site (attributed to low water levels and management regime) and many of the stands attributed to this syntaxon have strong floristic affinities to M24 so that – as with Chippenham Fen – a case could be made for regarding this as the characteristic vegetation type of the site. The carr is largely alder buckthorn, buckthorn and sallow.

Substratum and Water Supply: Although Wicken Fen has been the object of many ecological studies, rather little is known about its hydrodynamics. The fen is situated upon Gault and it is presumed that it does not receive groundwater inputs. The main supply of telluric water appears to be provided by the (chalk water-fed) Wicken Lode. However, this does not normally flood the surface of the fen, and there is evidence that in general the Lode – and its offshoot dykes – do not seem to influence fen water levels more than for about 25 m into the fen, with the consequence that summer water levels in the centre of the compartments can drop well below the surface (<–75 cm bgl). Winter water levels are close to the surface, apparently largely caused by rainwater. It is thought that, even in winter, the rôle of the Wicken Lode is primarily one of supporting fen water levels rather than as a water source (*fide* A. Colston). There is some evidence for the local expansion of acidophilic species, which may perhaps be attributed to the lack of substantial telluric water inputs.

An impermeable membrane has been inserted around the periphery of part of the fen in an attempt to maintain higher summer water levels. This is now being supplemented by excavation of an additional network of dykes to help maintain higher water levels in parts of the fen currently distant from surface water sources.

***Conclusion**:* Areas near the dykes and Lode may receive some lateral inputs of telluric water, but much of the site appears to be precipitation-fed and experiences low summer water tables.

4.4 WOODWALTON FEN

CAMBRIDGESHIRE: TL230840

***Status*:** SSSI; SAC: Fenland

Key Samples: 11

WETMECs: Type 7 (perhaps small patches of Type 9)

Description: A large fen site at the SW edge of the Fenland Basin, adjoining the upland on the south side but forming an isolated 'undrained' block elevated slightly above the level of the farmland on the west, north and east sides. The Raveley Drain runs from the upland into the Fens along the east side of the fen. This is an IDB drain which carries water from the high ground to the west of the area.

Vegetation: Woodwalton Fen is part of the Whittlesea Mere complex and as such was one of the last parts of Fenland to be drained (in the mid-nineteenth century). Along with Holme Fen, it probably supported, in part, an ombrogenous bog surface, though much of the ombrogenous peat was removed, along with fen peat, by late 19th century peat excavation. Part of the site was used for arable farming, before becoming a nature reserve in the early part of the 20th century. Much of the vegetation of the site has therefore developed more-or-less *de novo* and there is reason to suspect that the spread of populations of some plant species, and the development of community composition, within the site is an ongoing process. The vegetation is mainly a mixture of fen scrub and woodland, with tall herb fen (*cf.* S24) and reedbed and with areas of fen meadow and fen grassland maintained by grazing and mowing. Fairly small stands of *Cirsio-Molinietum* and *Cladio-Molinietum* (the latter with *Erica tetralix* and *Calluna vulgaris*) pick out some of the residual surface patches of acidic peat.

Substratum: Peat depth is variable, typically some 3m, and consists mainly of brushwood and herbaceous fen peats, but the latter have some sloppy horizons which may have high hydraulic conductivities. In the north of the site, buttery clay forms a thin layer within the peat, though it has a strikingly irregular surface, thickness and distribution. The peat has developed upon Oxford Clay.

Water Supply: The west and north sides of the site have clay-cored walls, to reduce losses from the fen into the adjoining agricultural land, and the east side is bordered by the Raveley Drain (also with a clay-cored wall). Groundwater inputs are not suspected and the site appears to be fed by rainfall and surface water from the Raveley Drain. In winter, water tables are near, or slightly above, the surface over much of the fen and in normal years appear to be maintained by rainfall. However, provision is made for the fen to be used for flood storage (to 1 m depth or more), and the site typically receives some flood water inputs every 3-5 years. Deep flooding is mainly a feature of winter, but does occur at other times in spring (last in April 1998) and summer (last in July 1968). Controlled intake of water from the Raveley Drain into the dykes occurs between June and September and is essential to maintain the dyke water levels. However, away from the dykes fen water tables usually fall well below the surface during the summer. This problem also affects a reedbed at the north end of the fen, developed in a fairly recent, large peat scrape, and into which water is now pumped to try to keep it wet.

