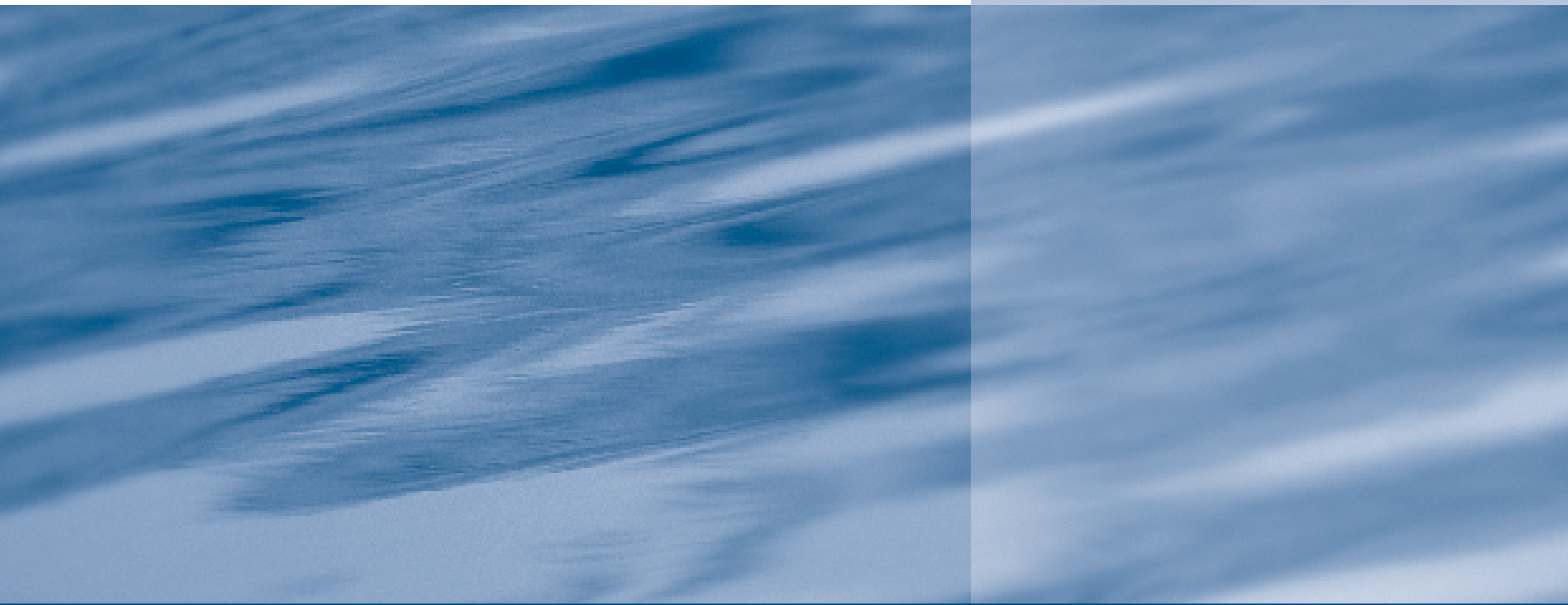

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Ranunculus in Chalk Rivers Phase 2

Science Report W1-042/TR

Environment Agency

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Professor Mike Depledge   Head of Science

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Thanks are due to Allan Frake and Nigel Holmes for the management of this project and to the Project Board for their input and advice. Also to the many staff of the Environment Agency who contributed their considerable knowledge and experience of Chalk rivers to the production of this report. Special thanks are also due to the riparian owners, keepers and fishing club representatives who shared their unique knowledge of their favourite rivers. Grateful thanks are due to Hugh Dawson for bringing relevant but as yet unpublished work on *Ranunculus* to the attention of the project. There are also thanks due to the many other individuals, agencies and organisations who gave their time to fill in proformas and pass on their knowledge of *Ranunculus* and Chalk rivers.

Project Board Members:
Hugh Dawson, Jim Glasspool, John Murray-Bligh, Lawrence Talks, Terry Newman, Robin Crawshaw, David van Beeston and Chris Newbold.

EXECUTIVE SUMMARY

In the last decade following a series of low flow years concern was expressed that *Ranunculus* in Chalk rivers appeared to be suffering a decline. Factors suggested as affecting *Ranunculus* include low flows due to changing rainfall patterns, over abstraction, enrichment, siltation and channel management. A large number of surveys and research projects have been conducted on Chalk rivers before and during the 1990s. There was, however, a feeling that the information available was not widely disseminated and needed to be collated and reviewed to more effectively address pressing issues of management and conservation.

The aim of this project was to draw together and review all relevant information on *Ranunculus* in Chalk rivers and recommend a strategy for future management. In Phase 1 of the project source material on *Ranunculus* in Chalk rivers was gathered together and given a preliminary review against a set of criteria affecting *Ranunculus*. Relevant material was then collated into a database. Questionnaires on *Ranunculus* were sent to Environment Agency Areas with Chalk rivers as well as a range of agencies, groups and individuals including riparian owners, river keepers and others with experience of Chalk rivers. Phase 2 of the project involved a more detailed review of the source material. Summaries of the source material and a matrix of 'Factors' and 'Drivers' affecting *Ranunculus*, 'Type' and 'Basis of Information' together with potential 'Management Applications' were compiled and entered onto a database. Additional information on *Ranunculus* status in Chalk rivers together with details of research and rehabilitation projects were requested from Environment Agency Areas to update the information from Phase 1.

The findings of this report therefore are based on the documents reviewed and the information supplied by outside sources.

A primary output of the review was to identify the cause and effect of the various influences (Factors and Drivers) on the growth and distribution of *Ranunculus*. Factors are primarily measurable variables considered to affect *Ranunculus* growth and Drivers are anthropogenic influences that change the character of the Factors. This knowledge was seen as being potentially useful to the Environment Agency and others in the management of Chalk rivers.

The review of the documents has not revealed any numerical measurements for the Factors affecting *Ranunculus*. The inter-relatedness of the many environmental variables affecting *Ranunculus* growth creates difficulties in isolating the impacts of the individual Factors. However, the review does show the fundamental importance of the effect of discharge or flow and as a result, velocity. High flows appear, in part at least, to alleviate the impacts of other factors allowing *Ranunculus* to flourish whereas low flows exacerbate the impacts of other factors.

During Phase 2 of the project a total of 311 documents were reviewed of which 172 were accepted as relevant and used in the production of this report. From the information supplied there appears to be a general lack of knowledge of the status of *Ranunculus* prior to 1990, except on some of the larger rivers. The current status of *Ranunculus* is also unknown for many stretches of river and even for some whole river lengths. Of 156 listed Chalk rivers, 98 were not mentioned in the documents reviewed.

The highest number of citations in the documents is to the Factors of Velocity/Depth/Levels, Discharge/Seasonal Annual Changes, Substrate/Siltation and Light/Shade/Temperature.

There is quantitative information on the importance of Discharge, Velocity and Light whereas virtually all of the information documented on Substrate/Siltation is qualitative or inferred. The lowest number of citations is to the Factors of Grazing and Physical Dimensions.

Generally the documents show that the most reported influences on *Ranunculus* growth are Factor, rather than Driver, led. Amongst the Drivers the largest number of citations is to Natural Climate Cycles followed by Channel Management and to a lesser extent Enrichment from Point Sources. The large number of documents commenting on Discharge and *Ranunculus* growth considers this Factor primarily in relation to Natural Climate Cycles. The effect of discharge is universally regarded as of prime importance to the growth and distribution of *Ranunculus*.

There is evidence of the adverse impact on *Ranunculus* of the drought in 1976 and its subsequent recovery following higher flows e.g. the Rivers Lambourn and Kennet. There was widespread reporting that *Ranunculus* had suffered in 1989 and early 1990s from the effects of low flows on most Chalk rivers. *Ranunculus* is now reported to be dominant on many river reaches following two years of higher flows in 1999 and 2000. The reporting of poor growth in low-flow years and then recovery following higher flows is consistent with the conclusions drawn from the documents that Natural Climate Cycles is the key Driver in most cases.

Velocity, invariably related to discharge, is acknowledged as being of particular importance to *Ranunculus*, with low velocity commonly cited as a reason for poor *Ranunculus* growth. Quantitative data have identified *Ranunculus* as a plant requiring fast flows to aid the rapid delivery of oxygen and carbon to support its high photosynthetic rate. Velocity is also seen to act indirectly by removing potentially competitive or shading algae.

Competition is seen to be a major factor affecting *Ranunculus* growth in Chalk rivers and the main Drivers appear to be Vegetation Management, Light/Shade/Temperature and Enrichment from Point Sources; the effects of which are variously exaggerated or alleviated by discharge.

Abstraction is a Driver that can have considerable influence on discharge. Much work has been done on the impacts of abstraction but few of the documents actually describe the impact of abstraction on *Ranunculus*. The greatest number of references relate to how abstraction affects *Ranunculus* through its impact on discharge and velocity.

There is agreement that many channels have become over-wide or deep. The impact is seen in the literature to be manifested largely through the Factors Substrate/Siltation, and Velocity/Depth/Levels. There is little quantitative work on the dimensions of channels preferred by *Ranunculus*. Over-wide channels and consequent reductions in velocity are cited as having a detrimental impact on *Ranunculus*. There was little reference in the literature to gradient, a natural influence on velocity, that is greatly modified locally by sluices etc.

A much greater emphasis is placed on phosphate than nitrate in the literature. It is suggested that phosphorus is a fundamental influence on riverine macrophyte communities and may set the underlying potential for impact to which other factors contribute. The impact of phosphorus on *Ranunculus* is highly confounded by other environmental factors.

It is frequently observed that the dominant macrophyte of Chalk rivers, *Ranunculus penicillatus* subsp. *pseudofluitans*, is generally found in fast flowing conditions. It is presumably this observation which has led to so much rehabilitation work involving changing channel dimensions to increase velocity. Recently completed projects on the River Avon have seen *Ranunculus* returning and occupying most of the in-channel habitat.

However, recent high flow conditions may be more responsible for the spectacular return of *Ranunculus* than the contributions made by the project design. Many of the rehabilitation projects did not have any systematic or comprehensive monitoring of the impact of the scheme. This has greatly reduced the potential value of these schemes to future management of Chalk rivers.

It is recommended that in order for the Environment Agency to fulfil its responsibilities under the Chalk Streams Biodiversity Action Plan the status of *Ranunculus* on all listed Chalk rivers should be established as soon as possible. In view of the importance of discharge in determining good *Ranunculus* growth there is also a need to establish the relationship between discharge, physical dimensions, water quality and sediment loading. In addition, there is an urgent requirement, given future climate change, to predict what discharge is required in any one catchment, river or reach to conserve *Ranunculus* and the health of Chalk rivers in general. These investigations will be particularly helpful in establishing criteria for rehabilitation projects. Monitoring the impacts of rehabilitation projects will provide data for comparison with the original criteria.

In many Chalk rivers *Ranunculus* is maintained at high levels by management practices which have favoured it over its competitors. There is a need to strive for management that is in the best interests of the whole of the Chalk river ecosystem.

CONTENTS

1 INTRODUCTION

1.1 Background and Project Description

The Environment Agency (the Agency) is the lead organisation responsible for delivering obligations within the UK Chalk Stream Biodiversity Action Plan. A significant part of that obligation is the maintenance of the characteristic plant community dominated by *Ranunculus*. Under the Habitats and Species Directive (92/43/EEC) the proposed Special Areas of Conservation (SAC) include protection of Floating vegetation of *Ranunculus* of plain and sub-mountain rivers. English Nature (EN) has produced draft targets for the desirable 'favourable status'/'condition' that should be achieved for SAC Chalk rivers including those for the conservation of 'Floating vegetation of *Ranunculus* of plain and sub-mountain rivers'.

Many of the Chalk rivers (see Appendix 1) listed by the Biodiversity Action Plan (BAP) Steering Group are renowned fisheries where for centuries *Ranunculus* has been managed to provide the most favourable conditions for angling as well as to control water levels and reduce flood risks. In the last decade considerable concern has been expressed about the deteriorating condition of Chalk rivers and in particular the apparent decline in *Ranunculus*. Factors identified as possible causes for this decline include increased levels of phosphates, variable flows resulting from fluctuations in rainfall or over abstraction, competition from other macrophytes including algae and physical changes to the river environment. Despite these concerns there have been major recoveries of *Ranunculus* reported in 1998, 1999 and 2000 on some rivers.

Ranunculus and Chalk rivers have been the subject of much research over the last three decades. There is concern however that in the past the research has been carried out in isolation and the results not disseminated widely enough. Few of the research projects have been collaborative to maximize the value of existing knowledge and the conclusions have rarely been linked.

To fulfil its numerous responsibilities under the 'Habitats and Species' Directive, for flood defence, water resources, water quality, fisheries, recreation and environmental protection the Environment Agency needs to understand the factors governing the success and failure of *Ranunculus* in Chalk rivers. This Research and Development (R&D) project aims to assess the current state of knowledge of those factors and the way forward to fulfil that need. This will be achieved by appraising the data available on *Ranunculus* in Chalk rivers with particular reference to the many responsibilities of the Environment Agency.

1.2 Phase 1 and Phase 2

1.2.1 Phase 1

It was decided to undertake the project in two phases. Phase 1 involved the gathering together of data. Phase 2 required a detailed appraisal of those data together with the drawing up future recommendations. The full Terms of Reference for the project are contained in the R&D Project Record (W1-042/PR).

Phase 1 of the project drew together all available source material on *Ranunculus* in Chalk rivers. To increase the value of the data being collated a number of Environment Agency staff in those regions containing Chalk rivers agreed to collate information in their areas about *Ranunculus* and Chalk rivers. They were asked to complete a proforma for rivers which they and their colleagues were familiar with. In addition, they were asked to supply details of any relevant internal reports together with details of any on-going research projects. A copy of the proforma was also sent to owners and river keepers (names supplied by the Environment Agency) whose knowledge and experience would be particularly useful to the project. An important component of the total material gathered in Phase 1 were the observations of the people who have lived, fished and worked on Chalk rivers.

A copy of the Phase 1 proforma and completed replies are contained in the Project Record.

A number of other individuals with knowledge of *Ranunculus* and Chalk rivers were contacted and also asked to fill in a proforma. Amongst those contacted were EN, The Wildlife Trusts, Royal Society for the Protection of Birds, Centre for Aquatic Plant Management, consultants and academics.

It was agreed that all documents gathered during Phase 1 should be given a preliminary classification as either Primary (P), Important (I) or Secondary (S) against 13 criteria which had been identified by the Environment Agency as important influences on *Ranunculus* growth in rivers. The 13 criteria are as follows :

1. Physical changes in Chalk rivers resulting from flood defence and other structural changes;
2. Habitat changes resulting from rehabilitation and restoration projects on Chalk rivers;
3. Changes in flow velocities and volumes whether caused by natural annual variations in rainfall or by abstraction;
4. The importance of velocity and water level, and relationship with abstraction, climate change and river dimensions;
5. Land-use and other catchment changes, including the nature of water use;
6. Vegetation management and control (chemical, mechanical, hand) for fisheries, land drainage, flood defence etc. (both strategic and reactive management regimes);
7. Nutrient enrichment, particularly point source increases in phosphate and diffuse sources from agriculture;
8. Suspended solid inputs from point source and diffuse sources;
9. Substrate characteristics, with special reference to changes in extent and patterns of siltation and where possible their causes;
10. Influence of competition with other macrophytes and algae (filamentous, epiphytic, diatomaceous);
11. Influence of management of other macrophytes of Chalk rivers and the effect on *Ranunculus* life cycles, colonization etc.;
12. Grazing by swans and other animals; and
13. Others - specify.

All material obtained or brought to the attention of the contractor from literature searches and other sources such as the Environment Agency (including documents that were rejected), was entered on a database using Microsoft Access software. The proforma responses are also held in a separate database table. Tables extracted from the Phase 1 database showing these details are in the Project Record.

1.2.2 Phase 2

Phase 2 of the project involved a detailed appraisal of the data gathered together with recommendations for future action. It was agreed that Phase 2 would seek to reach the objectives of the project by three main routes :

1. a review of documents collated primarily during Phase 1 together with any gathered during Phase 2;
2. an analysis of information provided on a snapshot form filled in by contacts within the Environment Agency giving brief details of the status of *Ranunculus* on Chalk rivers as well as river rehabilitation and research projects; and
3. a separate analysis of details of rehabilitation projects from Environment Agency and non Environment Agency sources.

The project was designed to provide conclusions from the data examined.

An essential requisite of the project was to identify if there was, within the documents, clear evidence of the cause and effect of various environmental and anthropomorphic influences on the growth and distribution of *Ranunculus*. It was felt that the review of the documents was the most productive approach in attempting to answer that question. The review would identify the extent of current knowledge on factors affecting *Ranunculus* and propose how to address any deficiencies in that knowledge. The review process was therefore the key to realizing the objectives of the project. Evidence of cause and effect could then be used to inform the day to day management of Chalk rivers. The project therefore has the potential to benefit the Environment Agency, and by dissemination, other agencies and owners, to meet their responsibilities to water resources, nature conservation, fisheries and flood defence. Equally, in key areas where evidence is insufficient or absent, recommendations would be made as to how these could be addressed. The data provided by the snapshot form and the details of rehabilitation projects together with discussion with Environment Agency contacts and non-Environment Agency staff added additional value to the review process, helping to consolidate information provided by the documents with observation and experience in the field.

2 METHODS

2.1 Review of Documents

The majority of documents were collated during Phase 1. They were included in the Phase 1 database on the basis of :

1. a quick review by the contractors;
2. comments by Environment Agency staff or non Environment Agency staff; and
3. were unseen but believed to be relevant to the project.

Documents were included in the database if they were believed to identify factors affecting *Ranunculus* growth and distribution or rejected if they clearly failed to establish any relationship.

In Phase 2 all of those relevant documents together with additional documents which subsequently came to light were collated and reviewed according to the methodology outlined below. They were then included on a new Phase 2 database in Microsoft Access. Part of the process of collating documents for review in Phase 2 included a trawl of publications in the library of the Centre for Ecology and Hydrology (CEH), Winfrith.

With the more thorough review that took place during Phase 2, and with the reviewing of previously unseen documents, several documents were found to be more or less informative for the purposes of this project than was apparent during the initial Phase 1 review. This led to several documents being re-evaluated and rejected. Although retained within the Phase 2 database these rejected documents were still reviewed but this was limited to a concise summary of the reasons for their rejection. A total of 311 documents were entered onto the Phase 2 database, 172 documents were accepted and 139 rejected.

The database of reviews undertaken in Phase 2 is contained on CDs (W1-042/CD) in Appendix 2 and in the Project Record (W1-042/PR). A copy of the database form is also in Appendix 2.

A number of documents were reviewed, using the agreed methodology, by others. In particular Hugh Dawson, CEH and *Ranunculus* Board Member, reviewed a body of research he and other colleagues have undertaken which is of interest to this project but is not yet published. These reviews indicate the nature of the research but at this stage are unable to define precisely what the results will be. These reviews are included in the database because they identify unpublished, but relevant, work. The research is described in Section 4.7.1.

2.2 Methodology of the Review

The review of each document that was accepted provides a summary of the salient points of the document. Since the primary requirement of the project was to understand the factors affecting *Ranunculus* the reviewing process concerned itself almost solely with those aspects of the documents that related to factors affecting

Ranunculus. A very general account is given of the work described in the document but those aspects which are not related to factors affecting *Ranunculus* are referred to only very briefly. In short, the purpose of the review was not to provide a comprehensive account of the whole document but only those aspects relating to factors affecting *Ranunculus*. Other data such as title, author, and date are included.

The identification of the cause and effect of the factors affecting *Ranunculus* was seen as a major output of the project. Equally, it was recognized that the inter-related nature of the environmental variables acting together in a Chalk river system would complicate the identification of the cause and effect. For example, there is general acceptance that velocity is a prime factor affecting *Ranunculus* growth. Velocity is a product, amongst other things, of discharge. Discharge is itself influenced by a variety of processes including weather and climate cycles, abstraction and river management. Despite the connectivity of the variables involved it was necessary to find agreement on the inter-relationships of influences on *Ranunculus* in order for the project to have a useful output that could be directly linked to the management responsibilities of the Environment Agency.

2.3 Factors and Drivers

The 13 criteria used for the Phase 1 review had been drawn up by the Environment Agency as part of the Project Specification and were considered as potentially the major factors affecting *Ranunculus* growth.

Between Phase 1 and 2 the numerous variables and their interactions were drawn up into a flow chart where some were nested together to show the interlinking nature of the potential influences on *Ranunculus* growth. The prime purpose of the chart was to attempt to link groups of criteria that had common factors and show how these are influenced by a multitude of drivers. The flow chart was presented to an invited forum of Environment Agency staff, academics, river keepers and others at the Reading offices of the Environment Agency on 9 May 2000 following the presentation of the results of Phase 1 of the project.

Following these discussions at the forum meeting and at a subsequent Project Board Meeting, it was concluded that nesting did not help with the process of determining what the key influences on *Ranunculus* growth are in Chalk rivers. Instead, the Phase 2 review process would be driven by identifying the key factors influencing *Ranunculus* success and the drivers influencing those factors. A list of the Factors and Drivers is given below:

<u>Factors</u>
A - Competition/Interaction/Life Cycle/Colonization;
B - Discharge/Seasonal Annual Changes;
C - Light/Shade/Temperature;
D - Substrate/Siltation;
E - Velocity/Depth/Levels;
F - Water Quality/Enrichment/Suspended Solids;
G - Grazing;
H - Physical Dimensions;
I - Drivers Identified but not linked to Factors; and

J - Most/All of the above.

Drivers

1 - Channel Management;
2 - Enrichment from Point Sources;
3 - Natural Climate Cycles;
4 - Factors not linked to Drivers;
5 - Others e.g. Shading by algae;
6 - Vegetation Management;
7 - Abstraction/Catchment Water Use;
8 - Land Use/Diffuse Enrichment;
9 - Rehabilitation/Augmentation/Fencing etc.; and
10 - Most/All of the above.

Thus the Factors are primarily measurable variables considered to affect *Ranunculus* growth and the Drivers are anthropogenic and natural influences that change the character of the Factors. Many of the Drivers are influenced by management and are the consenting responsibility of the Environment Agency. By linking the Factors to the Drivers it would therefore be possible to identify ways in which the Environment Agency could be assisted in their management of Chalk rivers for the benefit of *Ranunculus*. To help in the review process where there was no clear cut assessment of Factors and Drivers categories I and J and 10 were included.

2.4 Type and Basis of Information

Having established the Factors and Drivers to be identified during the review process it was also imperative to understand how they had been measured and determined. For example, was the conclusion in the document based on quantified data backed by statistical analysis from a field or laboratory experiment or was it a review of previously published material or a deduction or inferred conclusion based on previous research or personal observation. A list of the Types and the Basis of the Information is given below:

Type of Information

A - Quantitative with Statistical analysis;
B - Quantitative;
C - Qualitative; and
D - Interpretation/Inferred.

Basis of the Information

1 - Field (data collected in the field);
2 - Field/Experimental;
3 - Laboratory/Experimental;
4 - Review; and
5 - Not applicable.