The converse of the summer drying is that it is difficult to reduce the wetness of the fen surface in winter. Persistently high spring water tables may not only hinder management operations on the site, but may also be detrimental to aspects of the conservation interest (*e.g.* it is possible that they contribute to the poor performance of the Red Data Book species *Viola persicifolia*).

Although storage of winter rainwater is seen as useful in helping to maintain the water balance, flood storage is of dubious benefit to the site, because of its capricious character and its associated input of silts and nutrients across the fen surface (these are almost certainly more damaging to the ecology of the site than are the regular summer inputs of nutrient-rich water into the dyke system).

Poore (1956) specifically points out that the fen areas at Woodwalton seem less responsive to water sources and sinks than is that case at Wicken Fen. He suggests that the rise in water level in response to rainfall is less than at Wicken (he suggests a 4 cm increase for 1cm rainfall, compared with a 7–12 cm increase at Wicken) and that the transfer of water between the fen and drains is particularly slow (though variable).

Conclusions: Fed by rainwater and surface water, but summer surface water inputs *via* the dyke system do not maintain high water tables in the fen, nor can winter water excess be drained readily, probably because of limited transmission of water through the peats. In the fen, the dry summer and wet winter / spring conditions present a combination which probably constrains the development of components of the conservation interest of the site.

5. SOUTH EAST MIDLANDS VALLEYHEAD FENS

5.1 BLACKEND SPINNEY FEN

BUCKINGHAMSHIRE: SP857253

Status**:** No statutory designation (now drained)

Key Samples: 1

WETMECs: formerly Type 4

Description and Vegetation: This small site occupies a shallow depression at the headwaters of a stream that drains into the R. Ouzel. The site is nowadays not as wet as was the case in the 1970s, and has apparently been drained, though it is not obvious how. It is possible that the outflow channel has been deepened. Until drainage, this site was permanently wet (shallow flooded) and supported a tiny example of M9 vegetation, surrounded by fen meadow (M22). There is also a small area of alder woodland (rare in north Bucks).

Substratum and Water Supply: The fen is surrounded by, and underlain by, till which here contains thick lenses of sand and gravel. The till is underlain by Kimmeridge Clay (up to 30 m thick), which is underlain by Corallian Clay and Oxford Clay. Kimmeridge Clay is exposed in the southern part of the site. Several domestic and agricultural wells appear to derive their water from sand and gravel lenses within the till, and this appears to be the most likely source of water for the fen (limestone beds within the Kimmeridge Clay appear to be dry). It is likely that the telluric water supply is largely due to groundwater discharge (springs/seepage), but an unusual feature of this site (in the N Bucks context) is its pan-like configuration, which has created a swampy sump which retains discharge water. Bedrock is Oxford Clay. There are no direct field drain inputs, though there may be under-drainage inputs. The stream drains the site and is not a source of water

Conclusion: Groundwater fed, from a perched drift aquifer, formerly a permanent seepage basin.

5.2 BONEMILLS HOLLOW (HORNSTOCKS VALLEY)

CAMBRIDGESHIRE: TF038013

***Status*: SSSI**

Key Samples: 3

WETMECs: Type 1 (small flushed areas), Type 2 (much of valley), Type 8 (valley bottom in lower part of fen)

Description: A long, thin fen occupying much of a narrow valley extending for about 1 km SW of Bonemills Farm.

Vegetation: The upper parts of the valley are quite shallow and intimately associated with the surrounding agricultural land at least on the west side of the stream. Here (on the N side) there are a series of small wet areas, formed by springs draining into the stream. There is some variation between the vegetation of these, some are closed and lack surface water, but two have an open vegetation with runnels. These have a variable vegetation but generally contain *Juncus subnodulosus*, *Carex lepidocarpa*, *Mentha aquatica*, *Cratoneuron commutatum* etc. and by the side of one of these is a fair quantity of *Anagallis tenella*. They can be regarded as transitional between M13 and M22. Between these wetter depressions is a variable vegetation. In some cases it is a variant of the wetter type with *Juncus subnodulosus, Hydrocotyle* etc. but a more widespread type is dominated by grasses (*Arrhenatherum elatius*), sometimes with *Epilobium hirsutum* dominant near the agricultural land.

Lower down (i.e. east of the point the track crosses the stream) the stream flows between two quite steep limestone slopes, but the valley bottom is wider. At the top of this there is an area of fairly mixed fen with *Carex rostrata*; adjacent and below this *Carex acutiformis* meadow (± *Carex paniculata*) occurs. In some places it is highly dominant. Below this the marshy ground is fairly closely confined to the stream, the adjacent area being damp, but not marshy, but towards the road the valley bottom becomes much wetter, with standing water and *Phragmites* is important. Immediately east of the road and north of the main stream there is a further spring area. The spring head has *Rorippa nasturtium-aquatica*, a little *Carex lepidocarpa* and some *Cratoneuron commutatum.* Surrounding this, particularly on the south side is species rich fen meadow.

Substratum and Water Supply: In the upper parts of the valley, the fen is very narrow and occurs in association with seepage slopes and springs alongside the stream, but lower down the soligenous influence is less obvious and the wetland occurs mainly on clays and silts along the valley bottom. East of the road that forms the eastern limit of most of the fen, there is another small spring fed area (near Bonemills Farm).

The western part of the site is fed primarily by springs issuing from the Lincolnshire Limestone. This is separated from the underlying Northampton Sands by Lower Estuarine clays. The Sands are underlain by Upper Lias clays, and the lower (eastern) valley bottom may receive seepage inputs from the Northampton Sand / Upper Lias interface. However, this part of the valley has been filled by Glacial Head (sandy, stony loam and clay), which probably helps create a rather low permeability (and high fertility) valley floor (as is reflected in the contrasting vegetation of this lower part of the site).

Conclusion: A groundwater fed valley, with soligenous wetlands (permanent and intermittent seepages) fed mainly from the Lincolnshire Limestone, and with a valley bottom area with much impeded drainage, possibly fed partly from the Northampton Sand aquifer.

5.3 CLACK FEN

BUCKINGHAMSHIRE: SP855275

Status**:** No statutory designation

Key Samples: 8

WETMECs: Type 1 (spring mounds), Type 2 (peripheral to main seepages). Type 8 (small areas of 'flat' valley bottom)

Description: A fairly small, linear valleyhead fen developed on seepage slopes on either side of a small stream close to its headwaters. The stream drains eastwards to the R. Ouzel and appears to have little relevance to the seepage slopes. The valley is quite steeply incised and most of the fen occupies the lowermost valley slopes, with only a relatively small amount of flattish valley bottom. The slopes consist of a series of permanent spring mounds, some ferrugineous, one with some marl, connected by intermittent seepages.

Vegetation: The vegetation of grazed areas is a form of fen meadow (M22). Ungrazed areas are mainly occupied by species-poor tall-herb fen (*Epilobium hirsutum*-dominated), especially at the main points of groundwater discharge (with impoverished, rank, remnant fen meadow on the intervening intermittent seepages). Wheeler (1983) showed that springs beneath the arable fields contained greater concentrations of NPK than springs beneath pasture, but the main cause of the occurrence of M22 *versus* tall herb fen was the presence or absence of grazing, not differences in nutrient availability (though these latter did help regulate productivity)

Substratum & Water Supply: The area surrounding the fen is covered with Boulder Clay, which has been eroded in the valleys of major streams to expose the underlying Jurassic Clays (Corallian Clay and Oxford Clay) (up to 100 m thick). Thick lenses of sand and gravel occur within the till, with a large example some 10–20 m thick in the vicinity of the fen. This provides the main aquifer for the fen, possibly connected to smaller unmapped lenses. Field drains do not discharge into the fen, but there are some under-drainage inputs.