The data in the document relating to *Ranunculus* were then condensed into a matrix consisting of Factors and Drivers, Type of Information, and the Basis of the Information. If a Factor was identified but was not linked to a Driver or if a Driver was identified but not linked to a Factor then this was also included in the matrix. Many of the documents are reviews of previous work that may have used a variety of types of study. These documents were classed in the matrix as a review and the Type of Information as interpretation/inferred. Some documents contained such a multiplicity of Factors, Drivers, Type and Basis of Information that they were given a Most/All category to avoid creating an over-large matrix.

2.5 Management Applications

Where a document provided information that had potentially useful applications for the Environment Agency's management of Chalk rivers this was indicated in a table of Management Applications. A list of these is given below :

Management Applications
A - Licensing: abstraction, discharges, cutting, dredging etc.;
B - Water resources: setting acceptable flow regimes, AMP etc.;
C - Conservation: wider countryside, SSSI, SAC, rehabilitation etc.;
D - Management: for Flood Defence, fisheries, weed management;
E - Determining protocols;
F - Not Applicable;
G - Responses to Land Use Changes;
H - Responses to Climate Changes; and
I - Most/All of the above.

This completed the review process. The Review Summary, Factor/Driver matrix and Management table were given a document number and entered on a database. The database could then be interrogated to produce the outputs presented later in this report.

2.6 Species Nomenclature

Of interest is the fact that the review revealed a considerable diversity of approaches to the naming of *Ranunculus* species (Table 2.1). Of the 172 accepted documents in the database 62 did not specify the species of *Ranunculus* cited. It is likely that the majority of these do relate to the Stream Water-crowfoot *Ranunculus penicillatus* subsp. *pseudofluitans*. In some documents the information relates to macrophytes, or weeds and the comment is made elsewhere that the dominant macrophyte or weed is *Ranunculus*. This information has therefore been taken to relate to *R. penicillatus* subsp. *pseudofluitans*, but has been recorded as '*Ranunculus* species not specified' in the keywords.

In 110 of the documents the species of *Ranunculus* is identified. Table 2.1 indicates how many documents contain information relating to the different species.

This table also indicates the range of Latin names given to Stream Water-crowfoot in the documents. Where a Latin name or common name has been used in the document it has been retained in the summary review and keywords of the database. This should be borne in mind if the database is interrogated for documents relating to a particular species. For example, if a query was placed to find all documents relating to *R. penicillatus* subsp. *pseudofluitans* var. *calcareus* the search would fail to find such documents where the author(s) had called the species *R. calcareus*.

Table 2.1 Species nomenclature utilized in database documents

Note	Nomenclature Used	No. of Docs
	Ranunculus penicillatus var. *calcareus*	24
	Ranunculus calcareus	20
	Ranunculus penicillatus subsp. *pseudofluitans*	16
1	*Ranunculus penicillatus calcareus*	15
	Ranunculus penicillatus pseudofluitans	11
	Ranunculus penicillatus ssp. *pseudofluitans* var. *calcareus*	3
	Ranunculus pseudofluitans	3
	Ranunculus penicillatus ssp. *pseudofluitans*	2
	Total	94
	Ranunculus penicillatus	6
2	*Ranunculus penicillatus* var. *penicillatus*	24
	Ranunculus penicillatus penicillatus	1
	Total	31
3	*Ranunculus penicillatus* var. *trichophyllus*	9
4	*Ranunculus penicillatus* var. *vertumnus*	5
5	*Ranunculus peltatus*	30
6	*Ranunculus fluitans*	20
7	*Ranunculus aquatilis*	7
8	*Ranunculus circinatus*	2
9	*Ranunculus baudotii*	1
10	*Ranunculus hedeaceus*	1
11	*Ranunculus omniophyllus*	1

Note 1: All the same species (subspecies).
Note 2: Any reference to *R. penicillatus* subsp. *penicillatus* is most likely to be in error if reported for UK Chalk rivers. (Holmes pers. comm. 2001)

2.7 Snapshot Forms

Environment Agency contacts of Phase 1 were contacted again in Phase 2 for information on the known status of *Ranunculus.* They were asked to fill in a snapshot form for each of the Chalk rivers in their Area or Region. The purpose of this form was to:

1. obtain an indication of the changes in *Ranunculus* status on the rivers over a period of several years or decades; and
2. identify the nature of the data held on *Ranunculus* by the Environment Agency.

To this end contacts were given a list of Chalk rivers in their Area and asked to indicate if they knew the status of *Ranunculus* on winterbourne, upper, middle and lower reaches during, and prior to, the 1990s. They were asked to indicate :

1. what data were available (e.g. surveys, reports and research projects);
2. whether there were any proposed research projects on *Ranunculus*; and

3. what rehabilitation projects had been carried out on Chalk rivers and whether or not these were intended to improve the status of *Ranunculus*, and if there had been a change since.

A summary of the information supplied by the Environment Agency contacts together with a copy of the snapshot form is in Appendix 3. The returned snapshot forms are contained in the Project Record.

2.8 Rehabilitation Projects

Contacts in the Environment Agency were asked to include rehabilitation projects on the snapshot form. Non Environment Agency staff engaged on rehabilitation projects and contacted in Phase 1 were also asked to provide details of their projects. All of these projects have been combined into a Table in Appendix 4.

A large numbers of small rehabilitation works take place every season on Chalk rivers, and as such are too numerous to mention. They generally take the form of narrowing or installation of flow deflectors to improve flow velocity and clean gravel for fisheries and to benefit *Ranunculus* and Chalk river ecology. The projects listed in this report are generally speaking more substantial.

3 RESULTS AND OBSERVATIONS

3.1 Introduction

This section presents the general results for each Factor and Driver by Type and Basis of Information. In addition, the links with Management Applications are presented together with the number of times particular Chalk rivers are cited. The snapshot form returns, details of the rehabilitation projects and relevant research projects are also discussed.

3.2 Factors

A total of 172 documents were reviewed. The breakdown of the number of documents and the number of times a Factor is cited by Type of Information is given in Table 3.1.

Table 3.1 Number of citations in documents to Factors by Type of Information

Type of Information Factor	A Quantitative with Stats No. of Citations in No. Docs	B Quantitative No. of Citations in No. Docs	C Qualitative No. of Citations in No. Docs	D Interpretation No. of Citations in No. Docs	Total No. of Citations in No. Docs
A - Competition etc.	3 in 3	2 in 2	10 in 9	30 in 25	45 in 39
B - Discharge etc.	5 in 5	8 in 7	26 in 23	31 in 31	70 in 54
C - Light etc.	7 in 6	10 in 10	11 in 9	31 in 31	59 in 51
D - Substrate etc.	1 in 1	4 in 4	38 in 27	24 in 22	67 in 54
E - Velocity etc.	7 in 5	11 in 11	41 in 30	30 in 28	89 in 72
F - Water Quality etc.	6 in 6	7 in 5	10 in 8	22 in 20	45 in 21
G - Grazing	0 in 0	1 in 1	9 in 9	8 in 8	18 in 18
H - Dimensions	0 in 0	2 in 2	3 in 3	9 in 7	14 in 12
I - Not linked	3 in 3	3 in 3	13 in 11	17 in 13	36 in 30
J - Most/All	9 in 8	3 in 2	5 in 5	32 in 25	49 in 31

Many documents have multiple citations to a particular Factor, or multiple citations to several of the Factors.

For example, a document could contain a quantitative piece of information relating to how Natural Climate Cycles affect Discharge which in turn affects *Ranunculus*. This same document could also contain information on Discharge that is not related to any particular Driver and is purely observational, or indeed based on interpretation of other workers findings. This document would therefore contain two citations to Discharge as the Factor, but they would be different in terms of linkages to Drivers and Type of Information.

The greatest number of citations within the documents reviewed (89) is to Velocity/Depth/Levels and the majority of this information is either qualitative (Type C) or inferential/interpretation (Type D). Discharge/Seasonal Annual Changes and Substrate/Siltation have the next highest number of citations, followed by

Light/Shade/Temperature. Both Discharge etc. and Velocity etc. have a body of information related to *Ranunculus* which is quantitative (Types A and B), but such information is scarce for Factor D which is much more dominated by qualitative or inferential/interpretation-type information.

The lowest number of citations are to Factors G (Grazing) and H (Physical Dimensions), neither of which have any information which is quantitative with statistical analysis.

A breakdown of the number of times an individual Factor is cited and linked to a Driver is given below. The Type of Information and the Basis of the Information is also given.

3.2.1 Factor A - Competition/Interaction/Life Cycle/Colonization

There are 39 documents which contain information relating to this Factor (Table 3.2). Of the total number of citations to Factor A over 50% are inferential/interpretation and are linked to a variety of Drivers. Natural Climate Cycles, Enrichment from Point Sources, Vegetation Management and Not linked to a Driver accounted for the majority of citations. Of the three studies that contained Type A quantitative information only one made a link to a Driver (Other - Shading).

Table 3.2 Number of citations to Factor A by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Not linked to Driver	1 x Field, 1 x Field Experimental
	Other:- Shading	1 x Lab
Quantitative	Natural Climate Cycles	1 x Field
	Not linked to Driver	1 x Field Experimental
Qualitative	Enrichment from Point Sources	1 x Field
	Natural Climate Cycles	4 x Field
	Not linked to Driver	1 x Field Experimental
	Other: Shade	1 x Field
	Vegetation Management	1 x Field
	Abstraction/Catchment Water Use	1 x Field
	Land Use/Diffuse Enrichment	1 x Field
Interpretation / Inferred	Channel Management	1 x Review
	Enrichment from Point Sources	4 x Field, 4 x Review
	Natural Climate Cycles	2 x Field, 2 x Review
	Not linked to Driver	1 x Field Experimental, 5 x Review
	Vegetation Management	2 x Field, 5 x Review
	Land Use/Diffuse Enrichment	2 x Review
	Rehabilitation/Augmentation etc.	1 x Field, 1 x Review

3.2.2 Factor B - Discharge/Seasonal Annual Changes

Factor B has the second highest number of citations, the highest number being to the allied Factor of Velocity (see Table 3.3). Over half the citations to Factor B are qualitative or interpretation/inferred information. The five which have Type A quantitative information were mostly linked with Natural Climate Cycles.

Table 3.3 Number of citations to Factor B by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Natural Climate Cycles	4 x Field
	Not linked to Driver	1 x Field
Quantitative	Natural Climate Cycles	4 x Field
	Not linked to Driver	1 x Field Experimental
	Abstraction/Catchment Water Use	1 x Field
	Rehabilitation/Augmentation etc.	1 x Field
	Most/All	1 x Field Experimental
Qualitative	Enrichment from Point Sources	1 x Field
	Natural Climate Cycles	19 x Field
	Not linked to Driver	1 x Field
	Abstraction/Catchment Water Use	1 x Field
	Rehabilitation/Augmentation etc.	3 x Field, 1 x Review
Interpretation / Inferred	Natural Climate Cycles	1 x Field, 3 x Review
	Not linked to Driver	3 x Field, 2 x Field Experimental, 5 x Review
	Other: hatch management, shading	2 x Review
	Abstraction/Catchment Water Use	11 x Field, 2 x Review
	Land Use/Diffuse Enrichment	1 x Field
	Rehabilitation/Augmentation etc.	1 x Field

3.2.3 Factor C - Light/Shade/Temperature

This Factor has one of the highest number and proportion of studies that contain quantitative information related to *Ranunculus* (Type A and B information) (see Table 3.4). The linkage to Drivers is also commonly made, not surprisingly the Driver frequently identified is Natural Climate Cycles.

Table 3.4 Number of citations to Factor C by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Natural Climate Cycles	2 x Field, 2 x Field Experimental
	Not linked to Driver	1 x Field Experimental, 1 x Lab
	Vegetation Management	1 x Field
Quantitative	Natural Climate Cycles	1 x Field
	Not linked to Driver	3 x Field, 2 x Lab
	Vegetation Management	2 x Field, 2 x Field Experimental
Qualitative	Channel Management	1 x Field
	Natural Climate Cycles	2 x Field
	Not linked to Driver	4 x Field
	Other: shading	4 x Field
Interpretation / Inferred	Natural Climate Cycles	3 x Field
	Not linked to Driver	2 x Field, 2 x Field Experimental, 7 x Review
	Other: shading	2 x Field, 1 x Field Experimental, 3 x Review
	Vegetation Management	3 x Field, 8 x Review

3.2.4 Factor D - Substrate/Siltation

Factor D has one of the highest number of citations in total with most of the studies being field based and yielding qualitative information, predominantly linked with Channel Management and Natural Climate Cycles (Table 3.5). Only one citation was Type A quantitative and this was not linked to a Driver. Two documents also describe the workings of this Factor on *Ranunculus* as a result of Rehabilitation/Augmentation work.

Table 3.5 Number of citations to Factor D by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Not linked to Driver	1 x Field Experimental
Quantitative	Channel Management	1 x Field
	Not linked to Driver	2 x Field, 1 x Field Experimental
Qualitative	Channel Management	13 x Field, 1 x Field Experimental, 1 x Review
	Natural Climate Cycles	13 x Field, 1 x Field Experimental
	Not linked to Driver	5 x Field, 2 x Review
	Rehabilitation/Augmentation etc.	2 x Field
Interpretation / Inferred	Channel Management	1 x Review
	Enrichment from Point Sources	2 x Field
	Natural Climate Cycles	1 x Field, 2 x Review
	Not linked to Driver	6 x Field, 1 x Field Experimental, 3 x Review
	Vegetation Management	1 x Field
	Abstraction/Catchment Water Use	3 x Review
	Land Use/Diffuse Enrichment	4 x Review

3.2.5 Factor E - Velocity/Depth/Levels

Factor E has the highest number of citations of all the Factors (Table 3.6). Most of the citations are qualitative and based on fieldwork with an obvious connection to Natural Climate Cycles, and Channel Management. However, there is also a significant body of information which contains statistical work on the relationship between this Factor and *Ranunculus*. Much of this is based on field or laboratory experiments.

Table 3.6 Number of citations to Factor E by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Channel Management	2 x Field Experimental
	Natural Climate Cycles	2 x Field Experimental, 1 x Lab
	Not linked to Driver	1 x Field, 1 x Field Experimental
Quantitative	Natural Climate Cycles	2 x Field
	Not linked to Driver	4 x Field, 2 x Field Experimental, 1 x Lab
	Vegetation Management	1 x Field Experimental
	Rehabilitation/Augmentation etc.	1 x Field
Qualitative	Channel Management	11 x Field, 1 x Review
	Natural Climate Cycles	16 x Field
	Not linked to Driver	4 x Field, 2 x Review
	Vegetation Management	1 x Field, 1 x Field Experimental
	Rehabilitation/Augmentation etc.	4 x Field, 1 x Review
Interpretation / Inferred	Channel Management	1 x Review
	Natural Climate Cycles	1 x Field, 3 x Review
	Not linked to Driver	5 x Field, 2 x Field Experimental, 9 x Review
	Other: hatch management	1 x Review
	Vegetation Management	1 x Field, 2 x Review
	Abstraction/Catchment Water Use	2 x Field, 3 x Review

3.2.6 Factor F - Water Quality/Enrichment/Suspended Solids

Nearly 50% of the citations to this Factor are based on interpretation or the impact on *Ranunculus* is inferred (Table 3.7). The Factor is most frequently linked to Driver 2 - Enrichment from Point Sources, however relatively few citations are made to the other Water Quality Driver - Land Use/Diffuse Enrichment (Driver 8). Of the six documents containing Type A quantitative information three were linked to Natural Climate Cycles, the others not being linked to a Driver.

Table 3.7 Number of citations to Factor F by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Natural Climate Cycles	2 x Field, 1 x Field Experimental
	Not linked to Driver	1 x Field, 2 x Field Experimental
Quantitative	Enrichment from Point Sources	3 x Field, 1 x Lab
	Not linked to Driver	1 x Field
	Land Use/Diffuse Enrichment	2 x Field
Qualitative	Channel Management	2 x Field
	Enrichment from Point Sources	4 x Field
	Natural Climate Cycles	1 x Field
	Abstraction/Catchment Water Use	1 x Field
	Land Use/Diffuse Enrichment	2 x Field
Interpretation / Inferred	Enrichment from Point Sources	3 x Field, 1 x Lab, 2 x Review
	Natural Climate Cycles	2 x Field
	Not linked to Driver	3 x Field, 6 x Review
	Land Use/Diffuse Enrichment	1 x Field, 3 x Review
	Rehabilitation/Augmentation etc.	1 x Field

3.2.7 Factor G - Grazing

This Factor had one of the least number of citations, practically all of which were qualitative or based on interpretation or inference and Not linked to a Driver (Table 3.8). There were no studies that were Type A quantitative. It can be seen that one document contains quantitative information on the impact of Grazing on *Ranunculus* based on field experiments.

Table 3.8 Number of citations to Factor G by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative	Not linked to Driver	1 x Field, 1 x Field Experimental
Qualitative	Not linked to Driver	6 x Field, 1 x Review
	Rehabilitation/Augmentation etc.	2 x Field
Interpretation / Inferred	Natural Climate Cycles	1 x Review
	Not linked to Driver	5 x Review
	Land Use/Diffuse Enrichment	1 x Field, 1 x Review

3.2.8 Factor H - Physical Dimensions

Factor H had the least number of citations, and a high proportion of this information is inferential or based on interpretation and occurs in reviews (Table 3.9). Most of these are based on qualitative studies and interpretation. Channel Management and Rehabilitation/Augmentation etc. are Drivers that are linked to this Factor in the literature. The document which presents field/experimental, quantitative information that links this Factor with Most/All of the Drivers is the work by Dawson on aspects of the hydraulic resistance of *Ranunculus* (Dawson. In Prep. doc 306).

Table 3.9 Number of citations to Factor H by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative	Not linked to Driver	1 x Field
	Most/All	1 x Field/Experimental
Qualitative	Not linked to Driver	1 x Field
	Rehabilitation/Augmentation etc.	1 x Field, 1 x Review
Interpretation / Inferred	Channel Management	4 x Review
	Not linked to Driver	2 x Field
	Vegetation Management	1 x Review
	Rehabilitation/Augmentation etc.	2 x Review

3.2.9 Factor I - Drivers Identified but not linked to Factors

Most of the citations to this Factor are based on qualitative studies and interpretation. The majority of these are linked to Vegetation Management (Table 3.10).

Table 3.10 Number of citations to Factor I by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Vegetation Management	2 x Field/Experimental
	Rehabilitation/Augmentation etc.	1 x Field
Quantitative	Vegetation Management	2 x Field, 1 x Lab
Qualitative	Other - poaching	1 x Field
	Vegetation Management	6 x Field, 1 x Field/Experimental
	Abstraction/Catchment Water Use	1 x Field
	Rehabilitation/Augmentation etc.	4 x Field
Interpretation / Inferred	Channel Management	1 x Review
	Enrichment from Point Sources	2 x Review
	Natural Climate Cycles	1 x Review
	Vegetation Management	1 x Field, 1 x Field/Experimental, 5 x Review
	Abstraction/Catchment Water Use	1 x Field, 3 x Review
	Land Use/Diffuse Enrichment	1 x Review
	Rehabilitation/Augmentation etc.	1 x Field

3.2.10 Factor J - Most/All

This 'catch all' category is used to identify those documents that contained a multiplicity of Factors, Drivers, Types and Basis (Table 3.11). This category contains two main types of information and documents. The greatest number are broad Review documents with inferred or interpretation based work which also linked the Factors with Most/All Drivers at some point in the review. However, this category also had the largest number of Type A quantitative studies with Natural Climate Cycles standing out as the main Driver. These documents tend to be the comprehensive research studies which consider many of the Factors and Drivers in a statistical way.

Table 3.11 Number of citations to Factor J by Type, Driver and Basis

Type of Information	Driver	Number & Basis of Citations
Quantitative with Stats	Channel Management	1 x Field
	Natural Climate Cycles	2 x Field, 2 x Field/Experimental
	Not linked to Driver	1 x Field
	Most/All	2 x Field, 1 x Review
Quantitative	Channel Management	1 x Field/Experimental
	Vegetation Management	1 x Field/Experimental
	Most/All	1 x Field/Experimental
Qualitative	Not linked to Driver	1 x Field/Experimental
	Most/All	2 x Field, 2 x Review
Interpretation / Inferred	Natural Climate Cycles	3 x Review
	Not linked to Driver	2 x Field, 1 x Field/Experimental, 1 x Review
	Other:- Shading	1 x Review
	Vegetation Management	2 x Review
	Abstraction/Catchment Water Use	3 x Review
	Land Use/Diffuse Enrichment	1 x Review
	Rehabilitation/Augmentation etc.	1 x Review
	Most/All	1 x Field, 16 x Review

3.3 Drivers

Table 3.12 shows the number of times each Driver is identified in the matrices together with the numbers of times this is linked with a particular Factor. The greatest number of citations are to Driver 4 (Factor not linked to Driver), indicating a common lack of linking Factors affecting *Ranunculus* with specific anthropogenic influences. The 'catch all' Driver (5) is least mentioned, and most commonly includes influences such as shade from algae, bankside or marginal vegetation. On one occasion poaching, and on two occasions hatch management, are cited as triggers to Factors operating on *Ranunculus*.

Climate is by far the most commonly identified Driver (3). Water Quality Drivers 2 and 8 (point source and diffuse enrichment), are relatively infrequently identified.

This should not be taken as meaning that they are not important, but that the emphasis of work reviewed for this study is not the origin of the water quality issues but more the mechanisms by which it operates in the river. Also this only refers to numbers of citations not the extent of study within each citation. Some major studies cover the issue of water quality in Chalk rivers, both source and impacts.

Table 3.12 Number of citations to Drivers by Factor

Driver	Factor	A – Competition etc.	B – Discharge etc.	C – Light etc.	D – Substrate etc.	E – Velocity etc.	F - Water Quality	G - Grazing	H - Dimensions	I - Not linked	J – Most / All	Total
1 - Channel Management		1	0	1	17	15	2	0	4	1	2	43
2 - Enrichment from Point Sources		9	2	0	2	0	13	0	0	2	0	28
3 - Natural Climate Cycles		9	31	10	17	25	6	1	0	1	7	107
4 - Driver not Linked to Factors		10	13	22	21	31	13	13	4	0	6	133
5 - Other e.g. Shading		2	2	10	0	1	0	0	0	1	1	17
6 - Vegetation Management		8	0	16	1	6	0	0	1	19	3	54
7 - Abstraction / Water Use		1	15	0	3	5	1	0	0	5	3	33
8 - Land Use / Diffuse Enrichment		3	1	0	4	0	8	2	0	1	1	20
9 - Rehabilitation / Augmentation		2	6	0	2	6	1	2	4	6	1	30
10 - Most / All		0	1	0	0	0	0	0	1	0	25	27

3.3.1 Driver 1 - Channel Management

The majority of citations to Channel Management as a Driver are qualitative rather than quantitative. The majority of these relate to how Channel Management affects *Ranunculus* through its impact on Substrate/Siltation and Velocity/Depth/Levels.

Table 3.13 Number of citations to Channel Management (Driver 1) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics					2					1	3
Quantitative				1						1	2
Qualitative			1	15	12	2					30
Interpretation/Inferred	1			1	1			4	1		8
Total	1	0	1	17	15	2	0	4	1	2	43

For Factors see Table 3.12

3.3.2 Driver 2 - Enrichment from Point Sources

Enrichment from Point Sources has relatively few citations in the database, and none of those refer to statistical work, in terms of impact on *Ranunculus.* The two mechanisms by which this enrichment is considered to affect *Ranunculus* is through Factor A (Competition/Interaction/Life Cycle/Colonization) and Factor F (Water Quality/Enrichment/Suspended Solids). Much work refers to the affect that enrichment has on affecting the competitive balance and interactions between species in Chalk rivers. The main tranche of information refers to the more direct effects of water quality on *Ranunculus* itself, for example stimulating growth. The point sources mostly relate to fish farms, but also include sewage treatment work, Water-cress beds and include observations regarding the effects of phosphate stripping. Comments regarding lack of observable impact are also recorded.

Table 3.14 Number of citations to Enrichment from Point Sources (Driver 2) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics											0
Quantitative		1				3					4
Qualitative	1	1				4					6
Interpretation/Inferred	8			2		6			2		18
Total	9	2	0	2	0	13	0	0	2	0	28

For Factors see Table 3.12

3.3.3 Driver 3 - Natural Climate Cycles

A great deal of work has been undertaken which relates *Ranunculus* growth to Natural Climate Cycles, largely through the influence of Discharge and Velocity/Depth/Levels (Factors A and B). As might be expected these two Factors resulting from variations in natural climate account for a large part of the work. Much of the work is qualitative but there is also a considerable bank of quantitative and statistical work. Amongst the quantitative work, including that involving statistical analysis, is the work done relating Natural Climate Cycles to *Ranunculus* growth through the effect on Light/Shade/Temperature.

Much of this work was undertaken by Dawson, Westlake and colleagues from 1968 to the present at the Institute of Freshwater Ecology (IFE) now CEH.

Table 3.15 Number of citations to Natural Climate Cycles (Driver 3) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics		4	4		3	3				4	18
Quantitative	1	4	1		2						8
Qualitative	4	19	2	14	16						56
Interpretation/Inferred	4	4	3	3	4	3	1		1	3	25
Total	9	31	10	17	25	6	1	0	1	7	107

For Factors see Table 3.12

3.3.4 Driver 4 - Factors not linked to Drivers

This category is the largest indicating that most of the citations are Factor-led, rather than Driver-led. This is spread fairly evenly across the Factors but with a higher proportion of information relating to Light/Shade/Temperature, Velocity/Depth/Levels, and Substrate/Siltation (Factors E, C and D respectively) not being linked to any Driver.

Table 3.16 Number of citations to Factors not linked to Drivers (Driver 4) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics	2	1	2	1	2	3				1	12
Quantitative	1	1	5	3	7	1	1	1			20
Qualitative	1	1	4	7	6		7	1		1	28
Interpretation/Inferred	6	10	11	10	16	9	5	2		4	73
Total	10	13	22	21	31	13	13	4	0	6	133

For Factors see Table 3.12

3.3.5 Driver 5 - 'Other'

The vast majority of citations to this Driver relate to shade from algae. This is not necessarily presented as competition but more as a response to enrichment which leads to increased algal growth, particularly epiphytic growth which then impacts on *Ranunculus* by physical shading.

Table 3.17 Number of citations to 'Other' (Driver 5) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics	1										1
Quantitative											0
Qualitative	1		4						1		6
Interpretation/Inferred		2	6		1					1	10
Total	2	2	10	0	1	0	0	0	1	1	17

For Factors see Table 3.12

3.3.6 Driver 6 - Vegetation Management

Vegetation Management could be considered both a Driver and a Factor. The requirement to manage the vegetation is driven by such needs as flood defence and fisheries management. Weed cutting has a direct effect on *Ranunculus* growth which is well documented in the literature. It is this direct effect which accounts for the large proportion of information which does not specify the Factor involved (therefore Factor I), as it is the Driver Vegetation Management creating the direct effect.

A number of documents show how *Ranunculus* responds to cutting at different times of year and under different hydro-climatic conditions. A relatively high proportion of this information is quantitative. A second element to the impact of vegetation management is how it affects other conditions in the river and how these then affect *Ranunculus*. A lot of this work has been carried out, over a considerable time span and on several rivers, by Westlake, Dawson and colleagues at IFE/CEH. The main indirect effects of vegetation management are through changes in the light environment, reduction in self shading, alteration of the competitive balance between macrophytes and algae and the effects on life cycle, particularly flowering, and ability to spread by vegetative means.

Table 3.18 Number of citations to Vegetation Management (Driver 6) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics			1						2		3
Quantitative			4		1				3	1	9
Qualitative	1				2				7		10
Interpretation/Inferred	7		11	1	3			1	7	2	32
Total	8	0	16	1	6	0	0	1	19	3	54

For Factors see Table 3.12

3.3.7 Driver 7 - Abstraction/Catchment Water Use

The first observation regarding the information relating to this Driver is the low number of citations to it within the literature reviewed. Much work has been done on the impacts of abstraction but very few documents or citations relate this directly to *Ranunculus.*

The second observation is the extent to which the information that exists is inferential with 85% of citations being of this type. Not surprisingly the greatest number of citations relate to how Abstraction etc. affects *Ranunculus* through its impact on Discharge and Velocity/Depth/Levels.

Table 3.19 Number of citations to Abstraction/Catchment Water Use (Driver 7) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics											0
Quantitative		1									1
Qualitative	1	1				1			1		4
Interpretation/Inferred		13		3	5				4	3	28
Total	1	15	0	3	5	1	0	0	5	3	33

For Factors see Table 3.12

3.3.8 Driver 8 - Land Use/Diffuse Enrichment

This is another Driver where there is a relative scarcity of information relating *Ranunculus* to the broader picture of catchment land use. Also a large proportion (75%) of the information only infers the link rather than describes or quantifies it. The greatest number of links are between Land Use, Diffuse Enrichment and the direct impact of Water Quality, Enrichment and Suspended Solids on *Ranunculus*. The documentation also includes a few inferences relating to the impact of Land Use and Diffuse Enrichment on Substrate/Siltation which in turn impacts *Ranunculus*.

Table 3.20 Number of citations to Land Use/Diffuse Enrichment (Driver 8) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics											0
Quantitative						2					2
Qualitative	1					2					3
Interpretation/Inferred	2	1		4		4	2		1	1	15
Total	3	1	0	4	0	8	2	0	1	1	20

For Factors see Table 3.12

3.3.9 Driver 9 - Rehabilitation/Augmentation etc.

There are relatively few references to rehabilitation within the literature reviewed. Some of these refer to major rehabilitation schemes whilst others are comments about small operations such as the observed effects of fencing on the *Ranunculus* within a small reach of Chalk river. The majority of citations are qualitative, describing how the rehabilitation affects Discharge and Velocity/Depth/Levels and thence *Ranunculus* within the study area.

A number of references are made to the fact that rehabilitation has an impact on *Ranunculus* but the Factor or mechanism involved is not mentioned (Factor I). The lack of quantitative or statistically tested data is noteworthy. This suggests either that the rehabilitation work is being carried out without systematic testing of the methods in relation to *Ranunculus*, or that if this is happening in the field it is not being written up and being made available. Additional data are held within the snapshots (Section 3.6 and Appendix 3) and within the section on rehabilitation (Section 3.7).

Table 3.21 Number of citations to Rehabilitation/Augmentation etc. (Driver 9) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics									1		1
Quantitative		1			1						2
Qualitative		4		2	5		2	2	4		19
Interpretation/Inferred	2	1				1		2	1	1	8
Total	2	6	0	2	6	1	2	4	6	1	30

For Factors see Table 3.12

3.3.10 Driver 10 - Most/All

Category 10 was utilized for documents which contained multiple citations to the Factors and Drivers often in different combinations of information type. Many of these documents are significant for that very reason. They tend to link the immediate Factors affecting *Ranunculus* with the Drivers that influence them. Many of the proofs of evidence given at the Axford Inquiry concerning abstraction on the River Kennet are included within this category. So are the major reviews of macrophytes, such as Haslam 1978 (doc 300) or Chalk streams, such as Mainstone 1999 (doc 298). Several of Dawson's papers in preparation (doc 301, 306, 310) suggest that they may deal with many of the Drivers.

Table 3.22 Number of citations to Most/All (Driver 10) by Factor and Type

Factor Type of Information	A	B	C	D	E	F	G	H	I	J	Total
Quantitative with Statistics										3	3
Quantitative		1						1		1	3
Qualitative										4	4
Interpretation/Inferred										17	17
Total	0	1	0	0	0	0	0	1	0	25	27

For Factors see Table 3.12

3.4 Links to Management Applications

The greatest number of citations is deemed to be applicable to Management (83 citations), particularly in respect of Flood Defence and Vegetation Management (Table 3.23). Licensing had the second highest number of citations (79) closely followed by Conservation with 77 citations.

Table 3.23 Management Applications

Management Category		No. of Citations	No. of Docs
A	Licensing	79	70
	- abstraction		32
	- discharges		26
	- weed-cutting		18
	- dredging etc.		3
B	Water Resources	33	33
C	Conservation	77	74
	- Conservation general		47
	- Conservation - rehabilitation etc.		13
	- Conservation - setting targets		6
	- Conservation - SSSI, SAC		9
	- Conservation - wider countryside		2
D	Management	83	60
	- Flood defence management		37
	- Channel Management		5
	- Vegetation Management		39
E	Determining protocols	13	13
F	Not Applicable	19	19
G	Responses to land use issues	7	7
H	Responses to climate change	10	10
I	Most/All of the above	20	20

3.5 Chalk Rivers and Numbers of Documents

Table 3.24 shows the listed Chalk rivers by region and catchment together with the number of documents in the database which have the river in the keywords. Some of the documents refer to many rivers, and some of the citations may be based on fairly slight information. However, it is clear from the table that the majority of Chalk rivers have no information relating to *Ranunculus* status or factors affecting *Ranunculus* growth. Within the literature reviewed for the database this amounted to 98 out of the 156 listed rivers, some 62%.

Table 3.24 Number of documents relating to the Chalk rivers

a) South West Region

River	No. Docs
HANTS/WILTS AVON	18
Etchilhampton Water	0
River Bourne	3
Nine Mile River	3
River Wylye,	17
Chitterne Brook	4
R Till	6
Fonthill Bishop Stream	0
River Ebble	3
Rockbourne Stream	0
Allen River	0
Teffont Stream	0
Ashford Water	0
DORSET STOUR	0
River Allen	2
Gussage Brook	0
Crichel Stream	0
River Iwerne	0
River Tarrant	2
North Winterbourne	1
Shreen Water, Ashfield Water	0
River Crane	0
RIVER FROME	25
Hooke Stream	0
Sydling Water	1
River Cerne	0
South Winterbourne	1
Tadnoll Brook, Empool Bottom, Watergates Stream	0
River Win	0
RIVER PIDDLE	10
Bere Stream	16
Devils Brook	1
Cheselbourne stream	0
River Bride	0
River Jordan	0
River Wey excl. Pucksey Brook	1
Osmington Mills Stream	0
Lulworth Stream	0

b) Southern Region

River	No. Docs
Bourne Rivulet	0
River Dever	0
River Anton, Pilhill Brook	0
Wallop Brook	1
Somborne Stream	0
RIVER ITCHEN	13
Candover Stream	4
River Alre	0
Cheriton Stream	0
RIVER MEON	1
Whitewool Stream	0
RIVER STOUR (KENT)	
Great Stour	2
Nailbourne/Little Stour	1
Wingham streams	0
North Stream.	0
South Stream.	0
RIVER DARENT	3
River Cray	0
River Ems (Sussex)	0
River Lavant (Sussex)	0
Lewes Winterbourne (Sussex)	0
River Dour (Kent)	0
Holborough streams	0

c) Thames Region

River	No. Docs
River Lambourn, Winterbourne	23
River Og	1
River Dun	1
River Aldbourne	0
River Shalbourne.	0
RIVER COLNE	1
River Ver	11
River Gade	5
River Bulbourne	4
River Misbourne	6
River Chess	2
RIVER LEE	0
River Stort	0
River Bean	4
River Rib	2
River Ash	0
River Quin	0
River Mimram	5
RIVER LODDON	1
River Lyde	0
River Whitewater	0
River Pang	6
Wye and Hughenden Stream	0
Letcombe Brook	1
Hamble Brook	0
River Wey (North)	1
Caker Stream	0
River Hogsmill	0
River Wandle	0
River Mole	0
Ewelme Stream	0
Chalgrove Stream	0
Horsenden Stream	0

d) Anglian Region

River	No. Docs
River Hiz	0
Little Ouse	0
River Cam	0
Rhee Upper Tribs e.g. Shep	0
Rhee	0
River Granta	0
Snail	0
Kennett	0
River Lark - Tribs	1
Cavenham Stream	0
River Thet	0
Sapiston	0
River Wissey & Tribs	3
Gadder	0
River Nar	1
Babingley	0
River Heacham	0

Anglian Region continued

River	No. Docs
RIVER YARE CATCHMENT	
River Wensum	1
River Tat	0
River Bure	1
RIVER EAU	0
Great Eau	0
Long Eau	0
OTHERS - Lincolnshire	
Waithe Beck	0
Thoresway Beck	0
Laceby Beck	0
River Lud	0
Keelby Beck	0
Barrow Beck	0
East Halton Beck	0
Skitter Beck	0
Burlands Beck	0
Stainfield Beck	0
Brocklesby Beck	0
River Bain	0
River Rase	0
Butforth Drain	0
River Stiffkey	0
River Burn	0
River Glaven	0

e) North East Region

River	No. Docs
RIVER HULL	12
Watton Beck	0
Skerne Beck	2
Driffield Trout Stream	0
Southburn Beck	0
Eastburn Beck	0
Driffield Beck	1
Elmswell Beck	0
Water Forlorns	0
West Beck	7
Nafferton Beck	0
Kelk Beck	0
RIVER DERWENT	1
Hayton Beck and Tribs	1
Pocklington Beck Tribs	1
Tribs. of Barlam Beck	1
Menethorpe Beck and Tribs.	1
Setrington Beck & Tribs.	1
Scampston Beck and Tribs.	1
The Gypsey Race	0

Table 3.25 is a condensed list of rivers mentioned in five or more documents. The Kennet is mentioned in 29 documents. This may be a reflection of the long term research undertaken on this river, together with documents taken from the Axford Inquiry and interest shown in the river since the Inquiry. The Frome and Lambourn are mentioned 25 and 23 times respectively undoubtedly attributable to the years of research carried out on these rivers by CEH personnel. Surprisingly, the Test, so long regarded as the classic Chalk river, was only mentioned in eight documents.

Table 3.25 Chalk rivers cited in five or more documents

River	No. of Docs
River Kennet	29
River Frome	25
River Lambourn, Winterbourne	23
Hants/Wilts Avon	18
River Wylye	17
Bere Stream	16
River Itchen	13
River Hull	12
River Ver	11
River Piddle	10
River Test	8
West Beck	7
River Till	6
River Misbourne	6
River Pang	6
River Gade	5
River Mimram	5

Additional information about Chalk rivers and *Ranunculus* status resides in the snapshot survey returns and analyses. Although this is not comprehensive it gives a further indication of the extent of knowledge regarding *Ranunculus* in these rivers.

3.6 Snapshot Form Returns

The summary of snapshot form returns in Appendix 3 is based on information supplied and discussion with Environment Agency contacts. Not all of the Environment Agency contacts were able to supply information on *Ranunculus*. This was because some areas of the Environment Agency where there are Chalk rivers the status of *Ranunculus* was not known or the rivers had little or no *Ranunculus* present. In addition many rivers have had little or no survey work undertaken which specifically set out to determine the status of *Ranunculus*. River Corridor Survey and/or River Habitat Survey exist for many rivers. Extracting data on *Ranunculus* however is time consuming and due to the nature of the survey methodology employed is either unlikely to be recorded (RHS) or unlikely to reveal more than the most general picture of *Ranunculus* distribution (RCS). Lack of routine or follow up surveys also make it difficult to determine *Ranunculus* status over a number of years. The regular biological monitoring of rivers is, unfortunately, rarely accompanied by surveys of macrophytes due to constraints of time and resource.

All Environment Agency contacts mentioned that despite the low flows of the late 1980s and early 1990s and the reported reduction in *Ranunculus* presence as a consequence, *Ranunculus* appeared to have had particularly successful years in 1999 and 2000. This has been attributed to improved winter discharge. The reporting of poor growth in low-flow years in the early 1990s, and the recovery in 1999/2000 is very consistent with the conclusions drawn from the literature that climate is the key driver in most cases. This observation was general, Environment Agency staff rarely referred to all the Chalk rivers in their Area. Knowledge of the status of *Ranunculus* appears to be restricted to a relatively small number of Chalk rivers, although this is not the case in every Environment Agency Area. Many of the smaller tributaries even on the more well known rivers such as the Itchen have not been surveyed in detail on a regular basis. The snapshot forms reveal that there are many rivers where there is no specific information on *Ranunculus*. Information is often also lacking on certain reaches where *Ranunculus* is not a significant or dominant macrophyte.

There are many listed Chalk rivers that do not have and have never had any significant quantities of *Ranunculus*. This raises significant questions about the proposed conservation of these rivers.

Rehabilitation data from the snapshot form are in Appendix 4.

3.7 Rehabilitation Projects

The majority of rehabilitation schemes specifically intended to improve habitat for *Ranunculus* were designed to increase flow velocity (Appendix 4). This is also the usually desired result of fisheries rehabilitation projects. This invariably results in the increased presence of *Ranunculus*, for reasons such as more efficient utilization of available carbon, reduction in silt and reduction in the presence of algae. Some of the results have been spectacular. Recent projects on the Avon near Salisbury have seen *Ranunculus* returning and occupying most of the in-channel habitat (S. Cain pers. comm. 2000). Most of the schemes listed here are of recent origin and few have had the benefit of comprehensive monitoring. Whether the initial outcome will be sustained, must for the moment, remain unknown. There is also the question of whether wholesale increases in *Ranunculus* are ultimately desirable if this proves to be to the detriment of other members of the macrophyte community.

The results of recent projects should also be treated with caution for more practical reasons. Higher flows in the late 1990s and particularly 1999/2000 and the winter of 2000/2001 have provided conditions favourable to *Ranunculus* growth (Holmes - Kennet, Grieve - Avon - pers. comm. 2000). Under such improved discharge conditions the relative contribution of the rehabilitation scheme may be difficult to determine.

3.8 Research Projects

The research projects on Chalk rivers brought to the attention of this project are outlined below. These are discussed in more detail in Section 4.7.

3.8.1 Various aspects of *Ranunculus* and Chalk rivers, Hugh Dawson *et al.*, CEH

A number of unpublished papers of Hugh Dawson *et al.*. on many important aspects of *Ranunculus* ecology have been collated and previewed for this project.

3.8.2 Assessment of the impact of nutrient removal on eutrophic rivers

University of Leicester are investigating the impact of nutrient removal on the River Wensum.

3.8.3 Assessment of rehabilitation schemes on Chalk rivers

Peter Shaw and Terry Langford at Southampton University are to expand their study of rehabilitation projects on Chalk rivers.

3.8.4 Investigation of ecological change in the Rivers Kennet and Lambourn

This is a study into the long term ecological change and impact of the 1996 to 1997 drought.

3.8.5 River Itchen Sustainability study

Study by Halcrow Group Ltd to meet the requirements of the SAC status of this river, including the maintenance of 'favourable condition' and 'status' for *Ranunculus*.

3.8.6 Macrophyte survey of the River Misbourne

Ardeola Environmental Services (AES) have carried out a macrophyte survey for the Environment Agency of the River Misbourne.

3.8.7 Ecological assessment of river rehabilitation schemes

PhD study by Judy England, Thames Region Environment Agency, investigating rehabilitation projects and plant colonization.

3.8.8 Study of the sediment preferences of macrophytes

Dr Stewart Clarke, Queen Mary College, London has completed work on the sediment preferences of a number of macrophytes including *R. penicillatus* subsp. *pseudofluitans.*

4 ANALYSIS AND DISCUSSION

4.1 Introduction

The Factors identified from the documents are discussed in Section 4.2. The relative number of documents dealing with a particular Factor is not necessarily indicative of the importance of that Factor. Nevertheless, Velocity, is mentioned in 72 documents and has the highest number of citations. Discharge has the second highest number of citations at 70 and is mentioned in 54 documents. Water quality is mentioned in 21 documents.

Drivers that influence *Ranunculus* growth through their effects on the Factors, and their links with Management Applications, are discussed later in Section 4.3.

4.2 Factors

4.2.1 Factor A - Competition/Interaction/Life Cycle/Colonization

The natural life cycle of *Ranunculus* is described in many papers. Under natural flow conditions there is a succession from *Ranunculus* when velocities are high in spring and early summer to Water-cress in late summer and early autumn. Water-cress is then normally washed out by high winter flows. A number of papers describe the relationship between *Ranunculus* and Water-cress and flow (Ham *et al.* 1981 doc 4; Ladle & Casey 1971 doc 13; Dawson *et al.* 1978 doc 105; Westlake 1967 doc 106; Dawson 1979 doc 122; Dawson 1979 doc 130; Armitage 1995 doc 141; Giles *et al.* 1991 doc 142; Westlake 1981 doc 148; Cave 2000 doc 283). The typical seasonal succession is dominated by *Ranunculus* which requires the high spring flow rates and consequent growth rates to achieve early dominance. It is the rapid growth and seasonal slowing of flows that combine to induce these important cycles of dominance in Chalk plant communities. The cycle of *Ranunculus* and Water-cress is delicately balanced and usually entirely dependent on flow sequence.

Other cycles have variously been described with *Apium nodiflorum* (Ladle & Bass 1981 doc 88; Giles *et al.* 1991 doc 142), and with *Berula erecta* and *Callitriche* species (Ham *et al.* 1981 doc 4; Ham *et al.*. 1982 doc 10; Wright *et al.* 1982 doc 115; Haslam undated doc 120; Westlake 1981 doc 148; Ham 1977 doc 182; Haslam 1978 doc 300).

Haslam (1978 doc 300) suggests that the overall controlling factors in the distribution of river plants are flow and substrate, and that competition is much less important in river communities than in typical land communities. However, competition is mentioned frequently in the literature regarding factors affecting *Ranunculus*. Ham *et al.* (1981 doc 4) describe the natural cycles of *Ranunculus*, *Berula* and *Callitriche* in the Lambourn between 1971 and 1976 in relation to cycles of flow and changes in environmental conditions. They found that the growth of *Berula* and *Callitriche* appeared to be controlled by the growth and recession of *Ranunculus*, which was the dominant plant in the system. In a later study (Ham *et al.* 1982 doc 10) using data from 1971 to 1980, on a shaded site they were able to study further the interactions of the three species and make comments on factors which altered this balance. They suggested that there were relatively low levels of interaction due to temporal and spatial separation.

An important observation was that in shade, conditions sub-optimal for *Ranunculus*, it was less able to compete with *Berula*, except in conditions of high discharge. Haslam (undated doc 120 and 1978 doc 300) also describes the interaction between *Berula* and *Ranunculus*. The importance of light for good *Ranunculus* growth is highlighted.