Conclusion: Groundwater fed, from a perched aquifer of glacial sand and gravel, which the stream valley partly cuts through, with permanent and intermittent seepages.

5.4 DRAYTON PARSLOW FEN

BUCKINGHAMSHIRE: SP848280

Status**:** No statutory designation

Key Samples: 4

WETMECs: Type 1 (spring mounds); Type 2 (diffuse and peripheral seepages); Type 8 (valley bottom)

Description: A narrow, elongate fen developed along both sides of a small tributary stream of the R. Ouzel, near to its headwaters.

Vegetation: The main vegetation is a form of fen meadow (M22), with much *Juncus subnodulosus* in the main spring areas, but with *Carex acutiformis* tending to dominate the intermittent seepages. The valley bottom vegetation is mainly a form of *Carex acutiformis* meadow or a coarse grassland with *Arrhenatherum elatius, Festuca arundinacea etc.* There is some localised developed of fen carr (*Salix fragilis etc.*) with patches of *Phragmites* (which is rare in fens in this region).

Substratum & Water Supply: The area surrounding the fen is covered with Boulder Clay, which has been eroded in the valleys of major streams to expose the underlying Jurassic Clays (Corallian Clay and Oxford Clay). Thick lenses of sand and gravel occur within the till, with a large example some 10–20 m thick in the vicinity of the fen. This provides the main aquifer for the fen, possibly connected to smaller unmapped lenses. Field drains do not discharge into the fen, but there are some under-drainage inputs.

The main water supply to this site is from springs and seepages on the lower valley slopes, with a series of well-developed spring mounds separated by intermittent seepages. The axial stream, which is locally quite deeply incised, is mostly well separated from the main seepage areas and the intervening valley floor is relatively dry in summer. Rare stream flooding occurs of the valley bottom, but the stream probably has no normal water supply function.

Conclusion: Groundwater fed, from a perched aquifer of glacial sand and gravel, which the stream valley partly cuts through, with permanent and intermittent seepages.

5.5 DRAYTON PARSLOW NORTH FEN

BUCKINGHAMSHIRE: SP832289

Status**:** No statutory designation

Key Samples: 1

WETMECs: Type 2

A small flushed area forming the head of a small stream which drains NE to the R. Ouzel. It occupies a pan-like depression incised into the E edge of a field, with quite steeply-sloping intermittent seepage slopes grading into a flatter centre. The seepage slopes continue alongside the outlet for a very short distance in the field immediately east of the main fen area. The vegetation is a form a tall herb fen with some persistent fen meadow species.

The bedrock is Oxford Clay, so groundwater is likely to be derived from the sandy drift overlying this. The site is located near the top of the interfluve.

Conclusion: Groundwater fed, from a (probably phreatic) drift aquifer, with intermittent seepage.

5.6 NASH FEN

BUCKINGHAMSHIRE: SP794336

Status**:** No statutory designation

Key Samples: 4

WETMECs: Type 1 (spring mounds), Type 2 (other seepages), Type 8 (valley bottom)

Description: A series of patches of fen developed along the bottom and north east slopes of a rather deep valley draining northwestwards to the R. Ouse. Three main components can be recognised: (i) gently-sloping (or ± flat) valley bottom, mostly occupied by (rather dry) fen; (ii) a series of fairly small, separated permanent seepages, scattered across lower parts of the slope, usually grading outwards into intermittent seepages and 'dry' grassland; and (iii) a long, thin intermittent seepage surface that follows the contour along much of the shoulder of the west side of valley, with grassland above and below, the latter clearly separating this upper band from the lower seepages. Some small runnels originate on the valley slope and feed some of the lower fens, but field drain inputs only really discharge into the valley bottom.