In winterbournes or upper perennial reaches interaction/competition between *R. calcareus*, (Stream Water-crowfoot) and *R. peltatus* (Pond Water-crowfoot), and *A. nodiflorum* is described (Westlake 1981 doc 52; Ladle & Bass 1981 doc 88; Giles *et al.* 1991 doc 142). Ladle and Bass (1981 doc 88) describe the process in a small Chalk stream responding to drying during drought conditions. The normal cycle was disrupted by drought such that winter flows failed to remove the accumulated *Apium*, which heavily shaded the *Ranunculus* thereby preventing late season regrowth.

Following the dry period a number of *Ranunculus* seedlings were observed but these were subsequently found to be *R. peltatus*, which quickly came to dominate once the *Apium* had been removed for flood alleviation purposes. The paper illustrates the competitive advantage *R. peltatus* and *Apium* have over *R. calcareus* in such situations, in part, due to reproductive strategy (see also Holmes 1999 doc 30).

Many documents deal with the consequences for *Ranunculus* when these natural cycles/balances are disrupted by some perturbation. A wealth of information relates to the effect of weed cutting on *Ranunculus* life cycle, growth, recession, flowering etc. These are discussed in the section on Factor I (Section 4.2.9). Specific impacts of vegetation management on the competitive balance are mentioned in some documents. Soulsby (Soulsby 1974 doc 6) describing a heavy autumn cut on the Candover Brook suggested that the pattern of dominance had been changed and that *Ranunculus* had increased due to space being created by the removal of *Callitriche*. On the River Petteril (not chalk) it was observed that cutting plants (*Ranunculus*) in July meant that they had to compete with well established *Cladophora* which probably accounted for the poor regrowth.

In terms of the impact of cutting on the competitive advantage of *Ranunculus*, Westlake suggests that, especially in small streams, it is only regular cutting of the weed beds and grazing of the banks that allows *Ranunculus* to survive. He reports that a three month neglect of a small stream led to *Ranunculus* disappearing under Water-cress and Water celery. The implication made here and elsewhere (Mainstone 1999 doc 298) is that in many Chalk rivers the natural state would not be for large amounts of *Ranunculus* and that it is maintained at artificially high levels by vegetation management and other practices which have favoured it over its competitors. In fact management of *Ranunculus* and Chalk rivers has helped create the habitat and diversity that the UK Chalk Stream Biodiversity Action Plan and Habitats Directive (SACs) now require to be protected.

The other main perturbations discussed in the literature are enrichment and low flows. Spink *et al.*. (1993 doc 3) set up an experiment to investigate the effect on *Ranunculus* of phosphate elevation and competition with *Potamogeton pectinatus*.

Due to algal growth in the enriched experiments they were also able to comment on the role of algae in the equation. When competing with *P. pectinatus*, *Ranunculus* ordinarily responded with reduced root growth. Under enrichment, shoot and root growth were reduced, the most likely cause being shading from the algae. They were able to conclude that *P. pectinatus* is more competitive than *Ranunculus* under enrichment. This was supported by the observation that *R. fluitans* and *R. penicillatus* subsp. *pseudofluitans* are often replaced by *P. pectinatus* where there is an inflow of polluted water, for example sewage effluent.

The majority of the documents dealing with competition and enrichment describe the effect of algae on *Ranunculus*. Parr *et al.* (1998 doc 174) describes the process: Rooted plants can gain much of their nutrient requirements from the sediment, whilst algae rely principally on uptake directly from the water column. Elevated phosphorus concentrations in either the sediment or water column can therefore seriously affect the macrophyte community.

A body of work exists on the effect of enrichment on algae. Some of this is discussed in relation to *Ranunculus* in the section on Water Quality/Enrichment/Suspended Solids (Section 4.2.6). Much of the work relating to the impact on competition is observational. However Cranston *et al.* (1996 doc 295), modelling macrophytes in the Test and Itchen, attempted to quantify some of the interactions. Statistical analyses of longitudinal macrophyte survey data on the two rivers revealed a significant negative correlation between the cover of the *Ranunculus* and the cover of filamentous algae, underlining the importance of competition between the two species.

Some work on the Hull (Goulder & Carr 1994 doc 77; Robbins 1982 doc 183; Chalk 1986 doc 221; Chalk 1982 doc 256) showed that the competitive balance between *Ranunculus* and algae is not only influenced by enrichment, but is also further complicated by vegetation management, discharge, time of year and depth. For example, the organic enrichment from a fish farm was found to encourage the growth of filamentous algae.

This was accompanied by a decrease in the growth of *Ranunculus* particularly at times of low flow when growth became stunted and epiphytic algae and silt were deposited on the plant. However, at times of higher flow *Ranunculus* growth seemed to be stimulated by the enrichment.

Low flows are frequently cited as exacerbating the factors affecting *Ranunculus*. Mantle and Mantle (1992 doc 17) provide a review of how low flows affect the balance between *Ranunculus* and Water-cress. They also make the important point regarding timing and impact. If the winter/spring flows are inadequate to wash out the accumulated silt and previous year's growth of Water-cress, then the early spring growth of *Ranunculus* will be retarded and it will lose its advantage over other species.

From the literature competition is seen to be a major factor affecting *Ranunculus* growth in Chalk streams and the main Drivers appear to be Vegetation Management, Shade and Enrichment, the effects of which are variously exaggerated or alleviated by discharge. High discharge alleviates the competitive stresses on *Ranunculus* and low flows exaggerate them.

Included within this Factor are the processes of reproduction and colonization. Quantitative data on seed production and viability appear very scant for *R. penicillatus* subsp. *pseudofluitans*. Preston and Croft (1997 doc 287) report that the extent to which subsp. *pseudofluitans* reproduces by seed or by the spread of vegetative fragments is unknown; reproduction by seed may be rare. Westlake (1981 doc 52) suggests that *R. calcareus* is thought to be a hybrid which does not set much fertile seed, so reproduction is usually vegetative. The opinion regarding low seed production, germination and seedling production is echoed in the literature e.g. (Holmes 1999 doc 30; Holmes 1996 doc 35; Dawson 1980 doc 47; Ladle & Bass 1981 doc 88).

R. peltatus is reported to produce prodigious amounts of seed (Holmes 1999 doc 30). *R. fluitans* has been studied by Decamps (1985 doc 23) and he reports the role of sexual reproduction to be far from negligible.

Large numbers of fertile seeds are produced which have long viability and are able to withstand drying. The germinative power was also studied, with *R. fluitans* characterized by slow germination with a maximum of 45% viability after 7 months. The young plants grow rapidly in favourable conditions and preferentially in heterogeneous substrates. They produce adventitious roots forming a root stock at the beginning of growth.

4.2.2 Factor B - Discharge/Seasonal Annual Changes

The large number of documents commenting on Discharge generally, Seasonal Annual Changes in flow, and *Ranunculus* growth, consider this Factor primarily in relation to Natural Climate Cycles (Driver 3). The impact of this Factor is universally regarded as of prime importance to the growth and distribution of *Ranunculus*. In sufficient quantity it is instrumental in stimulating healthy growth, clearing away senesced plant material and silt at the end of the growing season along with potential competitors and cleaning the substrate ready for regeneration and colonization the following year.

From their 10 year study on the Lambourn, Ham *et al.* (1981 doc 4 & 1982 doc 10) and Ham (1977 doc 182) obtained a positive correlation between spring discharge (March, April, May) and *Ranunculus* growth and a negative correlation between discharge and the area of silt under *Ranunculus* beds. In higher discharge years a higher proportion of *Ranunculus* rooted in gravel and under these more favourable conditions *Ranunculus* was able to over grow *Berula* even in shade. During the 1976 drought on the Lambourn *Ranunculus* at two sites was only 50% of that recorded at higher discharges. Heavy rains in the following year removed silt and *Ranunculus* returned to its normal status. The timing of the seasonal increase in discharge is important. *Ranunculus* is co-dominant with Water-cress, the latter invading the *Ranunculus* as velocity decreases towards the end of the summer. Typically autumn floods wash out the Water-cress allowing *Ranunculus* to quickly regrow and occupy the majority of the channel. If the floods are late, Water-cress expands and restricts the growth of *Ranunculus*. The timing of the autumn floods therefore leads to higher or lower *Ranunculus* survival the next year (Dawson *et al.* 1978 doc 105).

Increased pumping in 1976 on the Candover Brook did not have a noticeable effect on the growth of *Ranunculus* suggesting the pattern of poor growth may be determined before May after which the plant is unable to respond (in that year) to changes in flow. It is said that impacts on the flora would have to be considerable to be detectable over and above the high level of natural variation in macrophyte cover and biomass (Southern Water Authority 1979 doc 159).

The low flow years of the late 1980s and early 1990s with their lack of rain, summer droughts and inadequate winter recharge are identified as a time when major changes in *Ranunculus* distribution took place on many Chalk rivers (Mantle & Mantle 1992 doc 17). There are numerous studies, accounts and reviews of the impacts of those years demonstrating the adverse impact that low flows and associated conditions had on *Ranunculus* in Chalk rivers and documenting the recovery of *Ranunculus* following good recharge. Examples of this include numerous headwater reaches (Holmes 1999 doc 30), the Lambourn and Kennet (Wright *et al.* 1999 doc 132; Green 1999 doc 134; Wright *et al.* 2000 doc 137) and the Lower Wylye (McIvor 1998 doc 124).

On the Allen very low summer flows weakened the growth of *Ranunculus* making it vulnerable to being removed by high winter flows which occurred in 1989/90 and 1994/95 with recovery in the years in between. The findings of this study have produced provisional recommendations to maintain the minimum prescribed flow of >0.60 cumecs from April to July and in the middle Allen >0.40 cumecs for August and September (Green & Cooling 1993 doc 53; Green & Crowhurst 1999 doc 50). In considering the impact of low flows on the Wylye and tributaries it was concluded that there was not sufficient information to decide if there was a deteriorating situation or just a natural cyclical one. It appears however that a recovery from the low flows of 1980s/90s has taken place due to the appearance of healthy *Ranunculus* growth following the improved flow regimes of 1998 and 1999 (Green 1999 doc 134).

Many observers have implicated increasing abstraction as exacerbating the impact of low flows. At the Axford Inquiry into abstraction on the River Kennet in 1996, Newbold (1996 doc 180) quoted figures taken from a previous study on the Kennet by Berrie and Wright (1978 doc 136). The study indicated that the relationship of flow and *Ranunculus* growth appears to disappear at a critical flow rate of approximately 0.5 cumecs. A winter flow rate of between 0.929 cumecs and 1.427 cumecs prevented an increase in sedimentation and *Ranunculus* appeared to be healthy at a minimum summer flow rate of 1.291 cumecs. Calculating that sediment loads had increased since the late 1970s winter flows would need to be 2.814 cumecs rising to 6.79 cumecs and summer in excess of 1.291 cumecs to effect the essential rip out of plant material and removal of silt. Newbold quotes Berrie and Wright (1978 doc 136) as saying that *Ranunculus* grows best when silt loads only cover 4% of the river bed at a winter flow rate of 2.84 to 6.79 cumecs with a minimum summer rate of 1.29 cumecs. However, these figures can only be helpful in determining the in river needs of *Ranunculus* when linked to information on channel dimensions, gradient etc.

The Inspector at the Inquiry was not entirely clear what winter flow was required (Inspector's Report 1996 doc 277). A typical winter peak was 400 Mld. Thames Water calculated 200/300 Mld to effect scour whereas EN had put the figure at 170 to 590 Mld. The Inspector had no particular concern about the impact the maximum 20 Mld abstraction demand would have on the effect of scour in a normal winter. He estimated the limiting flow rate on *Ranunculus* growth to be between 43 Mld and 112 Mld. It was also argued at the Inquiry that even in the drought year of 1991 stopping abstraction would have had little effect on flows and a more sensible long term improvement would be to remove sluices and hatches together with a programme of rehabilitation (Crafer 1996 doc 131).

Abstraction is accepted as having an effect on flows on the Upper Wylye and Chitterne (Holmes 1999 doc 257). Loss of *R. penicillatus* subsp. *pseudofluitans* on the Darent and *R. peltatus* on the Ver and possible loss or decline of *Ranunculus* on the Misbourne and Pang have all been attributed to abstraction (Halcrow 1987 doc 281).

In their draft generic targets for floating formations of *Ranunculus* of plain and sub-mountainous rivers, EN specify that the flow regime should be characteristic of the river. As a guide at least 90% of the naturalized flow (flow in the absence of abstractions and discharges) should be maintained throughout the year at all points in the river system (EN 2001 doc 76).

Despite the high winter flows of 1998/1999, 2000/2001 the problems of maintaining adequate discharge to conserve *Ranunculus* may be limited by climatic factors. It was noted during the macrophyte study on the Test and Itchen from 1991 to 1997 that the study had taken place against a background of profound changes in the hydroclimate of the British Isles since the 1960s with declines in summer storms, lower summer rainfall totals and higher temperatures (Cranston *et al.* 1998 doc 296). The south east of England in particular is predicted to experience much drier summers due to climate warming.

4.2.3 Factor C - Light/Shade/Temperature

In 1927 Butcher (doc 5) recorded the fact that *Ranunculus* on the Itchen diminished when it was in shade. Experiment and observation have confirmed that *Ranunculus* is shade intolerant and that shade is an important stress factor limiting its growth (Spink *et al.* 1990 doc 8). In the classic 10 year study of a shaded and unshaded site on the Lambourn high light availability enabled *Ranunculus* to dominate and out-grow *Berula* but on the shaded site *Berula* was dominant (Wright *et al.* 1982 doc 115). Furthermore, shading by epiphytic diatoms during periods of low flow was thought to hold back *Ranunculus* growth even on the unshaded site (Wright 1973 doc 119; Berrie & Wright 1978 doc 136; Wright *et al.* 1982 doc 115).

One of the impacts of the low flow years of 1989 and early 1990s cited by witnesses at the Axford Inquiry was the increased filamentous and epiphytic algae in the Kennet (and other Chalk rivers) coating and shading *Ranunculus* and adding to the other stresses suffered by the plant. Accumulation of silt also associated with low flows will reduce light intensities and oxygen levels jeopardizing seed germination (Mainstone 1999 doc 298).

The analysis of data from the macrophyte study of the Test and Itchen from 1991 to 1995, showed that the most frequently occurring group of statistically significant variables was that relating to flow regime followed by those relating to the sunlight/temperature regime (Wilby *et al.* 1998 doc 289). Grieve stated that shade, along with water velocity and depth, were of primary importance in determining the local distribution of *Ranunculus* in the Avon catchment (Grieve *et al.* 1999 doc 228). Weston thought that the headwaters of becks of the Derwent catchment (Yorks.) were too small and too heavily shaded to support *Ranunculus* (Weston 1996 doc 253). From his work on the Frome, Dawson (1976 doc 108) found a significant correlation between biomass and mean water depth (0.35 m to 2.75 m), which was explained by shading and light availability.

Dawson proposes the use of artificial and, particularly, natural shade as a means of controlling *Ranunculus* growth. He suggests a range of options, depending on the size and aspect of the river, for planting or leaving uncut marginal and bankside vegetation to effectively control growth in the channel. These methods are recommended as a more benign form of management than traditional weed cutting with all its attendant ecological impacts (Dawson 1978 doc 79; Dawson & Kern Hansen 1978 doc 78; Dawson & Hallows 1983 doc 91 and others).

The literature on the effects of temperature is limited with Crisp *et al.* 1982 stating that little is known about temperature responses of plants in rivers (Crisp *et al.* 1982 doc 168). What is available suggests that light in general is the main limiting factor. Experimentally *Ranunculus* respiration rates increased with temperatures up to 25 ^{o}C with permanent damage at higher temperatures (Dawson *et al.* 1981 doc 49).

4.2.4 Factor D - Substrate/Siltation

Many documents mention that both substrate and siltation are important influences on *Ranunculus* occurrence in Chalk rivers. The majority of this information is qualitative or inferred. The closely related Factor of suspended solids inputs (Factor F) is dealt with in Section 4.2.6.

The sources of silt into the system are rarely detailed however, the contribution by Water-cress farming is quantified by Casey & Smith (1994 doc 1) and the delivery of fine sediment from agricultural land and mechanisms for controlling it are briefly discussed by Wood and Armitage (1997 doc 84 and 1999 doc 94).

The impact of sympathetic or non-sympathetic land use and its effect on siltation and *Ranunculus* health on the Avon system is briefly mentioned by Grieve *et al.* (2001 doc 311).

Channel Management including dredging are implicated occasionally (Wood & Armitage 1997 doc 84; Wright *et al.* 1982 doc 115; Crafer 1996 doc 131) as is cattle poaching (Greenwood 1988 doc 231; Holmes 1996 doc 236; Terry Newman pers. comm.)

Several documents illustrate the importance of substrate type to the flora in general and *Ranunculus* in particular. Many of these documents also recognize how velocity and substrate type are inextricably linked (e.g. Mainstone *et al.* 1993 doc 149). The earliest observations of the link between flow, substrate and macrophytes were made by Butcher 1927 and 1933. (docs 5 and 33). He observed on the River Itchen that *Ranunculus* was associated with coarser substrates. He also recognized the importance of silt and designated communities as non-silted or silted. *R. fluitans* and *R. penicillatus* subsp. *pseudofluitans* were both in the non-silted category.

Many later works have observed the preference of *Ranunculus* for coarser substrates e.g. Holmes' classification of Winterbournes (Holmes 1996 doc 35), Goriup's classification of Rivers and Streams in South England (Goriup 1981 doc 150; Goriup 1978 doc 151). Goriup also found *R. penicillatus* to have a broad preference of substrate types, including silt. The consensus is, however, that *Ranunculus* prefers non-silted, coarse substrate. *R. fluitans*, in particular, is considered to require a stable substratum of pebbles and that the physical nature of the substrate is the limiting factor in its distribution (Cook 1966 doc 226).

Quantitative studies on the impact of substrate size on *Ranunculus* growth and distribution are very limited. Only one of these studies is confined to a Chalk river, and is that undertaken by Maddock and Petts on the habitat availability for *Ranunculus* in the River Kennet (Maddock & Petts doc 153). However the preference curves constructed for *Ranunculus* were based on professional judgement.

Other quantitative work on substrate preferences is either across river types, such as Spink's work on the ecological strategies of aquatic *Ranunculus* species (Spink 1992 doc 291), and Goriup's work on many rivers of the South of England (Goriup 1981 doc 150; Goriup 1978 doc 151), or is not on Chalk rivers at all e.g. Mountford and Gomes' work on PHABSIM (1990 doc 143) and de la Haye and Botterweg's work on *R. fluitans* in the River Meuse, Netherlands (1994 doc 24).

Spink (1992 doc 291) in a major study of all river types and all aquatic *Ranunculus* species found sediment chemistry to be amongst the most important factors determining *R. penicillatus* subsp. *pseudofluitans* occurrence, along with pH and velocity. *R. fluitans* was most influenced by the nature of the substrate. Goriup's work (1981 doc 150 and 1978 doc 151) also illustrated the general importance of substratum in determining floral composition. However, experiments on the River Mouse (limestone not chalk) found substrate size had no apparent influence on the growth of *R. penicillatus* subsp. *pseudofluitans*.

In their work on assessing the habitat preference of River Water-crowfoot, Mountford and Gomes (1990 doc 143) found that on the River Blithe (not chalk) *R. fluitans* grew on a wide range of substrates but was commonest on fine substrate. They comment that *R. fluitans* tends to replace *R. penicillatus* where the substrate is silty. De la Haye and Botterweg (1994 doc 24) found no impact from substrate size in their quantitative study of the effect of substrate and siltation on *R. fluitans*.

The consensus of opinion in the bulk of documents relating to *Ranunculus* and substrate is that in Chalk rivers *Ranunculus* prefers coarse non-silted substrates (Butcher 1927 doc 5; Holmes 1999 doc 30; Butcher 1933 doc 33; Holmes 1996 doc 35; Goriup 1981 doc 150; Goriup 1978 doc 151; Ferguson 1993 doc 154; Petts & Bickerton 1994 doc 160; Cook 1966 doc 226; Argus Ecological Services 1996 doc 241). Mainstone (1999 doc 298) provides a table showing that *R. penicillatus* subsp.

pseudofluitans is most associated with gravel and pebble substrate. He also emphasizes the importance of flow type, and the preference for non-silted gravels.

A further raft of documents cite the detrimental impact on *Ranunculus* growth of silt accumulation as a result of low flows.

The process of siltation as opposed to simply the nature of the bed is also of critical importance to *R. penicillatus* subsp. *pseudofluitans* in particular. Haslam introduces the problem (1978 doc 300). She presents a series of histograms of substrate preference for *Ranunculus* species. She discusses how *Ranunculus* species are shallow rooting with a constant rooting depth. Siltation therefore can smother the roots and damage *Ranunculus* through various mechanisms. However, she states that this is not usually a problem in Chalk rivers as little sediment accumulates. This observation was made from fieldwork undertaken probably in the early 1970s. Recent studies suggests that there is at least a perceived increase in the amount of silt entering Chalk rivers and that during low flows the ability of the river to transport the silt is decreased. Siltation may now be more of a problem in Chalk rivers than the earlier work suggests. For example, Wood and Armitage (1999 doc 94) quote Brookes' observation of the elimination of *Ranunculus* due to rapid sedimentation after dredging work. Many studies implicate siltation in the demise of *Ranunculus* in other Chalk rivers (Grieve & Newman 1999 doc 230; Greenwood 1988 doc 231; Bass *et al.* 1998 doc 234; Holmes 1999 doc 257; Sweeting 1996 doc 266; Giles *et al.* 1991 doc 142; Hounslow 1996 doc 269; Grieve *et al.* 1999 doc 228)

Siltation affects rooting stability, susceptibility to wash-out, germination and colonization. *Ranunculus* cannot establish stable roots in deep silt.

If these sediments are nutrient rich the roots become shallow and short making the plant vulnerable to wash-out. Giving evidence at the Axford inquiry Newbold quotes the work of Berrie and Wright (1978 doc 136). He gives winter and summer discharge figures required to prevent sedimentation and promote healthy *Ranunculus* growth. On the Kennet these are winter flows of between 0.929 and 1.427 cumecs and summer flows of 1.291 cumecs. He adds the cautionary note that if sediment loads have increased since the work of Berrie and Wright (1970s) then even higher winter and summer flows are required.

Glasspool (undated doc 118) in his extracts of records from the Test and Itchen Association records frequent observations that *Ranunculus* rooted in silt was easily removed by increases in flow. On the Avon system Grieve *et al.* (1999 doc 228) recorded an observation from an experienced river keeper suggesting that cutting plants growing in silt tends to uproot them preventing regrowth.

In some experimental channels Armitage (1995 doc 141) reports on the effects of varying water velocity and depth primarily on macroinvertebrates but also macrophytes, including *Ranunculus*. He observed that in one channel the lower discharge/velocity may have allowed the deposition of organic fines. He quotes the work of Bolas & Lund, (1974) who found that where these clog the interstitial spaces in the gravel substratum leading to anaerobic conditions, rooted vegetation is destroyed. Westlake concurs that oxygen in the sediment can be important (Westlake

1981 doc 148) and that siltation may cause anaerobic conditions around the roots, especially if the organic content of the silt is high.

A few documents also cite the impact siltation may have on germination. Again much of this work is based on inference rather than experimental or quantitative study. The process is summarized by Mainstone (1999 doc 298). The reduced light intensities and oxygen levels in the top layers make successful germination of seeds and the rooting of shoot material from existing plants unlikely. This belief is repeated by Southey's review for the Hampshire/Wiltshire Avon (Southey 1998 doc 129; Southey 2000 doc 254).

The EN draft generic targets for floating formations of *Ranunculus* includes the comment that "elevated silt levels can interfere with the establishment of *Ranunculus* plants, by affecting the ability of the substrate to physically catch plant fragments in surface interstices and allow proper rooting" (EN 2001 doc 76).

Siltation of the leaves of *Ranunculus* is also discussed. Haslam (1978 doc 300) suggests that harm is done because siltation reduces light and therefore photosynthesis. Abrasion can also cause damage. The thread-like leaves of *Ranunculus* appear to be susceptible to siltation. The presence of epiphytic algae appears to facilitate the settling of silt on the leaves of *Ranunculus* (de la Haye & Botterweg 1994 doc 24).

The effect of silt on rooting strength and susceptibility to wash-out affects the competitive balance between *Ranunculus* and other macrophytes in the Chalk stream system, both during natural discharge cycles and during low flow conditions. These affects are discussed below.

Ladle & Casey (1971 doc 13) describe the role of silt on the cycle between *Ranunculus* and Water-cress. Mantle & Mantle (1992 doc 17) describes how this cycle is interrupted by low flow. If the winter/spring flows are inadequate to wash out the accumulated silt and previous year's growth of Water-cress, then the early spring growth of *Ranunculus* will be retarded and it will lose its advantage over other species. The Water-cress will become more firmly rooted and the natural cycle is disrupted. Crafer (1996 doc 131) also describes the importance of this cycle in respect of the River Kennet. He suggests that there has been a loss of traditional silt removal management, and that a change in the operation of hatches encourages siltation. Westlake (1968 doc 29) suggests that particularly in smaller Chalk streams it is only management that is preventing the accumulation and colonization of silt and the consequent disappearance of *Ranunculus* in favour of species such as Water-cress and Fool's Water-cress.

The largest number of documents relate to the impact of low flows on siltation and the subsequent poor growth of *Ranunculus* (e.g. Wright & Berrie 1987 doc 12; Ladle & Casey 1971 doc 13; Mantle & Mantle 1992 doc 17; Holmes 1993 doc 72; McIvor 1998 doc 124; Ladle 1996 doc 126; Wright *et al.* 1999 doc 132; Armitage 1995 doc 141; Hill & Langford 1992 doc 171; Hounslow 1996 doc 269; Bass *et al.* 1998 doc 234). Many of these documents are reviews that deal with all or many of the interrelated factors. But much direct observational recording is also presented.

Few absolute values relating to this Factor occur in the literature reviewed. Newbold (1996 doc 180) gives winter and summer discharge figures needed to prevent sedimentation and promote healthy *Ranunculus* growth in the Kennet at Axford. These are between 0.929 and 1.427 cumecs and 1.291 cumecs respectively, but may be more now as the sediment load may have increased. Even in shallow water at Axford a 20% cover of silt appears to have inhibited *Ranunculus* growth. He quotes the work of Berrie and Wright (1978 doc 136) as showing that *Ranunculus* grows best when silt loads only cover 4% of the channel.

English Nature (2001 doc 76) has set the generic targets for maintaining the floating formations of *Ranunculus* of plain and sub-mountainous rivers. In respect of substrate these targets state that the channels should be dominated by clean gravels with a maximum silt content of < 20% in the top 10 cm of the mid-channel gravels.

The results of a number of rehabilitation schemes are documented in the literature. Holmes (1999 doc 257) reports that on the River Wylye one section of the river which suffered from siltation due to land use changes had been improved by an augmentation scheme. Kirkpatrick (undated doc 284) presents results of a rehabilitation scheme on the River Avon. Following rehabilitation the channel became dominated by *Ranunculus*. This was thought to be due to the increases in velocity and a reduction in silt. Mainstone (1999 doc 298) discusses tackling silt and nutrient inputs and presents a table of measures for alleviating siltation problems. Southey (1998 doc 129) reports that the Environment Agency is hoping to address sedimentation problems on the Avon with its Landcare Project.

There are numerous rehabilitation projects (some included in Appendix 4) where localized siltation has been tackled largely through increasing velocity.

4.2.5 Factor E - Velocity/Depth/Levels

Velocity is acknowledged as one of the most important variables affecting the growth of *Ranunculus* and is cited in numerous documents. Butcher (1933 doc 33) observed on several Chalk rivers that the vegetation was determined by the speed of current which in turn determines the substrate. In a survey of the Avon catchment water velocity, along with depth and shade, were found to be of primary importance in determining the local distribution of *Ranunculus* (Grieve *et al.* 1999 doc 228). Few documents contain specific velocity rates but regard it implicitly as part of discharge with higher flow/discharge equating to higher velocities.

Much of the literature points to the importance of the role of velocity in clearing silt away from gravels thereby improving conditions for regrowth, reducing competition and the impact of shading by epiphytic algae.

Most of the Drivers for velocity were attributed to Natural Climate Cycles (Driver 3) and Factors not linked to Drivers (Driver 4). The literature reviewed did not mention the obvious physical importance of gradient as a major influence on velocity, but Newman (pers. comm.) notes the importance of this, which is locally greatly affected by sluices etc. The work on the Test and Itchen by Wilby *et al.* (1998 doc 289) and Cranston *et al.* (1998 doc 296) attempted to relate *Ranunculus* presence to various channel dimensions. They found positive correlations with gradient.

R. penicillatus subsp. *pseudofluitans*, the dominant macrophyte of Chalk rivers, has adapted a physiological response in shape to cope with the stresses of high currents (Dawson & Robinson 1984 doc 75). The effect of velocity appears to be influenced by the metabolic capacity of the plant. The metabolism of the plant is limited by the rate of transfer of carbon (or oxygen) to the surface of the leaves and increasing velocity facilitates this. Experiments have shown that the effects of velocity on net photosynthesis seem to be most profound between 0.02 mm/sec and 2 mm/sec levelling off at 5 mm/sec (Westlake 1967 doc 106).

Water velocity can limit biomass by reducing the supply of dissolved oxygen and mineral nutrients (Dawson 1979 doc 122). Velocity near the plant would probably have to fall well below 25 mm/sec for a significant response, implying a velocity outside of the *Ranunculus* bed of below 100 mm/sec (Westlake 1981 doc 148). The figure of 100 mm/sec was quoted at the Axford Inquiry in 1996 as being the point below which the availability of gases and nutrients would have a limiting affect on *Ranunculus* growth (Sweeting 1996 doc 266). The Inspector at the Inquiry noted that there appeared to be no general agreement on the absolute velocity required to maintain good *Ranunculus* growth. He conceded however that abstraction would alter the average velocity by 0.043 m/sec (4.3 cm/sec) and this could materially reduce growth where conditions were marginal (Inspector's Report 1996 doc 277).

What is abundantly clear from the documents and observations of river keepers, field workers and Environment Agency staff is that *R. penicillatus* subsp. *pseudofluitans* is generally found in fast flowing conditions.

Cranston *et al.* (1998 doc 296) found that there was a positive correlation of *Ranunculus* cover with flow velocity in the Test and Itchen. In his study of 118 sites of headwaters and upper perennial sites of Chalk streams Holmes (1996 doc 35) identified velocity as amongst the critical factors determining the resultant communities. Generally, *Ranunculus* was adversely affected when velocity was reduced. Velocity also affected the seasonal dominance of *Ranunculus* and Water-cress. Reduced velocity is invariably seen by a wide range of workers on Chalk rivers as one of the major causes of reduction in or loss of *Ranunculus* presence.

It is these principles that have guided many of the large and small rehabilitation schemes where management to increase velocity has invariably lead, at least in the short term, to the reappearance of or increases in *Ranunculus*. The exact reasons for these results should however be treated with caution.

On the Kennet keepers between Marlborough and Axford left hatches open between late autumn and spring to create higher velocities to promote *Ranunculus* growth (Ashby-Crane & Newall 1994 doc 233) but with limited success (Bass *et al.* 1998 doc 234) illustrating the difficulty of separating the many inter-connecting variables influencing the growth of *Ranunculus*.

R. fluitans also reacts badly to slower flow (Haslam doc 1978; Dawson in prep.)

Ranunculus beds can reduce velocities by up to 37% of external velocities (Marshall & Westlake 1990 doc 45) allowing siltation to take place and other plants to colonize.

Increase in biomass restricts flow, reduces velocity and turbulence and the uptake of nutrients and carbon is then reduced (Dawson 1976 doc 108).

On the Frome, Dawson (1973 doc 265) recorded a considerable reduction in biomass of *Ranunculus* as depth increased down to 2 to 3 m. There was also a significant correlation between biomass and mean water depth, 0.35 m to 2.75 m explained by shading and light availability (Dawson 1976 doc 108).

At the Axford Inquiry the Inspector believed that previous deepening on the Kennet was a contributory factor to the reduction in velocity and to the presence of *Ranunculus*. Southey (2000 doc 254) understood that *R. penicillatus* subsp. *pseudofluitans* preferred depths of between 50 and 150 cm (up to 200 cm and down to 2 cm), whereas *R. peltatus* preferred shallower depths of 0 to 30 cm.

Although the figure of 10 cm/sec is often quoted as a critical velocity to maintain the growth of *Ranunculus* much depends on other environmental variables at the time, such as light, depth, siltation and competition.

4.2.6 Factor F - Water Quality/Enrichment/Suspended Solids

Concern over elevated nutrient levels is frequently mentioned in the documents as a contributor to the general ecological deterioration of many Chalk rivers and as a cause of either increased or decreased *Ranunculus* growth (McIvor 1998 doc 124; Southey 1998 doc 129; Hill & Langford 1992 doc 171; Grieve *et al.* 1999 doc 228; Bass *et al.* 1998 doc 234; Kemp undated doc 285; Atkins 1992 doc 294).

On the Wylye high nutrients are blamed for poor *Ranunculus* growth (McIvor 1998 doc 124), and Southey (1998 doc 129) suggests there is anecdotal evidence of the Avon suffering eutrophication and this causing poor *Ranunculus* growth. Grieve *et al.* (1999 doc 228) concur with this interpretation as a result of their survey of the Avon system. They conclude that the decline in water quality, together with low flows, appear to be the critical factors in determining the success or failure of *Ranunculus* in the River Avon, Wylye and Nadder. However as on other rivers there are also inferences that enrichment can cause increased growth of *Ranunculus*, for example on the Avon a Wessex Water Authority report (undated doc 239) suggests that the increased use of nitrogenous fertilizers on the arable land may increase the nitrate loading of the groundwater which in turn could increase the biomass production rate of aquatic plants (also Kemp undated doc 285).

On the Kennet there is general agreement that *Ranunculus* declined downstream of Marlborough in the past two decades but there are conflicting views on the causes. These conflicting views include the role and extent of the decline in water quality (Bass *et al.* 1998 doc 234). Mixed information also emanates from work on the Hull downstream of fish farms where there are both inferences of decline and increase in *Ranunculus* as a result of nutrient elevation (Carr & Goulder 1990 doc 2; Goulder & Carr 1994 doc 77; Scientific Services 1987 doc 224; Chalk 1982 doc 256).

Several points from the above are summarized by Mainstone (1999 doc 298) :

1 effects are highly confounded by other environmental factors such that it is often difficult to disentangle the effect of the different influences, thereby obscuring the impact of nutrient enrichment;
2 thresholds operate such that although Brook Water-crowfoot is sensitive to nutrient enrichment at modest levels the standing crop is likely to be boosted before pollution tolerant species assume dominance; and
3 studies where the role of phosphorus (and nitrate) has been unequivocally demonstrated in the field are rare.

These observations are borne out by the documents reviewed. Considerably more documents record being unable to find strong correlations between *Ranunculus* growth and water quality parameters in the field than vice versa. This, of course, may not be due to the lack of correlation, so much as the difficulty of obtaining sufficient water quality and macrophyte data and the confounding factors mentioned above.

In the modelling work of Wilby *et al.* (1998 doc 289; Cranston *et al.* 1996 doc 295; and 1998 doc 296) some correlations with *Ranunculus* and water quality parameters were found but co-variance amongst variables was acknowledged as making interpretation of some of the results difficult. However, analysis showed that *Ranunculus* was most allied to high flows and DO concentrations. The most frequently occurring group of variables of those found to have significant correlations were those relating to flow regime, followed by sunlight/temperature, previous macrophyte cover, site characteristics and finally water quality.

On the Lambourn (Ham *et al.* 1982 doc 10) Spearman rank correlation was used to attempt to link observed changes in macrophytes with changes in the environment. The study period was from 1971 to 1980. They found that most of the chemical variables showed few correlations with the macrophyte gains and losses and it was thought unlikely that they would be controlling the pattern of growth.

A number of other studies attempted to correlate water chemistry with *Ranunculus* growth but found difficulties arising because the nutrient throughput greatly exceeded the requirements of the plant. For example, Casey and Westlake (1974 doc 31) found that difficulty on the Sydling Water as did Ladle and Casey (1971 doc 13) on the Bere Stream and Demars *et al.* found similar difficulties on the Wensum (2000 doc 114).

There is good evidence that nutrients are not limiting and are available in excess in Chalk rivers (Ladle & Casey 1971 doc 13; Westlake 1968 doc 29; Casey & Westlake 1974 doc 31; Westlake 1975 doc 116; Westlake 1981 doc 148; Spink 1992 doc 291). Westlake's 1968 work on the Frome (doc 29) suggested an annual utilization of 2% of nitrogen throughput and 2.5% of the phosphorus throughput by *Ranunculus*. Although suggesting that nitrate and phosphorus supply were not limiting he says that this does not preclude the possibility than an increase in supply could increase the uptake and growth further.

Experimental work is particularly important in this area because of the confounding influence of other factors in the field. Spink *et al.* (Spink *et al.* 1993 doc 3) undertook a quantitative, experimental study of the effect of elevated phosphorus on the growth and competition of *Ranunculus*. They showed the *Ranunculus* response to enrichment by reduced shoot growth and increased shoot to root ratio. In competition with *Potamogeton pectinatus* there was also a significant reduction in root growth. Shading by algae was implicated. These findings concurred with field observations of *R. fluitans* and *R. penicillatus* being replaced by *P. pectinatus* where there is an inflow of polluted water e.g. sewage effluent, due to a change in the competitive balance between the species. The experimental concentrations used were similar to those found in several Chalk streams and the work enabled the authors to conclude that if the concentrations of phosphate continue to increase it is likely that there may be a decline in macrophytes and an increase in filamentous algae.

In his PhD work Spink (1992, doc 291) analysed data from many river types. *R. fluitans* appears to be fairly tolerant of pollution as long as the water remains clear. Its distribution appears to be more limited by the nature of the substrate.

For *R. penicillatus* subsp. *pseudofluitans* he found the most important variables were sediment potassium, sediment phosphate, sediment nitrogen, pH and water velocity. He found the concentration of major plant nutrients in Chalk streams is far greater than the requirement of the plants and that up to a point eutrophication does not appear to be limiting growth, except that it may increase the competition and shading from other plants such as filamentous algae.

A greater consensus of opinion exists on the mechanism by which enrichment, particularly of by phosphorus, can affect *Ranunculus* via competition with algae or other plants. Much detailed experimental and quantitative work has been done on the response of algae to elevated phosphorus levels (see Mainstone 1999 doc 298 for summary). Several documents were reviewed for this project which described the algal or protozoan populations associated with Chalk streams and *Ranunculus* (e.g. Shamsudin & Sleigh 1995 doc 90). However, as these did not mention impacts on *Ranunculus* they were rejected from the present study. They can however, be found by using keywords in the summary field of the database. Within the documents which did report impacts on *Ranunculus* the actual impact on *Ranunculus* growth is often inferred (Ham *et al.* 1981 doc 4; Ham *et al.* 1982 doc 10; de la Haye & Botterweg 1994 doc 24; Wright *et al.* 1982 doc 115; McIvor 1998 doc 124; Newbold 1996 doc 180; Chalk 1986 doc 221; Grieve *et al.* 1999 doc 228; Grieve *et al.* 1999 doc 229; Southey 2000 doc 254; Sweeting 1996 doc 266; Mainstone 1999 doc 298).

Many of the documents detailing competition contain information relating to the competitive balance between *Ranunculus* and algae or other plants, in part, brought about by enrichment. Working on *R. fluitans* on the River Meuse de la Haye and Botterweg (1994 doc 24) describe the process. The concentration of nutrients stimulates the growth of epiphytic algae which deteriorate the access of light because they attach themselves to water plants. The presence of epiphytic algae facilitates the settling of silt on the plant surfaces which reinforces the reduction of light interception for macrophytes. As *R. fluitans* and *R. penicillatus* are sensitive to shade the growth of the species will easily stagnate under such conditions (Ham *et al.* 1981 doc 4). In a river which has a low flow velocity the effects of shading by algae-silt layer will be more pronounced.

Future work in this area should increase our knowledge of habitat and water quality preferences for *Ranunculus*. Dawson, in prep. (doc 307) intends to statistically analyse water samples (4500) taken during the RHS surveys, along with concurrent macrophyte data to identify preferences and tolerances. The extent of this dataset should allow for the associations to be found and quantified. Likewise the development of the prediction, assessment and classification system (PLANTPACS doc 309) should incorporate a predictive element based on physicochemical and morphological data but also the modification of stream habitat and water chemistry at the level of individual species, assemblages and communities.

Suspended solids are not frequently mentioned as such in the documents. Once settled, the impact on *Ranunculus* is expressed through siltation of the leaves, or substrate. Silt as a habitat and siltation as a process both have adverse implications for healthy *Ranunculus* growth. This is dealt with in Section 3.2.4.

In suspension fine sediments can reduce photosynthesis in plants by reducing light penetration. The main feature of water quality affecting the irradiance reaching the plants is turbidity. Westlake (1981 doc 148) discusses examples of reduction in irradiance and net photosynthesis due to turbidity. The importance of light is discussed in Section 3.2.3.

Wood and Armitage (1997 doc 84) discuss the nature, origins and impacts of fine sediments in the lotic environment. Haslam (1978 doc 300) reports *Ranunculus* species as one of the least tolerant species to turbidity. She suggests that variations in turbidity during normal flows are very important and the productivity of light-sensitive *Ranunculus* can vary over a two-fold range within these changes (these observations are not confined to Chalk rivers).

Examples are given in the literature where channel operations have caused high turbidity which has or has not had an impact on *Ranunculus* depending on the time of year and flow conditions under which it was undertaken (Ham *et al.* 1981 doc 4; Ham *et al.* 1982 doc 10; Wood & Armitage 1997 doc 84).

4.2.7 Factor G - Grazing

Of the 26 documents (including 8 Most/All documents) only one was considered to contain quantitative information relating to this Factor (Trump undated doc 152). Based on studies of the impact of swans on the Avon and Wylye non-breeding birds are identified as causing the most damage to *Ranunculus*. The birds showed a preference for shallow areas where plants were more easily accessed and in the summer were seen to graze mostly on *Ranunculus* that had already been cut. The results of the study however were inconclusive as to the overall impact of the grazing.

The majority of the other studies and observations were made on the Avon, Wylye and Kennet. River keepers, among others, report similar patterns of behaviour, with birds having the greatest impact on *Ranunculus* when water levels are low and plants were in poor condition (Atkins 1992 doc 294; Grieve *et al.* 1999 doc 228; Holmes 2000 doc 43).

At the Axford Inquiry one witness stated that at times of good flow, and therefore presumably good *Ranunculus* growth, swans were not a serious threat to *Ranunculus* on the Kennet and were not responsible for any significant decline (Hounslow 1996 doc 269). There seems to be general agreement that a breeding pair of swans will keep other birds away thereby reducing the impact on *Ranunculus*. Outside of the breeding season this control may not apply. Fencing reaches to reduce the availability of flight paths is also suggested (Unknown 1994 doc 243).

Although the impact of swans is not a new phenomenon (Glasspool undated doc 118) there is a concern that the situation is getting worse. Evidence suggests that the impacts are localized and have the greatest effect during periods of low flow.

A recent study on the Lambourn speculated that the poor performance of *Ranunculus* at one site may have been due, among a list of other impacts, to grazing by signal crayfish (Wright *et al.* 2000 doc 137).

4.2.8 Factor H - Physical Dimensions

Relatively few documents deal with this Factor to any extent but several mention channel dimensions or channel modification in respect of perceived deterioration of ecological quality or river function, and restoration of these conditions.

The documents divide into two broad types :

- those which discuss how channel modifications have impacted *Ranunculus* and what measures can be, or have been, taken to remedy this; and
- those that describe how channel dimension information can be utilized to control *Ranunculus* growth.

There is very little quantitative work on the dimensions preferred by *Ranunculus*. An attempt was made to incorporate physical dimensions into an assessment of habitat availability at different discharges on the R. Kennet (Maddock & Petts 1995 doc 153). The work on the Test and Itchen by Wilby *et al.* (1998 doc 289) and Cranston *et al.* (1998 doc 296) attempted to relate *Ranunculus* presence to various channel dimensions. They found positive correlations with gradient and lower wetted perimeter/water depth. Although site characteristics were generally less significant than other variables such as those relating to flow regime and sunlight/temperature regime.

Haslam (1978 doc 300) records the association of *Ranunculus* with river width, drainage order and depth. She reports *R. fluitans* and *R. penicillatus* to be associated with wide channels and *R. calcareus* with medium channels.

Several observations are made in the literature regarding sites being unsuitable for *Ranunculus* on the basis of channel dimensions, for example the Upper Piddle is considered too shallow and narrow to support *Ranunculus* (Greenwood 1988 doc 231). In his study of winterbournes Holmes (1996 doc 35) suggests that for example the R. Alre could support *Ranunculus* but in fact had poor *Ranunculus* due to over-management creating a ditch-like morphology.

Southey (2000 doc 254) also quotes this work as showing that rivers within the Avon system including the Bourne, Ebble and Chitterne also have less *Ranunculus* than they might have due, in part, to poor channel morphology.

The greatest number of documents describing impacts of poor channel dimensions on *Ranunculus* performance are related to the Kennet (Ladle 1996 doc 126; Crafer 1996 doc 131; Ashby Crane & Newall 1994 doc 233; Bass *et al.* 1998 doc 234; Atkins 1992 doc 294). Much of this debate arose from the Axford Inquiry and sought to understand how much of the perceived deterioration of ecological condition, including the status of *Ranunculus*, could be attributed to discharge related issues such as low flow, drought and abstraction, or due to channel dimension issues such as over-dredging, and over-widening.

The majority of the comments are from observation or interpretation. Ladle and Crafer (Ladle 1996 doc 126; Crafer 1996 doc 131) suggest that local absences or deficiencies in some reaches were thought to be due to siltation, lack of discharge and inadequate velocities associated with channel modification, and that over-deepening and over-widening has created conditions which favour emergent species over *Ranunculus*. This to some degree is refuted by the observations of the river keeper (Hounslow 1996 doc 269) who states that the dredging did not reduce the amount of *Ranunculus* in the 1970s but the decline in *Ranunculus* started in the mid-80s.

However, the overall consensus is that the Upper Kennet is over-wide in places which reduces the natural flow velocity and this is considered responsible for the loss of *Ranunculus* (Atkins 1992 doc 294).