Vegetation: The valley bottom areas mostly support *Carex acutiformis* meadow, tall herb fen or rank grassland. The spring mounds and permanent seepages are good examples of *Juncus subnodulosus*-dominated fen meadow (M22). The elongate seepage is also referable to M22, but shows distinct floristic differences from the spring mounds – it is generally less diverse and supports *Equisetum telmateia.*

Substratum and Water Supply: The bedrock is Oxford Clay (probably between 15–50 m thickness) overlying Kellaway Beds. It is covered by extensive deposits of Boulder Clay which contain large lenses of sand and gravel. The site valley cuts through a large sand and gravel lens (at least 50 m thick), down to the Oxford Clay. Soliflucted head deposits form a strip along the base of the sands and gravels and appear to be derived from them. There is a fan of tufa associated with a spring at the southern end of the fen and the valley bottom is covered by a strip of recent Alluvium.

There are two distinct groups of seepages down the slope. The sands and gravels, and to a lesser extent the Head deposits act as unconfined aquifer units perched on the Oxford Clay, and springs emerge where this intercepts the ground surface. There appears to be some discharge from the sands and gravels into the adjacent Head, which discharges further downslope as a separate group of seepages. The valley bottom appears to receive some groundwater inputs, but is rather dry in summer. The stream primarily drains the site.

Conclusion: Groundwater fed from one or more drift aquifers, with both permanent and intermittent seepages.

5.7 PILCH FIELDS

BUCKINGHAMSHIRE: SP747323

***Status*: SSSI**

Key Samples: 2

WETMECs: Type 1 (North Field), Type 2 (peripheral areas of North Field and South Field)

Description: Rather small patches of fen and flushed slopes developed at the headwaters of a small stream draining westwards to Claydon Brook. Two main patches of wetland occur, in two separate fields, both sloping quite steeply (for the region) northwest-wards. The lower (northern) field has the best development of true fen, with seepage slopes along the sides of a quite deeply incised channel and forming a band around part of the hillside. A bigger, elongate and less incised seepage area also occurs in the west-central part of the south field, though much of this is more wet grassland than fen. Also in the south field, there is a separate, very small spring fen beside the northern boundary, quite close to the junction with the north field.

Vegetation: The lower (north) field supports typical *Juncus subnodulosus*-dominated fen meadow (M22), with a shorter turf transitional to the adjoining drier grassland. *Juncus subnodulosus* also occurs in the south field, but is much more local, with *Juncus inflexus* being the principal rush. Much of this vegetation is probably better described as fen grassland than as fen meadow and seems to be transitional between M22 and M24 (though *Cirsium dissectum* does not occur). More fen-like vegetation forms a narrow band along the bottom of the shallow channel, marked by *Carex paniculata* tussocks and (near the bottom) by *Juncus subnodulosus*. A separate spring fen at the top of the field is a *Juncus inflexus*-dominated form of M22, surrounded by a narrow band of *Glyceria*-dominated vegetation where poached.

Substratum and Water Supply: The site and much of the surroundings is covered with boulder clay, which has been eroded in the valleys of rivers and major streams to expose the underlying bedrock. Cornbrash and Great Oolites form an aquifer beneath the site, but appear to be confined by an intervening Oxford Clay aquiclude (here probably some 2–5 m thick). The boulder clay, though regionally an aquitard, contains water-bearing lenses of sand and gravel, forming perched aquifers which discharge as springs and seepages where they intersect with the ground surface.

Conclusion*:* Primarily fed by groundwater discharge from lenses of sand and gravel within boulder clay (especially the north field), plus rainfall and generated run-off.

5.8 SHACKLEWELL HOLLOW

RUTLAND: SK977078

***Status*:** SSSI

WETMECs: Type 2

Description: A narrow, elongated site, located within a north-northeast trending valley on a small tributary of the River Gwash. The area of greatest wetland interest lies within the northern section of the SSSI (i.e. north of the A606), and is fed by two well-defined springs, which drain to a small stream that flows through the site from the south, joining the R. Gwash on the northern boundary. The majority of flow in the stream is thought to be derived from the wetland, other than after heavy rainfall events.

Vegetation: Much of this area is wet-moist grassland, grading upwards into limestone grassland, but there is a sort of fen meadow (with *Juncus subnodulosus*) near the stream issuing from the southern spring, but elevated some 50 cm above it. The northern spring feeds a shallow (artificial) pool, which is becoming colonised with vegetation, especially *Juncus subnodulosus.*

Substratum: Regionally, the geology consists of a series of Jurassic marine and estuarine sediments which have been exposed by fluvial erosion. The massively bedded oolitic Lincolnshire Limestone outcrops over much of the general area. Within the site the Limestone is exposed along the eastern slope from approximately 46m aOD, and is underlain by the sandy Grantham formation, which changes to clay at depth, and occurs along the base of the slope. To the S & W the Northampton Sands underlie the Grantham Formation, but is assumed to thin out towards the site. Upper Liassic Clay of unproven thickness occurs in the valley bottom along the length of the site, and there is a patchy cover of alluvium within the valley.

Water Supply: Springs discharge from the Lincolnshire Limestone (the main aquifer) along the east of the site where the water table intersects the topography, or drain along the junction with the underlying clay aquitard. Groundwater flows are lateral, probably influenced by the fault and fissure networks, and are from the south and east of the site. There may be some contribution from the Northamptonshire Sands to the west of the site (probably mainly in winter).

Conclusion: The site is fed by strong spring discharge from the Lincolnshire limestone, but the main area of fen meadow is elevated above the spring stream and groundwater appears to be subsurface for much (all ?) of the year.

5.9 SUTTON HEATH AND BOG

CAMBRIDGESHIRE: TF090000

***Status*: SSSI**

Key Samples: 4

WETMECs: Type 1 (main seepages); Type 2 (peripheral seepages); Type 8 (valley bottom)

Description: Sutton Heath is located within the south-east trending valley of the Wittering Beck, a small tributary of the R. Nene, in northern Cambridgeshire. The main areas of wetland conservational interest are small, soligenous fens located in two small valleys cut back into SW-facing limestone slopes.

Vegetation: Fen vegetation (M13) is developed on spring/seepage slopes alongside (and above) small spring-sourced streams (a third, northernmost valley has a spring-fed stream but no associated M13). Away from the main seepage faces, and particularly along the valley bottom, the vegetation is a form of marshy grassland and fen meadow, some of which can be referred to M22, but is not a particularly 'good' example of this. The upper transition between the M13 vegetation and limestone grassland tends to be marked by a narrow band of M24.

Substratum: Within the site, the massively-bedded oolitic Lincolnshire Limestone is exposed on the upper slopes (from c. 15m aOD). It is underlain by sandy facies of c. 4m thick which form the top of the underlying Grantham formation and which change to clay at depth, and occur along the base of the slope. Extending to the northeast of the site, the Limestone is overlain by the Rutland Formation silt and mudstone, which is overlain by the Blisworth Limestone & Clay, with overlying Cornbrash. There is patchy cover of alluvium within the river valley.

Water Supply: The HSI monitoring report suggests that there is a complex sequence of aquifers/aquitards. Lincolnshire Limestone is the main aquifer – unconfined at outcrop on the upper slopes of the site (but confined to the northeast by Rutland Formation silt and mudstone, Blisworth Limestone & Clay & Cornbrash) and underlain by a sandy facies of the Grantham Formation. Some of the Lincolnshire Limestone water drains down into the Grantham Formation, and within the site, springs emerge from the Lincolnshire Limestone and Grantham Formation at outcrop where water levels are sufficiently high to intersect the topography. Flows are supported by seasonal spring discharges at the outcrop of the Blisworth & Cornbrash limestones. The greater storage capacity of the Lincolnshire Limestone may result in the possibly perennial spring and seepage discharges.