The mechanism by which the channel dimensions affect the *Ranunculus* are not always stated, but where it is stated it is usually linked with lack of sufficient velocity and siltation.

Mainstone (1999 doc 298) describes the approaches that can be taken to determine whether a reach is over-wide. He uses the illustration of RHS survey data on Chalk river SSSIs.

He provides figures which show the deviation at each site from the width predicted by the relationship with flow category. This suggests locations in each SSSI catchment where the channel may be considerably over-wide, including sites at the lower end of the Hampshire Avon, the middle reaches of the Nar and Test, and the upper reaches of the Frome and Kennet.

The situation on the Kennet has been described above. Some work on the Avon concurs with the suggestion of it being over-wide and this impacting on *Ranunculus* (Kirkpatrick undated doc 284; Aldrich 1989 doc 288).

There are numerous documents which either suggest or report on channel narrowing as a means of overcoming the deficiencies caused by over-widening. Again the majority of documents relate to the Kennet (Holmes 1999-2000 docs 41-43; Wright *et al.* 1999 doc 132; Giles *et al.* 1991 doc 142; Ashby Crane & Newall 1994 doc 233; Bass *et al.* 1998 doc 234), Avon (Grieve *et al.* 1999 doc 228; Shaw & Langford undated doc 282; Kirkpatrick undated doc 284) and Wylye (Solomon 1997 doc 128).

As early as 1933 Butcher (doc 56) suggests reducing the width of the River Colne in Middlesex in response to a reduction of volume of water in the system.

The Upper Kennet Rehabilitation Monitoring reports (Holmes 1999-2000 docs 41-43 and future) will provide quantitative data on the effects of narrowing. The majority of results so far are qualitative in respect of impacts of channel narrowing on *Ranunculus*. Two quantitative studies have been undertaken on the Avon where pre and post rehabilitation channel morphology was measured along with macrophytes (Shaw & Langford undated doc 282; Kirkpatrick undated doc 284). A review of rehabilitation in UK rivers has been compiled by Holmes (1996 doc 236) and contains some Chalk stream examples. For example a 35% narrowing of the Lambourn is documented. *Ranunculus* was also planted and after a slow start it then grew well. Major channel works were undertaken on the Ver and the Pang was also narrowed. The Pang had augmentation flow and both rivers had reduced or closure of pumping schemes.

A distinct group of documents deal with the issue of controlling *Ranunculus* by using information relating to channel dimensions. For example the use of width/depth ratios to suggest where streams could be deepened to control *Ranunculus* growth, or the use of width information to determine a planting strategy to control *Ranunculus* through shading (Dawson & Kern Hansen 1978 doc 78; Dawson 1978 doc 79; Dawson & Haslam 1983 doc 93; Dawson & Kern Hansen 1979 doc 97; Westlake & Dawson 1982 doc 107; Dawson 1979 doc 130).

Cattle have been implicated in studies on the River Piddle as a major contributory cause to changing natural channel dimensions. In 1981 on the Hampshire Avon and on the River Wylye in 1990 the Piscatorial Society carried out channel narrowing and fencing in direct response to cattle poaching. Their stated purpose was “to speed up flow” (Terry Newman pers. comm.).

4.2.9 Factor I - Drivers identified but not linked to Factors

The majority of documents covering this Factor are concerned with vegetation management. *Ranunculus* in Chalk rivers is, in favourable conditions, a vigorous growing macrophyte that traditionally is capable of occupying large stretches of a river during the spring and summer. For centuries the vegetation has been managed by cutting and removing to reduce the potential for flooding and to provide conditions which favour salmonid fishing.

Westlake (1968 doc 32) deduced that the traditional spring cut stimulated *Ranunculus* growth thus inducing further management and removal of plant material later in the year. Regular cutting induces synchronization of maximum plant biomass throughout the whole population (Dawson 1978 doc 104). The yearly removal of huge quantities of plant material from rivers such as the Avon, Test and Itchen and also smaller Chalk rivers is seen by Dawson as a drastic and potentially ecologically damaging action. He argues in favour of a more benign approach more closely linked to the known ecology of the plant. The biomass of *Ranunculus* on a previously managed site on the Bere Stream left unmanaged for four seasons declined to half of the original maximum biomass (Dawson 1978 doc 104).

A close autumn or pre-emptive cut reduced *Ranunculus* biomass on sites on the Frome by an average of 28% of that expected normally, although this effect may be limited to water deeper than 0.7 m compared to autumn uncut sections (Dawson & Westlake 1985 doc 102; Westlake & Dawson 1986 doc 101; Westlake & Dawson 1988 doc 99; Dawson 1989 doc 103). Intensive cutting of *Ranunculus* may also make it more susceptible to grazing by swans (Berrie & Wright 1978 doc 136).

An assessment was made of the effect of bar cutting on the growth and recession of *Ranunculus* at sites on the Kennet and Lambourn (Ham 1977 doc 182; Ham *et al.* 1982 doc 11). *Ranunculus* at an uncut site flowered in mid May and started washing out by July. Plants cut at the end of April flowered in early June but did not wash out until September. Cutting at the end of May delayed wash out but did not lead to increased winter cover. Plants cut in June did not flower but extensive growth led to higher levels of winter *Ranunculus* cover. Cutting in September controlled *Ranunculus* cover over winter but plants washed out naturally. It was concluded that it was best to leave *Ranunculus* uncut as it would begin to wash out naturally soon after flowering. A cut before flowering did not control growth and could increase the amount of *Ranunculus* during the following winter. Cutting, if necessary, should therefore be undertaken at the time of flowering, as the most effective way to control summer growth (Ham 1977 doc 182; Ham *et al.* 1982 doc 11).

A new approach to the management of *Ranunculus* that is tailored to the known ecology of the plant is recommended (Cranston *et al.* 1998 doc 296). To develop this new approach it is suggested that trials should be carried out to test a cutting regime involving cutting in early spring, only cutting after flowering if absolutely necessary and not cutting in the autumn. Mainstone (1999 doc 298) believes that in most cases land drainage and flood defence requirements can be satisfied by cutting no more than 30% of the channel width at any one time. For nature conservation purposes he suggests best practice is to allow plant succession to progress as naturally as possible.

The wisdom of removing large amounts of plant material from Chalk rivers has been raised by Dawson. Having recently reviewed the routine weed cuts on the SAC, SSSI Avon catchment, Menendez (doc 299) questions the current mechanical and manual cutting regimes for the lack of data on the effects on the floating *Ranunculus* community and the general riverine community. He accepts that leaving reaches unmanaged could mean a reversion to a more natural habitat but one that would not meet the requirements of the existing designated habitat. However, he argues that there is a particular need for any cutting regime to recognize and incorporate the ecological and environmental significance of this particular river system.

4.2.10 Factor J - Most/All

This is a Most/All category encompassing documents with a multiplicity of Factors/Drivers/Type of Information/Basis. These have been incorporated into the discussion relating to individual Factors.

4.3 Drivers and their Links with Management Applications

In the analysis of the information on Drivers it is apparent that a sizeable proportion of the *Ranunculus* literature does not make any link between the Drivers influencing the Factors which affect *Ranunculus*. This is particularly the case when the Factor is Velocity/Depth/Levels, as is borne out by Table 3.6.

The most frequently specified Driver is Natural Climate Cycles, which is cited as affecting *Ranunculus* most commonly through its influence on Discharge/Seasonal Annual Changes, and Velocity/Depth/Levels. All of the other Drivers are much less frequently mentioned in the literature or linked to the Factors affecting *Ranunculus*.

On the database the Management Application is held separately from the Factor/Driver matrices. Each entry into the Factor/Driver matrix refers to an information strand/type held in the particular document. A Management Application is not physically linked to these particular strands, but is held in a separate table.

Any one document may therefore have several types of information and have several Management Applications but these are not physically linked within the database other than by the document number.

4.3.1 Driver 1 - Channel Management

This involves alteration of the channel dimensions by, for example, dredging, widening, deepening, narrowing and has excluded vegetation management (see 4.3.6). There is a consensus within the literature that many channels have become over-wide or deep and that this has a detrimental effect on the river including *Ranunculus*.

The impact is seen in the literature to be manifested largely through Factors D (Substrate/Siltation), and E (Velocity/Depth/Levels). Although changes in Physical Dimensions (Factor H) are clearly the mechanism through which the Driver operates in the first instance they are only mentioned in a few documents.

Siltation is commonly regarded as having a detrimental impact on *Ranunculus*. The impact is through various mechanism including smothering, oxygen starvation of the roots, increased instability, untimely wash-out, siltation of the leaves and increased turbidity reducing photosynthesis, poor colonization, as well as other mechanisms such as increased substrate nutrient content leading to the production of shorter roots. Likewise velocity is universally seen as being central to the performance of *Ranunculus*, with low velocity commonly cited as a reason for poor *Ranunculus* growth. Good quantitative data exist to show that *Ranunculus* is a high velocity plant, needing the rapid delivery of oxygen and carbon to support its high photosynthetic rate. Velocity is also seen to act indirectly by removing potentially competitive or shading algae. Critical depths are quoted, by Haslam (1978 doc 300), and it has been observed elsewhere that at depths of greater than 1 m *Ranunculus* has reduced competitive ability against other plants such as *Potamogeton perfoliatus*.

Increased siltation can potentially arise as the result of channel management either directly from the works or from the subsequent alteration of the width:depth ratio and hence the ability of the river to convey the sediment load.

The alteration of the width:depth ratio also alters the depth and velocity for a given discharge which potentially affects *Ranunculus* performance.

The Environment Agency can potentially have a great influence on this Driver and therefore the associated Factors affecting *Ranunculus* through its own works, and the consenting of others. Some guide values exist for these Factors, such as velocity (Marshall & Westlake 1990 doc 45; Westlake 1967 doc 106) and depth (Haslam 1978 doc 300). There are also mechanisms available to assess whether reaches are over-wide (e.g. RHS data in Mainstone 1999 doc 298), however, the literature also contains information relating to confounding issues. For example in shaded conditions *Ranunculus* requires higher flows (discharge and also velocity) to compete with *Berula*. The implication being that in open sites a lower velocity is adequate (Ham *et al.* 1982 doc 10). The same concept applies to the confounding issue of water quality. There is some evidence that at high flows enrichment encourages the growth of *Ranunculus* but at low flows it can have a severe adverse affect, largely through the influence of algae (Chalk 1986 doc 221).

There is therefore no prescription regarding creating or maintaining a particular width:depth ratio through channel management. Possible solutions must always relate to the conditions prevailing in a particular catchment, river and reach. Lessons can be learnt through rehabilitation projects given sufficient monitoring.

EN has set generic targets for floating formations of *Ranunculus* of plain and sub-mountainous rivers. In respect of channel management and morphology the target is for channels to be generally characteristic of the river type and appropriate to the naturalized flow conditions. This should be assessed by hydro-geomorphological survey which can identify degraded stretches where restoration is required.

4.3.2 Driver 2 - Enrichment from Point Sources

Within the database the greatest number of citations to this impact on *Ranunculus* is associated with fish farm effluent. However, discharges from sewage treatment works and Water-cress farms are also discussed. A much greater emphasis is placed on phosphate than nitrate in the literature.

In their study of the nutrient budget of the upper reaches of the Hampshire Avon, Parr *et al.* (1998 doc 174) suggest that phosphorus is a fundamental influence on riverine macrophyte communities and may set the underlying potential for impact to which other factors contribute. A comprehensive review is presented by Mainstone *et al.* (1993 doc 149).

Within the documents reviewed the most frequently cited route of impact of this Driver is through Water Quality and Competition etc. There are quantitative, qualitative and inferred data on the direct impact of water quality on *Ranunculus* growth and there are many inferences to water quality disrupting the competitive balance between *Ranunculus* and other plants such as algae, *Berula* and *Callitriche*. Experimental work by Spink *et al.* (1993 doc 3) indicates that if the concentrations of phosphate continues to increase it is likely that there may be a decline in macrophytes and an increase in filamentous algae. These observations were made using experimental phosphate levels similar to those measured in southern English Chalk streams.

The Environment Agency has great potential to ameliorate adverse impacts of point source enrichment via the licensing of discharges, including promotion of phosphate stripping, and by the management of discharge to provide dilution.

Again there are confounding issues apparent from the literature, such as the seasonality of the impact of point source enrichment, and the alleviating impact of high discharge and high velocity. The exact levels at which phosphate becomes detrimental to *Ranunculus* would therefore appear to vary according to time of year, discharge and velocity. There does not appear to be a consensus from the literature as to the extent of the alleviation provided, for example, by increased velocity. In management terms this creates difficulties in determining the velocity required to maintain *Ranunculus* in a river or reach with a particular water quality level. A further difficulty arises attempting to determine the impact of phosphate stripping in already enriched waters. For example, Demars *et al.* working on the River Wensum (2000 doc 114) did not find it possible to predict the impact of phosphorus removal on the macrophyte community.

Wright *et al.* (1999 doc 132) working on a long term study on the Kennet suggests that one observation of improved *Ranunculus* growth could in part be attributed to the commencement of phosphate stripping at Marlborough STW, however, this also coincided with exceptionally high discharge of the previous month. It seems as yet it is difficult to show an improvement in *Ranunculus* linked to phosphate stripping.

English Nature has set generic targets for floating formations of *Ranunculus* of plain and sub-mountainous rivers. For Chalk river the target phosphorus level has been set at 0.06 mg/l.

4.3.3 Driver 3 - Natural Climate Cycles

There is considerable understanding of how natural climate cycles affect *Ranunculus* in Chalk rivers, manifestly through the Factors of Discharge, Velocity/Depth/Levels and Light/Shade/Temperature. Substrate/Siltation is frequently mentioned in relation to Natural Climate Cycles in the winterbourne studies by Holmes (docs 35 to 40), and the Upper Kennet rehabilitation documents by the same author (docs 40 to 43). The data generally show the importance of the seasonal cycle of discharge rather than absolute values. For example high winter flow is important to maintain clean gravels and remove competitive emergent vegetation or algae.

On the River Allen Green and Cooling (1993 doc 53) found evidence to suggest that improved summer flow would produce healthier *Ranunculus* plants better able to withstand winter scouring. They recommend maintaining a minimum prescribed flow of >0.6 cumecs from April to July, and > 0.4 cumecs for August and September. Such information is highly reach specific but ultimately this is what is required for every Chalk river.

The Environment Agency has no power over the natural climate cycles, but needs to be responsive to the climate of the future and the consequences of this to river flows, seasonal cycles and ecology. The climate change literature was not consulted as such in this project, only if it related to Chalk rivers and *Ranunculus* growth. Only one document deals with this issue in any comprehensive way.

Cranston *et al.* (1998 doc 296) considered the impacts of both recent changes in the climate and predicted future changes on the hydrology and ecology of the Rivers Test and Itchen. They produce a number of models showing how potential future climates could affect *Ranunculus*. The work is a preliminary attempt at a complex issue and needs further refining. However, it is the type of data that will be required by the Environment Agency to manage rivers for the future.

Understanding is also needed as to the extent to which detrimental factors combine with natural climate cycles to alleviate or exacerbate problems, for example natural drought and abstraction. This is significant to the setting of acceptable flows and licensing abstractions. The on-going winterbourne work of Holmes (docs 35 to 40) will provide valuable data on this.

A sustainability study on the River Itchen (Halcrow Group Ltd 2000) is aiming to define the way forward to establish target flows for the Itchen catchment. This should provide valuable information to guide Environment Agency management.

4.3.4 Driver 4 - Factors not linked to Drivers

With no Driver specified the impacts are described through the Factors alone. Further details of these are held in the Analysis and Discussion of Factors. Much of the information relating to Management Applications are repeated in association with other Drivers in this section.

4.3.5 Driver 5 - Other

The 'Other' Driver most commonly cited in the literature is shading, usually by algae. This category is used to express the physical impact filamentous or epiphytic algae has on *Ranunculus*. The causal Driver is frequently cited as Water Quality, be it point source or diffuse enrichment, which encourages the algae growth which then has this negative impact on *Ranunculus*. Shading by marginal and bank side vegetation is also discussed. It is clear from the literature that shading can be used effectively to control *Ranunculus* growth if this is the desired management input. Less has been demonstrated about removing shading to encourage *Ranunculus* growth. In rehabilitation projects the impact of shade should clearly be considered.

4.3.6 Driver 6 - Vegetation Management

The vegetation, primarily but not exclusively *Ranunculus*, of Chalk rivers is traditionally managed to control flood risk and to create favourable conditions for fishing. There is a wealth of quantitative, qualitative and inferred data on the various impacts of this practice on *Ranunculus* under normal conditions. What is less well understood is how cutting effects *Ranunculus* under stressed conditions such as low flows or enrichment. Spink (1992 doc 291) found that the cutting response of *Ranunculus* was distorted by enrichment.

Also the emphasis of the work in the past has been controlling *Ranunculus* whereas in the future the emphasis may be on maintaining *Ranunculus* communities. Menendez (2000 doc 299) discusses some of these points in relation to the River Avon catchment and its SAC designation. The Environment Agency has to find a delicate balance between these needs i.e. flood prevention, fisheries interests and the responsibility to maintain *Ranunculus* communities in SAC rivers in 'favourable condition'. It is also bound to maintain the Chalk stream habitat in accordance with the National BAP.

Vegetation management is a key management component along with water quality and quantity control. There appears to some confusion, however, over when, where and how much to cut. Mainstone (1999 doc 298) provides a useful summary of best-weed cutting practice for the different interests and how these might be combined.

The EN generic targets include the comment that any in-channel vegetation management should ensure that a significant proportion of the *Ranunculus* community is allowed to flower and set seed naturally and that management should aim to leave a patchy distribution of *Ranunculus*. As a guide they suggest leaving at least 25% to flower in any 100 m stretch.

4.3.7 Driver 7 - Abstraction/Catchment Water Use

Abstraction is an influential component of modern Chalk stream systems but it is numerically sparsely covered within the *Ranunculus* literature reviewed for this project. From those documents it is clear that the majority of citations are related to the impact Abstraction has on *Ranunculus* through effects on Discharge and to a lesser extent Velocity/Depth/Levels and Substrate/Siltation. The lack of quantitative data on the effects of abstraction on *Ranunculus* is critical in the light of future demand for water use, and maintenance of *Ranunculus* communities. The difficulty in isolating the effects of abstraction from channel management and natural climatic variation is highlighted in the Axford Inquiry documents. There is then further difficulty once the extent of the influence of the Drivers is established in assessing exactly the contribution the various Factors have on *Ranunculus* growth.

The impacts of abstraction can be more definitively recorded when cessation occurs and the ecological recovery is monitored. Such a situation arose on the Ver in 1993 and has been well documented. The cessation of groundwater pumping resulted in a return of perennial flows and within three years the reappearance of *R. penicillatus* subsp. *pseudofluitans* on a site that had been dry for years (Holmes 1999 doc 30; Holmes 1996 doc 236; Mainstone 1999 doc 298). Over the same time period Holmes was able to assess the changes in the flora of other winterbournes which, though experiencing the same climatic conditions (including the cessation of drought), had not experienced the additional impact of cessation of abstraction (Holmes docs 30 to 35). He found greater and more sustained changes to the flora on the Ver than on any of the other sites, inferring the impact of abstraction.

4.3.8 Driver 8 - Land Use/Diffuse Enrichment

As with Driver 2 (Enrichment from Point Sources) this Driver is understood as being important to *Ranunculus* performance but is relatively under reported, within the literature reviewed. A large proportion of the citations are also based on inference rather than observation or quantitative study. There are few citations to how changes in land use affect discharge and velocity patterns through changes in runoff and delivery to the stream system and how this affects *Ranunculus*.

There are some citations to the impact of Land Use and Diffuse Enrichment on Water Quality and Substrate/Siltation. A comprehensive review is presented by Mainstone *et al.* in *Phosphates in Freshwater. Standards for Nature Conservation* (1993 doc 149). An important point is made in this report concerning the relative impact of point source and diffuse sources of phosphate. The apparent load may be the same but the impact on *Ranunculus* is very different due to the timing of the delivery to the system. Diffuse enrichment is greatest at periods of high flow and runoff, typically winter when *Ranunculus* is not growing, and when dilution is greatest. Whilst point source enrichment is continual and can have the greatest impact at periods of low flow, particularly in low flow summers or low flow winters/springs.

This Driver is largely influenced by the type of land management operating in the catchment. In particular situations Land Care projects can be instigated. As part of rehabilitation projects buffer strips can be created but this is generally on a small scale, not the catchment scale that is required for systematic control.

4.3.9 Driver 9 - Rehabilitation/Augmentation/Fencing etc.

Rehabilitation is discussed in Section 4.6. Many small scale and some larger scale rehabilitation projects have taken place on Chalk rivers. It is evident that relatively little of this is work is being systematically monitored, documented and disseminated. Valuable and perhaps otherwise obscure lessons can be learnt through rehabilitation projects given sufficient monitoring, but this opportunity is largely being lost.

A study of a groundwater augmentation scheme on the Candover Brook (Southern Water Authority 1979 doc 159) found that the effects brought about by the augmentation would have to be considerable to be apparent above the high level of natural variation in macrophyte cover and biomass. The authors also suggest that the timing of the augmentation is important as the pattern of poor growth is already determined before the beginning of May after which *Ranunculus* is unable to respond to a change in flow conditions. This is potentially significant information for the Environment Agency (e.g. Water Resources and Conservation). A similar observation is made by Ham *et al.* on the River Lambourn (1981 doc 4).

In 1999 Holmes (doc 257) reporting on the macrophytes of the Upper Wylye suggested some local benefits to the flora. He reports that the effectiveness of the augmentation is being investigated by the Environment Agency and that an attempt is also being made to determine the optimum future flows for the catchment that take account of environmental needs as well as those of water supply. This work should provide key management information for both rehabilitation by augmentation, and water resources and the setting of acceptable flows.

4.4 Chalk Rivers and Number of Documents

Table 3.25 (Section 3.5) shows that of all the rivers the River Kennet is mentioned in more documents (29) than other rivers. Whilst this does not mean that all of the 29 documents are devoted entirely to that river it does give an indication of the extent to which *Ranunculus* has been considered on that river.

A breakdown of the 29 documents with 'River Kennet' in the keywords is as follows:

- 2 contain quantitative data with statistics (Berrie *et al.* undated doc 135; Wright 1978 doc 136);
- 3 contain quantitative information (Favre 2000 doc 96; Maddock & 1995 doc 153; Ham 1977 doc 182);
- 17 contain qualitative information;
- 23 contain interpretation/inferred information; and
- 20 involve some element of field observation.

The citations and documents relating to the River Kennet can also be broken down by Factor and Management Applications (Tables 4.1 and 4.2).

Table 4.1 Number of citations and documents relating to the River Kennet by Factor

Factor	No. of Citations	No. of Docs
A - Competition/Interaction/Life Cycle/Colonization	2	2
B - Discharge/Seasonal Annual Changes	25	18
C - Light/Shade/Temperature	6	5
D - Substrate/Siltation	22	14
E - Velocity/Depth/Levels	22	15
F - Water Quality/Enrichment/Suspended Solids	9	7
G - Grazing	4	4
H - Physical Dimensions	4	4
I - Factors not linked to Drivers	9	6
J - Most/All of the above	13	8

The greatest number of citations are to Factor B - Discharge/Seasonal Annual Changes, followed by D - Substrate/Siltation and E - Velocity/Depth/Levels.