Water level in the main drainage ditch is controlled by two sluices. Groundwater levels in the valley bottom are sustained both by seepage from the Grantham Formation and by flows from the Wittering Beck, but summer water levels here are often well below surface.

An additional feature of this site is that there is a lot of bare soil amongst tussocks of *Schoenus* and other vegetation, which often appears to be perched above the main ground level, and carpets of species-rich low-growing vegetation are only fragmentary. The appearance of the feature is suggestive of heavy trampling, but there are various reports of under-grazing at the site. This may therefore suggest that this feature (which was evident in the early 1970s as well as 1998) may be a product of scouring associated with high spring flows. This view of a rather dynamic system may be supported by anecdotal evidence which suggests that the main springs are thought to change their position, leading to drying of some former areas of mire and erosion of others.

***Conclusion**:* Soligenous slopes fed by lateral flow of water down from a partly-confined Lincolnshire Limestone aquifer.

5.10 SYRESHAM MARSHY MEADOWS (SOUTH MEADOW)

NORTHAMPTONSHIRE: SP638426

***Status*:** SSSI

Key Samples: 2

WETMECs: Type 2 (seepage slopes), Type 8 (valley bottom)

Description: This SSSI contains two wetland areas situated in narrow valleys drained by the upper headwaters of the River Great Ouse. Only the southern meadow is considered here; this is spring fed and contains seepage slopes. A strong spring sustains a strongly-flowing spring stream, which has cut a shallow, narrow valley back into the flanking seepage slopes. It feeds into, and maintains, a very wet valley bottom. A shallow channel drains this into the valley-bottom stream. It is possible that the valley-bottom drainage was once more effective than is now the case.

Vegetation: The vegetation is composed of a mixture of sedges, rushes, grasses and herbs with a ground cover of mosses. The south-facing slope consists of seepage areas grading out into less wet pasture. East of the spring stream, there are two main seepage areas, with much *Juncus subnodulosus*, which grade out into *Juncus inflexus*-dominated vegetation and thence grassland. West of the stream, the vegetation is mostly a species-poor *Carex acutiformis* fen meadow, with some *J. subnodulosus* along the lower margin. The swift spring stream contains much *Berula etc.* and is flanked by rather undistinguished fen meadow, though with some *Cratoneuron commutatum* on open mud. This feeds the valley bottom, which in the west part of the field is very wet, with a curious form of tall herb fen. East of this the valley bottom is relatively dry, and this is a very narrow dry strip along most of the length of the stream.

Substratum and Water Supply: The southern valley cuts through Boulder Clay to expose the Great Oolite limestone and the underlying estuarine limestone in the centre of the valley. Deposits of Head and glacial Sand and Gravel occur on the valley sides and may be present north of the site. The sands and gravels, the Great Oolites and the Upper Estuarine limestones are all water-bearing units. The last two at least are thought to be in hydraulic connection. The relative importance of sands and gravels *versus* limestone is not really known. HSI (2000) suggest that in the southern meadow "surface water course will tend to receive baseflow from the Great Oolite….. This appears to support a broad seepage area and a spring-fed stream, as described in the English Nature citation". However, a recent site visit suggested that the source of the spring-fed stream is actually the domestic well for Primrose Hill Farm (well number 1 – SP 64/12), which appears to derive its water from gravel deposits in the drift. It is not known whether these gravels are in hydraulic continuity with the underlying limestones.

Conclusion: A groundwater fed site, with a strong spring stream input, but it is not certain whether this is sourced from Oolitic limestone or sand and gravel deposits in the drift (or both). The throughflowing stream appears to drain the site and does not provide significant water inputs.