In terms of Management Applications (Table 4.2) the greatest number of documents are considered to have relevance to Licensing (14 of the 20 documents relate to licensing abstractions).

Table 4.2 Number of documents relating to the Management Applications on the River Kennet

Management Type	No. of Docs
A - Licensing	20
B - Water Resources	7
C - Conservation	6
D - Management	8
E - Determining protocols	3
F - not applicable	0
G - Responses to land use change	0
H - Responses to climate change	2
I - Most/All	6

A similar analysis of the documents citing work on the River Frome is given in Tables 4.3 and 4.4.

Table 4.3 Number of citations and documents relating to the River Frome by Factor

Factor	No. of Citations	No. of Docs
A - Competition/Interaction/Life Cycle/Colonization	6	6
B - Discharge/Seasonal Annual Changes	5	5
C - Light/Shade/Temperature	11	9
D - Substrate/Siltation	4	4
E - Velocity/Depth/Levels	12	10
F - Water Quality/Enrichment/Suspended Solids	7	6
G - Grazing	2	2
H - Physical Dimensions	0	0
I - Factors not linked to Drivers	8	8
J - Most/All of the above	7	4

Table 4.4 Number of documents relating to the Management Applications on the River Frome

Management Application	No. of Docs
A - Licensing	10
B - Water Resources	5
C - Conservation	12
D - Management	16
E - Determining protocols	1
F - not applicable	3
G - Responses to land use change	0
H - Responses to climate change	1
I - Most/All	0

Comparing the two datasets the River Kennet information has a greater emphasis on how Factors B, D and E (Discharge/Seasonal Annual Changes, Substrate/Siltation and Velocity/Depth/Levels) respectively impact on *Ranunculus*, and management issues relating to Licensing, particularly licensing abstractions. The information on the Frome relates more to the impacts of Velocity/Depth/Levels and Light/Shade/Temperature and is particularly related to weed cutting.

The Avon and Itchen, although mentioned in fewer documents, stand out as being the focus of recent work primarily due to their SAC status. They are also the rivers that have had comprehensive longitudinal surveys undertaken on them as well as several macrophyte surveys based on smaller study sites.

The work on the Avon (Grieve *et al.* 1999 doc 228; Grieve *et al.* 1999 doc 229; Grieve *et al.* 2001 doc 311) involved the survey of the R. Avon and Nadder in 1999 and 2000 to assess the extent and condition of *Ranunculus*. The result is a comprehensive assessment of the health of *Ranunculus* in the river.

The work on the Test and Itchen (Wilby *et al.* 1998 doc 289; Cranston *et al.* 1996 doc 295; Cranston *et al.* 1998 doc 296 & 297) involved a complete longitudinal macrophyte survey of both rivers in 1991 and a repeat survey of approximately a third of the sites in 1997. There were also a series of interim surveys at reference sites. *Ranunculus* was recorded on all occasions. These data, along with other environmental variables, were entered into spatial and temporal models to attempt to quantify the factors affecting macrophyte presence in the two rivers.

Other rivers have had long term monitoring of the macrophytes at certain sites which has allowed the elucidation of factors affecting *Ranunculus* growth over a time. For example macrophyte surveys have been undertaken at certain sites on the River Lambourn over the last thirty years (Ham *et al.* 1981 doc 4; Ham *et al.* 1982 doc 10; Wright *et al.* 1982 doc 115; Wright *et al.* 1999 doc 132 and doc 133; Berrie *et al.* undated doc 135; Berrie & Wright 1978 doc 136; Wright *et al.* 2000 doc 137).

The Frome and tributaries have had substantial amounts of research work carried out on them by FBA/IFE/CEH.

Work carried out on many rivers has had a particular emphasis, for example, on the Hull catchment much of the work entering the database relates to the impact of fish farm effluents on water quality, algal growth and *Ranunculus* performance (Jennings 1994 doc 169; Robbins 1982 doc 183; Chalk 1986 doc 221; Chalk 1983 doc 223; Scientific Services 1987 doc 224; Chalk 1982 doc 256).

The work on the Wylye catchment has an emphasis on the impact of low flows (e.g. Green 1999 doc 134; Casey 1981 doc 259), and the impact of swans (Ferguson 1993 doc 154; NRA 1996 doc 240; NRA 1994 doc 245).

The Frome, Lambourn, Bere Stream and Piddle have been used extensively to monitor the effects of weed cutting and the natural cycles of *Ranunculus* growth over the last thirty years (e.g. Westlake 1968 doc 32; Dawson 1977 doc 98; Dawson & Westlake 1985 doc 102; Dawson 1989 doc 103; Dawson *et al.* 1978 doc 105; Westlake & Dawson 1982 doc 107).

An overwhelming statistic that emerges from Table 3.25 (Section 3.5) is the 98 rivers that are not cited in any of the documents. This does not necessarily mean that there is no written information on these rivers or that the Environment Agency does not hold any information on them. However, cross-referencing with the summary of information from the snapshot forms confirms the likelihood that there are many of the Chalk rivers that are comparatively unknown and which lack detailed information on *Ranunculus*. If this proves to be the case and in view of the Agency's obligations under the BAP for Chalk Streams and responsibilities towards *Ranunculus* action should be taken to remedy this situation as soon as possible.

4.5 Snapshot Form Returns

Due to problems associated with deadlines for this project and general time constraints imposed on Environment Agency staff the information given in the snapshot forms should not be regarded as comprehensive.

The information summarized in Appendix 3 shows that 1998 to 2000 have seen *Ranunculus* becoming dominant in many river reaches. Information on the status of *Ranunculus* during the 1990s is less certain and there is a positive dearth of information pre 1990s on most rivers. Discussion with river keepers and field workers during Phase 1 of the project and the personal experience of the contractor indicate that on most Chalk rivers *Ranunculus* had suffered in the late 1980s and early 1990s from the effects of low flows. These impacts are not new. All Chalk rivers suffered during the drought of 1976 but most recovered and documents reviewed here describe that recovery (e.g. on the Lambourn and Kennet).

Dramatic changes to the flora of the Kennet were recorded by Colonel Maurice in the 1940s and W S Atkins Consultants Ltd (1992 doc 294) reported that the upper Kennet to Marlborough had dried about every 10 years during the 20th Century. Recovery of *Ranunculus* from the effects of low flows is largely dependent upon higher flows emphasizing the fundamental importance of adequate discharge throughout the system. Predicting what discharge is required in any one catchment, river or reach to maintain *Ranunculus* and the health of Chalk rivers in general has become an urgent requirement given the unpredictability of future climate scenarios.

4.6 Rehabilitation Projects

The data collated on rehabilitation schemes are not comprehensive. Discussion with Environment Agency and non Environment Agency staff indicate however that the list compiled here (Appendix 4) represents a good cross-section of the type of schemes likely to be undertaken on Chalk rivers. What is immediately noticeable about these projects is the lack of comprehensive monitoring undertaken after the work has been carried out. The majority of projects are either led by, or are undertaken in partnership with, the Environment Agency. The Environment Agency has obligations under the UK Chalk Stream BAP. Despite this obligation the monitoring of the impact of the rehabilitation projects on *Ranunculus* is the exception.

The higher winter flows of the last few years have provided favourable conditions for *Ranunculus* growth. It is likely that these conditions are responsible for some of the spectacular results in terms of *Ranunculus* growth. Without systematic or comprehensive monitoring it is impossible to assess the relative contributions of a scheme to the observed increase in *Ranunculus*. Monitoring may have provided the answer to this question. The initial results point to the value of increasing flow velocity, a known potential stimulant to *Ranunculus* growth. Whether this revival is sustainable or a less desirable outcome develops is not known because of the lack of sufficient monitoring.

It would seem therefore sensible to at least monitor some rehabilitation schemes if only because they represent an artificial and deliberate management intervention into BAP rivers that could potentially have both desirable and undesirable consequences.

There are a considerable number of small rehabilitation schemes associated with fisheries work. Few appear to make any note of the effects on *Ranunculus*.

4.7 Research Projects

The following is a summary of the main research projects brought to the attention of this project :

4.7.1 Various aspects of *Ranunculus* and Chalk rivers, Hugh Dawson *et al.*, CEH

Hugh Dawson has provided a summary of papers in preparation which have relevance to this project. These summaries have been included in the database for future reference. It is intended that the majority of these will be published in 2001 or early 2002. Brief details of these are given below:

Two papers are in preparation on the culture and growth of aquatic plants in streams. One includes the effects of water velocity on the submerged macrophyte *R. penicillatus* subsp. *pseudofluitans* var. *calcareus* (Dawson in prep., doc 301), and a second includes a model for the growth of the aforementioned species in a large Chalk stream based on light, temperature, dissolved oxygen and plant growth strategy (Dawson & Kelly in prep., doc 304).

The first study involves experimental work in stream channels where constant water clarity, chemistry and velocity can be maintained and other perturbations such as grazing controlled. Under these conditions the growth rate (as change in plant biomass during the year) can be assessed under a range of velocities of between 10 and 45 cm/sec. The results can potentially be fed into a *Ranunculus* growth model (see next paper).

The second paper involves the development and testing of a *Ranunculus* growth model based on surface and submerged light, water temperature, dissolved oxygen and the plant growth strategy. The results will include a model to predict potential growth rates and interactions with physical and some biotic components. This work involves the use of long-term datasets from 1961 to 1992.

A further two pieces of work are planned which will analyse some long term data and potentially feed into the *Ranunculus* growth model. These are further studies on the light climate for the submerged macrophytes of the River Frome (Dawson in prep. doc 302). This work involves detailed analysis of vertical light profile, turbidity and discharge data. Similar data analysis is in preparation regarding the seasonal variations of dissolved oxygen in large and a small Chalk stream (Dawson & Henville in prep. doc 303).

The work on the use of shade for the control of aquatic plants is also brought into this framework (Dawson in prep. doc 305). Predictions of incident light at any point across a river of any orientation will be used and the probability of different bankside vegetation can then be assessed in terms of probable control. RHS data along with previous material will be used for this, and other work on estimating organic input. The RHS dataset is also being used along with concurrent macrophyte and water quality data to produce preliminary habitat and water chemistry preferences and tolerances for most of the UK aquatic macrophytes including *Ranunculus* species. This work will be described in a paper on variation and prediction of major anions, cations and some trace metals with implications for aquatic vegetation of British rivers. The work includes data from 4500 water samples, and will include statistical analysis (Dawson in prep. doc 307).

Additional water quality work is to be presented as a continuation and refinement of the MTR work (Holmes *et al.* 1999 and Dawson *et al.* 1999). This will be entitled 'The distribution of aquatic plants in the assessment and prediction of environmental quality (PLANTPACS)' (doc 309).

This classification system will incorporate a predictive element based on physicochemical and morphological data and also the modification of stream habitat and water chemistry at the level of individual species as well as assemblages and communities.

Further work is also planned assessing aspects of hydraulic resistance of particularly *Ranunculus* and *Potamogeton* species (Dawson in prep. doc 306).

A summary review of various aquatic plant management techniques is also planned. This will discuss the advantages of water plants to stream habitat and the disadvantages of each management technique together with recommendations for more ecologically-sound techniques (Dawson in prep. doc 308).

Further ahead, probably in 2002 there is the production of the Biological Flora of *R. penicillatus*. This would be an overview and include all aspects of its biology, growth and control.

4.7.2 Assessment of the impact of nutrient removal on eutrophic rivers

University of Leicester (Demars *et al.* 2000 doc 114) are looking at the impact of nutrient removal on the River Wensum. Phosphate stripping began on the Wensum in 1999. Unfortunately preliminary conclusions are that predicting the impact of phosphorus removal is not possible. The study will continue however to include investigation of temporal variability of phosphorus in the sediment and water column and release and uptake of phosphorus in the sediment.

4.7.3 Assessment of rehabilitation schemes on Chalk rivers

Peter Shaw and Terry Langford at Southampton University have undertaken an assessment of a rehabilitation scheme on the River Avon (undated doc 282). Future work by Southampton University includes assessment of rehabilitation schemes in respect of salmonid spawning on the Frome, Itchen, Test, Avon and Meon.

4.7.4 An investigation of ecological change in the Rivers Kennet and Lambourn

This is a study into the long term ecological change and impact of the 1996 to 1997 drought using four sites on the Rivers Kennet and Lambourn that were the subject of a detailed study in the 1970s. The progress reports by Wright *et al.* of CEH have been reviewed for this project. Further reports and papers are expected from this study.

4.7.5 River Itchen Sustainability study

Halcrow Group Ltd are leading a project to determine a definition of 'favourable status' for species, communities and habitats including floating formations of *Ranunculus* of plain and sub-mountain rivers on the River Itchen SAC (Halcrow Group Ltd 2000). This is part of study that will eventually lead to determination of target flows for the Itchen catchment.

4.7.6 Macrophyte survey of the River Misbourne

Ardeola Environmental Services (AES) have carried out a macrophyte survey for the Environment Agency of the River Misbourne. The Misbourne has suffered from combined drought and abstraction conditions, particularly in the upper reaches, but water is now flowing again following two years of above average recharge (1999 and 2000). The report has not yet been completed but the drought appears to have had no significant effect on the status of *R. penicillatus* subsp. *pseudofluitans*. However the number of *Ranunculus* species recorded has increased. Richard Lansdown of AES believes that the recovery has been over and above the effect of the recharge (pers. comm. 2000).

4.7.7 Ecological assessment of river rehabilitation schemes

Judy England, Thames Region Environment Agency, is undertaking a part time PhD at the University of Hertfordshire on the Ecological Assessment of River Rehabilitation Schemes, which will include Chalk rivers and monitoring of in-stream plant colonization.

4.7.8 Study of the sediment preferences of macrophytes

Dr Stewart Clarke, Queen Mary College, London has recently written up an R&D report for the Environment Agency on sediment characteristics of a number of macrophytes including *R. penicillatus* subsp. *pseudofluitans*. The *Ranunculus* samples came from the rivers Allen, Dun, Frome, Hiz, Itchen, Loddon, Rhee, Test, Wey, Whitewater and Wylye. The work was undertaken to further develop the use of macrophytes in the biological assessment of rivers.

5 CONCLUSIONS

5.1 Methods and Outcome of the Project

Source material on factors affecting *Ranunculus* in Chalk rivers was collected, collated and reviewed. From this review it was possible to summarize the type and extent of information on *Ranunculus* in Chalk rivers. This project has been useful in identifying the extent of knowledge about *Ranunculus* and the difficulties of disentangling the interactions between environmental variables and their effects on *Ranunculus.*

The decade of the late 1980s to 1990s raised concerns about the future status of *Ranunculus* in Chalk rivers and the rivers themselves. The higher winter flows of recent years may have, temporarily at least, assuaged fears about the ability of *Ranunculus* to recover from a series of low flow years with all their associated stresses.

Under the BAP the Environment Agency now has responsibilities towards the future conservation of Chalk rivers and *Ranunculus*. There are also particular obligations for the status of floating formations of *Ranunculus* in SAC rivers.

The predictions of climate change however suggest that past events are no longer a guide to future weather conditions. In addition, the continuing impacts of enrichment, land use change, abstraction and the annual removal of huge quantities of plant material from Chalk rivers have yet to be fully investigated.

The data provided by the contacts in the Environment Agency and the experience of river keepers and many others have provided essential background information for this project. The accumulation and review of source material has helped to identify areas where knowledge is lacking and further research is required to help the Environment Agency fulfil its responsibilities.

The outcome of the project is not completely comprehensive due to time constraints imposed on Environment Agency staff. However, this project should not be seen as a once and for all exercise. More research will be undertaken to understand the factors affecting *Ranunculus* and the other flora and fauna of Chalk rivers. All of this work is potentially useful to guide the Agency's management responsibilities. The production of the database will enable further documents (e.g. Dawson in prep) to be added for future reference. This can readily be achieved by annual up-dates of the database.

5.2 *Ranunculus* and the Reviewed Documents

The number of documents on a particular Factor (or Driver) is not a guide to what are the key Factors (or Drivers). In many instances original work has been repeatedly cited by other authors. This has led to an increase in the number of citations to a particular Factor based on the same piece of work. Of the total of 311 documents reviewed, 172 were accepted and used in the production of this report. 98 Chalk rivers out of a total of 156 were not mentioned in the documents reviewed.

Most of the documents were about factors affecting the dominant macrophyte, *R. penicillatus* subsp. *pseudofluitans*. The status of *R. peltatus* in winterbournes and intermittent stretches is covered by the detailed survey work of Holmes (Holmes 1996 doc 35). River Water-crowfoot, *R. fluitans*, is briefly mentioned but it is difficult to derive a great deal from the documents reviewed. The project did not have the remit to review literature on the same *Ranunculus* species on non Chalk rivers.

The project was limited to factors affecting *Ranunculus* growth. The extensive literature of certain areas of potential interest was not reviewed. These are primarily climate change and algal ecology.

5.3 *Ranunculus* and the Snapshot Forms/Rehabilitation/Research

5.3.1 Snapshot forms

The snapshot forms together with discussion with Environment Agency staff indicate that *Ranunculus* is dominant on many river reaches following two years of higher flows in 1999 and 2000. This was in direct contrast to the low flow years of 1989 and the early 1990s when *Ranunculus* presence was reduced on many rivers. Knowledge of *Ranunculus* status prior to 1990, except on some of the larger rivers, seems to be particularly lacking. In addition, there was little or no information on the status of *Ranunculus* which included the total length of most rivers.

The monitoring of the status of *Ranunculus* in Chalk rivers does not appear to be part of any other regular Environment Agency monitoring activity such as biological monitoring.

5.3.2 Rehabilitation

The list of Rehabilitation projects, although not comprehensive, appears to give a fair indication of the types of project carried out on Chalk rivers over the last decade. Most of the projects were designed to increase flow and thereby velocity. The vast majority of these projects have had no formal monitoring for the effect on *Ranunculus*. The impression gained from discussion with Environment Agency staff was that the majority of rehabilitation projects the Agency is involved with were opportunistic, taking advantage of funding and partnerships whenever they arose. In the absence of hard data on the linkages between discharge, channel dimensions and water quality in terms of impact on *Ranunculus* there should be caution in promoting rehabilitation projects. Until at least a number of rehabilitation projects, are properly monitored, employing a variety of techniques the benefits or otherwise of this form of intervention will at best remain empirical. A more scientific monitoring methodology needs to be employed when carrying out rehabilitation projects.

5.3.3 Research projects

Much is anticipated from the proposed publication of a series of papers by Hugh Dawson, CEH. They should add considerably to the fund of knowledge about *Ranunculus* in Chalk rivers.

The preliminary results of the work by Leicester University investigating the effects of phosphate stripping on the River Wensum are disappointing. It would seem that it is not possible to use macrophytes to predict phosphate concentrations in the Wensum. This result seems to have been confirmed by Dr Stewart Clarke, Queen Mary College London who compared water and sediment and plant tissue nutrients upstream and downstream of STWs on the Test and Itchen. He found that the discharges affected the water and sediment concentrations but not the plant tissue levels.

The study of the impact of the 1996 to 1997 drought on the Rivers Kennet and Lambourn by Wright *et al.* is an excellent example of the importance of maintaining long term databases. The findings of that study can feed directly into the management of those two rivers and have applications for other Chalk rivers. The study has already provided valuable information to this project.

The River Itchen Sustainability Study will provide information on the status of *Ranunculus* on that river and eventually move towards the provision of target flows for the catchment.

5.4 Summary of Extent of Knowledge on *Ranunculus*

5.4.1 Factor A - Competition/Life Cycle/Colonization and Drivers

Competition is most frequently described under natural conditions of climate and hydrology. This competitive balance is, however, frequently disrupted and complicated by the conditions prevailing in Chalk rivers. Changes to normal flows such as drought, late or early autumn floods and abstraction, can give other competitors such as algae, *Callitriche* and *Berula* an advantage.

In conditions of shade, *Berula* and *Callitriche* can outgrow *Ranunculus*. With sufficient discharge even in shade *Ranunculus* can outgrow them both. Enriched water quality can trigger the increased growth of algae, epiphytes and other competitors. Channel dimensions affect velocity with shallow flows in over-wide sections allowing the encroachment of marginal vegetation or over-deep sections preventing the growth of *Ranunculus*.

There is little hard information about methods of reproduction.

5.4.2 Factor B - Discharge/Seasonal Annual Changes and Drivers

The fundamental importance of Discharge is well to the fore in the documents reviewed, with a linkage to the Drivers of Natural Climate Cycles, and complicated by Abstraction. Less well understood is the aggravation or alleviation of the impacts of the other Factors by discharge. The impact of land use change affecting drainage is alluded to but not defined.

5.4.3 Factor C - Light/Shade/Temperature and Drivers

There has been a lot of quantified field and experimental work on this Factor linked to Natural Climate Cycles. *Ranunculus* is a high light demanding plant intolerant of shade. Shade from algae and natural shading are documented. There appears to be little on the temperature requirements of *Ranunculus*.

5.4.4 Factor D - Substrate/Siltation and Drivers

There is a lot of observational evidence on the preference of *Ranunculus* for clean gravel substrates. There is a frequently inferred negative impact of siltation. By contrast there is very little hard data on the amount, source, changes in quantity and absolute effect of siltation.

5.4.5 Factor E - Velocity/Depth/Levels and Drivers

There is quantified study of the enhanced physiological response to fast flowing water and a lot of observational and inferred links between velocity and *Ranunculus* performance. Although the figure of 10 cm/sec is often quoted as the point below which there would be a limit on *Ranunculus* growth there are no absolute values.

Velocity is driven by discharge via Natural Climate Cycles and influenced by channel dimensions and abstraction. Depth can limit growth via shading and reduced light.

5.4.6 Factor F - Water Quality/Enrichment/Suspended Solids and Drivers

There is frequent inference to the problems associated with poor water quality and enrichment and its impact on *Ranunculus*. Water quality is invariably linked to point source enrichment inducing increases in algae and thereby threatening *Ranunculus* from competition and/or shading. Discharge and therefore Natural Climate Cycles are also identified as important contributors to this equation. There are relatively few links with Land Use and Diffuse Enrichment though it too is seen as having an adverse but unquantified impact. For this Factor there is a highly perceived cause and effect which is confounded by many other Factors.

There is little written on the water quality aspects of suspended solids and the impacts on *Ranunculus*. Reference to suspended solids is largely confined to the effects of siltation on leaves and substrate.

5.4.7 Factor G - Grazing and Drivers

Another highly perceived problem which lacks good quantitative field evidence to confirm the widely held belief that swans (in particular) pose a serious threat to *Ranunculus*. Observational evidence points to adverse impact when water levels are low. It would appear that in the short term at a site level the impact of swan grazing can be highly detrimental.

5.4.8 Factor H - Physical Dimensions and Drivers

There is little quantitative work on the dimensions of channels preferred by *Ranunculus*. Over-wide channels and consequent reductions in velocity, also linked to discharge and therefore Natural Climate Cycles, are cited as having a detrimental impact on *Ranunculus*. It is presumably this observation which has led to so much rehabilitation work involving changing channel dimensions to increase velocity.