5.11 TINGEWICK MEADOWS

BUCKINGHAMSHIRE: SP652313

***Status*:** SSSI

Key Samples: 1

WETMECs: Type 2

Description: A quite long, but narrow marshy bluff on the lower southwest slopes of a shallow valley, at the point where this curves south between Tingewick Wood and Round Wood. The stream drains south into the headwaters of Claydon Brook. The fen forms a broad sweep around the valleyside, mostly separated from the stream below by drier ground (presumably because of drainage by the stream), but in the NW corner, seepage slopes lead directly down to the stream.

Vegetation: Most of the area is fen meadow vegetation (M22) with much *Juncus subnodulosus*, with some lower-growing patches with *Carex disticha* and *C. binervis*. This is more-or-less surrounded by a zone (of varying thickness) of ranker vegetation with much *Deschampsia cespitosa* and *Arrhenatherum elatius*. This vegetation forms a thin band along the top of the fen and a broader zone below it, and is particularly prominent at the south end, where it effectively forms a southwards extension of the seepage slope. Much of the fen is adjoined by a drier base-rich grassland, with *Cirsium acaulon* etc. This is particularly extensive above the fen, but also occurs below the fen in the south east.

Substratum and Water Supply: The site and much of the surroundings is covered by a thick (20 m ?) boulder clay. This is underlain by Oxford Clay, probably no more than 10 m thick, upon Cornbrash and Great Oolites. The boulder clay contains significant quantities of sand and gravel, which contain perched aquifers that source several domestic and agricultural wells and appear to provide the main water source for the fen. The top-layer of the seepage slopes is a rather silty material which may constrain groundwater discharge and increase the importance of rainfall and generated run-off to the water balance. Most of the fen area is rather dry during the summer. The stream drains the site and does not provide water inputs.

The boulder clay north of the site is reported to contain Oolitic gravels. It may be noted that the drift in the vicinity of the fen is unusually calcareous in a North Buckinghamshire context.

***Conclusion**:* Seepage site fed by groundwater discharge from perched aquifers associated with sands and gravels within the drift.

5.12 VALLEY FARM FEN, SOULBURY

BUCKINGHAMSHIRE: SP896254

***Status*:** No statutory designation

Key Samples: 1

WETMECs: Type 1 (much of site); Type 2 (zone above permanent seepage)

Description: A small seepage fen developed along near the headwaters of a small tributary stream of the R. Ouzel. The fen occupies a narrow hollow located on a gently-sloping valley bottom below a seepage line at the base of a sharply-sloping valley side. It is situated on the south side of the stream, which it adjoins and into which it drains directly. Most of the site is formed of a permanent seepage mound, with a narrow intermittent seepage zone forming a band above this.

Vegetation: All of the herbaceous fen vegetation is referable to a form of fen meadow (M22), but shows a gradient of dominance through *Juncus acutiflorus* (associated with the upper intermittent seepage) through *J. subnodulosus* to *Carex paniculata* (near the stream). About half of the site is willow carr).

Substratum and Water Supply: Much of the surrounding area is covered with Till, which here contains thick lenses of sand and gravel. A large lens outcrops along the flanks of the site valley, as well as along the sides of the Ouzel valley. It is at least 10 m thick, possibly thicker, and downstream of the site is partly overlain by Head deposits. This deposit may well be continuous with smaller, unmapped sand and gravel lenses. The till is underlain by Kimmeridge Clay (up to 30 m thick), Corallian Clay and Oxford Clay. Immediately north of the site, the drift is underlain directly by Corallian Clay**.** The sand and gravel lenses form the main aquifer for the site, which is primarily groundwater fed. The stream has a drainage function and is not thought to provide a water source for the fen.

Conclusion: Groundwater fed, from a perched drift aquifer, which has been cut through by the valley, with permanent and intermittent seepages.