5.5 Extent and Value of Knowledge to Management Applications

The following discussion is based on the review of the documents in the database. It is summarized using the headings identified in 2.5 Management Applications. The EN target guidelines for maintaining floating formations of *Ranunculus* in SAC Chalk rivers provide a best practice framework in which to consider targets for other Chalk rivers.

5.5.1 Licensing - abstractions

To license abstractions in line with its obligations outlined elsewhere in this report the Environment Agency needs to know what discharge is required in whole rivers, (or reaches) to maintain healthy *Ranunculus*. If the Environment Agency knows what discharge is required for a given channel size throughout the year it can determine, in the light of future climatic change scenarios, what water can then be abstracted from the system without damage to *Ranunculus*.

There is considerable knowledge in the documents regarding the ways discharge influences velocity and depth, and then how velocity, in particular, works through various factors to influence *Ranunculus* growth. It is commonly stated that increased discharge leads to improved *Ranunculus* growth. From observations on certain rivers over the low flow years of the 1990s the discharge at which conditions start to become unsuitable for *Ranunculus* can also be approximately judged. What is clear is that there are very few if any absolute values given in the literature as to the discharge required to maintain good conditions for *Ranunculus* growth. The discharge required will vary with, amongst others, channel dimensions, silt load and water quality. A relatively greater discharge may be required, for instance, to maintain favourable conditions for *Ranunculus* if the channel is over-wide, silted or the water quality is poor.

Improving channel dimensions could alter the discharge required to create and maintain favourable conditions for *Ranunculus*. There is considerable evidence that many reaches of Chalk rivers have become over-wide.

Intensive management of the marginal vegetation also effectively keeps the channel wider than it would otherwise be.

Licensing abstractions therefore needs to take all of these factors into account on a whole catchment, river, or sector scale.

Absolute or precise values or formulae are not presented in the literature. The processes and linkages are well documented and understood however, such that professional judgement could provide guide values for the discharge that needs to be maintained through the seasons for good *Ranunculus* growth.

The EN generic guidelines for floating formations of *Ranunculus* set targets on the flow regime which should be maintained by, amongst other things, limiting licenses on abstraction, after modelling impacts. The target flow regime is that at least 90% of the naturalized daily mean flow should be maintained throughout the year at all points in the river system.

While this target may be appropriate for natural channels it may not be appropriate for modified channels. It is important to always consider discharge and channel dimensions together.

5.5.2 Licensing - discharges

Within the literature a range of views is present as to the extent and role of enrichment in the Chalk river system and the impacts on *Ranunculus*. Much work has focused on the role of phosphates. There would not appear to be a consensus regarding the direct effects of nutrients on *Ranunculus*. However, there is a wide understanding that the main impact is delivered indirectly through the impact of enrichment on the various forms of algae. Elevated phosphorus levels interfere with the competitive interactions. There is no unequivocal evidence that phosphate stripping results in improved *Ranunculus* growth, but confounding issues very much apply here. The literature on phosphates and algae undoubtedly provides more quantitative information on the levels which trigger increased algal production.

A few key papers relate these data to *Ranunculus* and have provided the basis for the EN guidelines set out below.

The EN generic guidelines set targets values for 0.06 mg/l Phosphorus.

Nitrate is known not to be limiting to *Ranunculus* growth in Chalk streams. No data are presented regarding the impact of elevated nitrate levels on *Ranunculus*.

It is known that *Ranunculus* has a high light requirement and suffers under shaded conditions. It is reported that turbidity from high suspended solids affects *Ranunculus* performance but figures are not given that could guide the consenting of licenses. The EN guidelines for floating formations of *Ranunculus* have not yet determined the targets for suspended solids, further underlining the lack of data.

5.5.3 Licensing - weed-cutting

A great deal of literature relating to weed cutting occurs in the database. The data appear somewhat conflicting but this is in part due to the conflicting interests involved, and the different conditions and requirements which apply. There is considerable evidence to support the use of more benign methods of weed cutting than are traditionally used, such as shading or not cutting at all to induce the 'four year effect' of reduced biomass. Mainstone (1999 doc 298) provides a clear summary of the conflicting issues involved in weed cutting and of ways of dealing with them. He details the best practice option for conservation as being to allow plant succession to progress as naturally as possible. This entails reducing cutting to the minimum necessary, including marginal plants to maintain a central low-flow channel. He reports that in most cases land drainage, flood defence requirements and fishing interests can be satisfied by cutting no more than 30% of the channel width at any time.

The EN guidelines recommend that any in-channel vegetation management should ensure that a significant proportion of the *Ranunculus* community is allowed to flower and set seed naturally.

Management should therefore aim to leave a patchy distribution of *Ranunculus* at all points in its range, with a guideline of at least 25% allowed to flower in any 100 m stretch.

5.5.4 Water resources: setting acceptable flows

This is dealt with under Section 5.5.1.

5.5.5 Conservation

There is much valuable information within the database documents to aid conservation management. However, it should be noted that the review of documents was very much focused on *Ranunculus* not on the wider macrophyte Chalk stream community. There is great consensus within the literature as to those factors which have a detrimental effect on *Ranunculus* and those that have a beneficial effect. What is frequently lacking are absolute values or even usefully narrow ranges of values to work to. The multiplicity of interactions probably means that figures derived from one reach or river are only very generally applicable to other reaches. It is therefore the principles that are of greatest value, rather than absolute figures.

The central role of discharge and velocity is apparent from the literature (See Section 5.5.1). However, it is also clear that channel dimensions have to be appropriate to that discharge. There is information within the documents on how to assess whether reaches are over-wide and therefore are candidates for rehabilitation. The notes on rehabilitation projects in Appendix 4 give an indication of some techniques used to narrow certain reaches.

Other techniques and the key personnel involved in rehabilitation work are also available from that list. With only ad hoc monitoring much of the information is held by these people, rather than in documents. They therefore remain the key source of knowledge. Vegetation management is also apparent as a pivotal activity in many Chalk rivers and the limited benefits of much of the current management techniques are apparent from the literature. As mentioned under weed-cutting, there is strong evidence to support moving away from these intensive techniques wherever possible.

The EN guidelines for floating formations of *Ranunculus* in SAC rivers should provide the guiding principles for the conservation of Chalk rivers, except those smaller ones which would not be expected to support significant stands of *Ranunculus*.

5.5.6 Management

Two of the main reasons why Chalk rivers are managed are for flood defence and fisheries. The main intervention is through vegetation management. As stated in the section on weed-cutting (Section 5.5.3) there is conflicting evidence and attitudes about vegetation management, but there is also information to support more benign and less intensive methods whilst achieving the goals of flood defence, land drainage and habitats for fisheries.

5.5.7 Determining protocols

Data collection is an essential requirement to help determine the best practices and procedures for Chalk river management. There are a small number of documents which illustrate the importance of procedures for the collection of data. They include long term studies on the Lambourn and Kennet, the Test and Itchen, the recent study of *Ranunculus* status on the Avon as well as procedures for securing monitoring on rehabilitation schemes.

Of particular interest is the recent study by Menendez (2000 doc 299) on weed cutting on the Avon catchment. He questions the current weed cutting regime and its impact on the biota of a SAC Chalk river.

5.5.8 Response to land use change

There is very little information within the reviewed documents which would provide sufficient evidence to support river management decisions based on land use change. What information there is, is very inferential. If the processes invoked by the land use change could be linked to any of the identified Drivers and particularly Factors then information on the impacts on *Ranunculus* could be derived from them.

5.5.9 Response to climate change

Only one document details the potential response of *Ranunculus* (and other macrophytes) to probable future climate scenarios. Cranston *et al.* (1998 doc 296) used macrophyte and environmental data from the Test and Itchen, combined with hydrological and climatological models to attempt a preliminary prediction of possible outcomes. This approach could form the basis of providing information to support decisions relating to climate change. As regional climate change models are becoming more refined this will lead to more accurate predictions of how the Factors detailed in this report will be expected to change, and thus the impact can be deduced from understanding the way the Factors operate.

5.5.10 Fieldwork

Despite the considerable amount of field work undertaken on Chalk rivers in the last 30 years there are many aspects of *Ranunculus* and the Factors and Drivers affecting its growth and distribution which remain undetermined or only partially answered.

Although time consuming and relatively costly, field work represents the only means of gathering data on a year to year basis throughout a variety of climatic and management conditions. It will enable data to be gathered that have been identified by this project as absent or currently only available in a limited form. Field work needs to be carried out on subjects such as the relationships between discharge, velocity and water quality needed to sustain *Ranunculus,* sediment loadings in catchments, the impact of past widening on *Ranunculus* distribution and the most appropriate forms of management. Meanwhile monitoring protocols like the ones recommended on the Itchen Sustainability Study need to be carried out to establish the current distribution of *Ranunculus* on all Chalk rivers. The gathering of data from this and other recommended fieldwork could then be used to improve the current status of models on *Ranunculus*.

5.5.11 Models

Models of factors affecting *Ranunculus* growth are still at a variety of stages of development. The conceptual model of Ham *et al.* was an excellent starting point for the future development of a mathematical model.

Cranston *et al.* (1996 and 1998 docs 295, 296) constructed hydrological models and a macrophyte model to investigate the principal environmental and physico-chemical controls on macrophytes in the Test and Itchen. The limitations of the model, primarily a function of available data, were acknowledged. Hugh Dawson, CEH, will soon be publishing papers which have the potential to be fed into a *Ranunculus* growth model. There is therefore a considerable imperative to review the status of *Ranunculus* models to determine how they can be progressed to the point where they can become a reliable and useful tool in the management of Chalk rivers.

5.6 Absence of Data

On the basis of the documents reviewed there is an absence of data on :

- The status of *Ranunculus* on many reaches of many Chalk rivers.
- Sediment dynamics. This is poorly documented yet it is important to know the sources including amount, changes over time and the potential nutrient input. In tandem with this is to understand the effects of more benign land use such as countryside stewardship, re-use of water meadows and the benefits of buffer strips.
- The impacts of silt on rooting and colonization via vegetative means and seed.
- The physical, biological and chemical effects of suspended solids (via turbidity) on *Ranunculus* growth.
- The likely impacts of climate change including regional scenarios, implications for water demand, water resources and hydrology.
- A fluvial geomorphological approach. This appears to be missing and is considered critical for sustainable rehabilitation projects.
- Scientific quantification of appropriate physical channel dimensions for good *Ranunculus* growth under a given discharge and in relation to water quality and sediment loadings.
- Monitoring on rehabilitation projects.
- The real impact of swan grazing.

In the last decade, when there were sustained conditions of low flow, accumulation of silt and competition with other plants such as algae, *Ranunculus* tended to fare badly (Mainstone 1999). It is reasonable to suppose that any return of these adverse conditions will once again reduce or severely deplete the distribution of *Ranunculus*. What is an unknown is the reaction of *Ranunculus* to even more prolonged low flow and associated conditions and its ability to recovery.

5.7 Most Pressing Issues

There is an urgent need to establish the status of *Ranunculus* on all Chalk rivers where these data are absent in order for the Environment Agency and EN to fulfil their obligations under the Chalk Streams BAP.

The most important Factor is Discharge with Natural Climate Cycles the key Driver in most cases. There is a need to establish the relationship between discharge, physical dimensions, water quality and sediment loading and *Ranunculus* growth.

Monitoring of Rehabilitation schemes to ensure they are meeting their aims without compromising other interests.

Clarification, and promotion of, vegetation management techniques that take full account of the needs of nature conservation (*Ranunculus* community) as well as flood defence and fisheries.

6 RECOMMENDATIONS

On the basis of the preceding Analysis and Discussion and Conclusions recommendations for further work are made in line with the requirements of the project. The following recommendations are made under appropriate headings and a suggested order of priority under each heading:

A. Research and Development

A1. As a precursor to any future proposals to develop a model for *Ranunculus* – establish if dataset(s) exist to determine relationships between discharge, velocity and water quality/quantity required to sustain *Ranunculus*.

A2. Set up a project to establish sediment loading in catchments and the impacts of changes in land-use and river management building on the River Avon Land-care initiative, and proposed work on the River Itchen Sustainability Study.

A3. Investigate the mechanism (and extent and importance) of success/failure in *Ranunculus* flowers setting viable seed and subsequent germination.

B. Field Trials

B1. Determine the effects of past widening and deepening of Chalk rivers on the geomorphology/habitats affecting *Ranunculus* growth and distribution and link to the effects of recent rehabilitation works to narrow or shallow rivers.

B2. Promotion, through field trials, of more benign management of selected Chalk rivers through working with Environment Agency flood defence and river keepers.

B3. Determine the overall impacts and extent of local impacts by grazing swans etc. and investigate methods of effective control.

C. Monitoring/Survey

C1. Urgently address lack of knowledge of *Ranunculus* distribution/abundance on many Chalk rivers. This is essential if obligations to protect, improve or restore this interest are to be met for this BAP and SAC interest.

C2. Establish selective monitoring of rehabilitation projects to determine relative effects on *Ranunculus* of each of the methods most commonly employed.

C3. Devise a SIMPLE protocol for routine reporting on the status of *Ranunculus* by EN and Environment Agency field staff when engaged in other survey/investigation tasks.

D. Dissemination/Advisory/Promoting Good Practice

D1. Set up a third Forum in November 2001 to disseminate information from this project and to discuss and refine the most urgent Research & Development needs.

D2. Develop and disseminate suitable outputs for river keepers and others on the key findings from this project.

D3. Widen the understanding of the *Ranunculus* community to include a better integration of other macrophytes that make up the desired assemblage.

D4. Make the database accessible and ensure it is updated on a regular basis.

LIST OF ACRONYMS

BAP - Biodiversity Action Plan

CAPM - Centre for Aquatic Plant Management

CEH - Centre for Ecology and Hydrology

Doc - Document

EC - European Community

EN - English Nature

FBA - Freshwater Biological Association

IFE - Institute of Freshwater Ecology

MTR - Mean Trophic Rank

NERC - Natural Environmental Research Council

NRA - National Rivers Authority

RCS - River Corridor Survey

RHS - River Habitat Survey

RRC - River Restoration Centre

SAC - Special Areas of Conservation

SSSI - Site of Special Scientific Interest

STW - Sewage Treatment Works

LIST OF TABLES

GLOSSARY

Chalk river - perennial rivers or river reaches in England which derive a significant part of their flow from chalk fed springs, flow over chalk for a significant part of their length and are locally considered to be Chalk rivers. A list of these rivers is given in Appendix 1. This report has used as its primary focus the definition for Chalk rivers prepared by the Chalk Rivers Biodiversity Action Steering Group. It is understood that this definition and the list of rivers that it includes has not yet been finalised.

Ranunculus - there are several species of *Ranunculus* that may be present in perennial Chalk rivers. Where possible a distinction has been made between each species. Most of the literature and the focus of this project however is concerned with the dominant macrophyte of Chalk rivers, *Ranunculus penicillatus* subsp. *pseudofluitans* (Syme) S.D.Webster, Stream Water-crowfoot. The use of the generic *Ranunculus* in this report should be taken to refer to *Ranunculus penicillatus* subsp. *pseudofluitans*.

Documents - a generic term used throughout the report to refer to the source material collated during Phases 1 and 2 of the project.

REFERENCES

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APPENDIX 1

LIST OF CHALK RIVERS

As at 19 July 1999, all of the named tributaries, source to confluence are included, unless otherwise indicated.

AGENCY REGION, CATCHMENT, CHALK RIVERS

SOUTH – WEST
HAMPSHIRE AVON
Main River to sea, including

- Eastern Avon
- Etchilhampton Water
- River Bourne
- Nine Mile River
- River Wylye (+ Chitterne Brook and River Till)
- Fonthill Bishop Stream (Trib. of Nadder)
- River Ebble
- Rockbourne Stream
- Allen River
- Teffont Stream + Ashford Water

DORSET STOUR
River Allen, including

- Gussage Brook
- Crichel Stream

River Iwerne
River Tarrant
North Winterbourne
Shreen Water + Ashfield Water
River Crane to SU 105 076

RIVER FROME
Main River to sea, including

- Hooke Stream
- Sydling Water
- River Cerne
- South Winterbourne
- Tadnoll Brook, including Empool Bottom and Watergates Stream
- River Win

RIVER PIDDLE
Main River to sea, including

- Bere Stream
- Devils Brook
- Cheselbourne Stream

SOUTH – WEST continued

OTHERS
River Bride
River Jordan
River Wey (excluding Pucksey Brook trib.)
Osmington Mills Stream
Lulworth Stream

SOUTHERN
RIVER TEST
Main River to sea, including
- Bourne Rivulet
- River Dever
- River Anton (+ Pilhill Brook)
- Wallop Brook
- Somborne Stream

RIVER ITCHEN
Main River to sea, including
- Candover Stream
- River Alre
- Cheriton Stream

RIVER MEON
Main River to Tichfiled SU 543 055 including
- Whitewool Stream

RIVER STOUR (KENT)
Great Stour: Wye TR 050 471 to Sturry (tidal limit) TR 175 600
Nailbourne / Little Stour: source to Wickhambreaux TR 220 588
Wingham streams – Port Rill TR 230 572 – TR 237 581
? TR 236 566 & TR 239 565 to TR 239 579
? 248 568 to 247 575
North Stream. Source to A258 nr Hacklinge TR 342 545
South Stream. Sources TR 337 521 and TR 349 522 to A258 nr Hacklinge TR 343 544

RIVER DARENT
River Darent – Otford TQ 523 596 to tidal limit TQ 541 749
River Cray Source to tidal limit TQ 527 755

OTHERS
River Ems (Sussex)
River Lavant (Sussex)
Lewes Winterbourne (Lewes, East Sussex)
River Dour (Dover, Kent)
Holborough streams (Tidal Medway)
Sources TQ

THAMES

RIVER KENNET

Source to Woolhampton (SU 572 667) including

- River Lambourn (+ Winterbourne)
- River Og
- River Dun
- River Aldbourne
- Rver Shalbourne

RIVER COLNE

Source to Denham (TQ 053 861)

- River Ver
- River Gade
- River Bulbourne
- River Misbourne
- River Chess

RIVER LEE

Source to Hertford (TL 325 127) including

- River Stort
- River Bean
- River Rib
- River Ash
- River Quin
- River Mimram

RIVER LODDON

Source to Standford End (SU 707 632) including

- River Lyde
- River Whitewater

OTHERS

River Pang
Wye and Hughenden Stream
Letcombe Brook
Hamble Brook
River Wey (North) to Farham (SU 848 472)
Caker Stream
River Hogsmill (to TQ 203 648)
River Wandle
River Mole, Dorking to Cobham (TQ 203 648 – TQ 099 608)
Ewelme Stream
Chalgrove Stream, source to SU 663 962
Horsenden Stream, source to SP 795 020

ANGLIAN

GREAT OUSE CATCHMENT
River Hiz
Little Ouse TM 039 790 – 780 870
River Cam TL 520 370 – 440 540
River Rhee upper tributaries e.g. Shep TL 405 451 – 380 486
Rhee TL 270 398 – 253 410
River Granta TL 561 464 – 463 515
Snail TL 642 677 – 618 732
Kennett TL 678 710 – TL 660 750
River Lark – Triutaries between TL 860 670 and TL 730 790
Cavenham Stream (source to River Lark) TL 765 702 – 775 721
River Thet TM 003 941 – TL 872 829
Sapiston TL 950 670 – 890 790
River Wissey & tributaries TF 865 067 – 709 995
Gadder TF 770 029 – TL 677 252
River Nar TF 905 188 – 740 130
Babingley TF 743 264 – 677 252
River Heacham TF 720 359 – 690 375

RIVER YARE CATCHMENT
River Wensum TF 898 238 – 199 101
River Tat (whole river to Wensum confluence) TF 836 312 – 875 280
River Bure TG 062 323 – 267 197

RIVER EAU
Great Eau to TF 425 826
Long Eau to TF 403 854

OTHERS - Lincolnshire
- North Norfolk

Waithe Beck TF 202 904 – TA 314 006
Thoresway Beck TF 170 967 – TA 203 001
Laceby Beck TA 220 041 – 240 091
River Lud TF 320 829 – 338 879
Keelby Beck TA 169 098 – 215 153
Barrow Beck TA 061 203 – 064 225
East Halton Beck TA 126 143 – 144 229
Skitter Beck TA 162 105 – 126 143
Burlands Beck TF 449 714 – 507 718
Stainfield Beck TF 449 714 – 507 718
Brocklesby Beck TA 109 112 – 126 143
River Bain TF 205 892 – 250 719
River Rase TF 159 925 – 032 910
Butforth Drain TA 099 168 – 072 222
River Stiffkey (excluding upper reaches) TF 920 352 – 990 441
River Burn (whole river) TF 862 342 – 834 438
River Glaven (mid reaches) TG 085 363 – 045 415

NORTH EAST

RIVER HULL

Headwaters above TA 0811 5161, including

- Watton Beck
- Skerne Beck
- Driffield Trout Stream
- Southburn Beck
- Eastburn Beck
- Driffeld Beck
- Elmswell Beck
- Water Forlorns
- West Beck
- Nafferton Beck
- Kelk Beck (or Foston Beck)

RIVER DERWENT

OTHERS

Hayton Beck and tributaries above SE 8203 4567
Pocklington Beck tributaries above SE 812 507
Tributaries of Barlam Beck above SE 7870 5870
Menethorpe Beck and all tributaries above Derwent confluence SE 765 677
Setrington Beck & tributaries above Derwent confluence SE 8192 7370
Scampson Beck and tributaries above Derwent confluence SE 8532 7877

The Gypsey Race (Highly ephemeral in nature to sea at Bridlington).

APPENDIX 2

CD OF DATABASE AND DATABASE FORM

Instructions for use of the Database

The read-only database must be opened in Microsoft Access 97. (See W1-042/CD enclosed with this report) A total of 311 documents were entered onto the Phase 2 database, 172 documents were accepted (Status 1) and 139 rejected (Status 2 or Status 3 as were in preparation at the time).

Data is organised in the following ways:

TABLES

TBL_DOCUMENTS shows column headings as:
Document ID (*an automatically assigned number*)
Document Number
Title
Author
Reference
Date
Keywords
Summary
Status

TBL_MANAGEMENT shows column headings as:
Document ID
Management (*These are listed as Applications A – I on page 7 of the report*)
Comment

TBL_MATRIX shows column headings as:
Document ID
Factor (*These are listed as A – J on page 5 of the report*)
Driver (*These are listed as 1-10 on page 6 of the report*)
Type of Study (*These are listed as A – D on page 6 of the report*)
Basis (*These are listed as 1 – 5 on page 6 of the report*)
Comment

QUERIES

The user can use the 'Queries' mechanism to find documents that have been 'Accepted' (Status 1), as opposed to Rejected or In preparation etc. (Status 2 or 3) by searching under:

author,
any word in the title,
any word in the summary review,

any word in the keywords (which includes the river if specified and the Ranunculus species if specified and as used in the document),
any Management Application,
any combination of Factors and Drivers, Types and Bases of information.

For example, using the query mechanism the user could:

i) identify any documents that were accepted that had quantitative data on velocity.

ii) **QRY_KEYWORD_TEMPLATE** asks for a parameter value.
E.g. Entering the keyword as "itchen" will show you 14 entries in a table with column headings:

Document ID
Doc No
Title
Author
Reference
Date
Status

iii) **QRY_FACTOR_TEMPLATE** When in this, by entering G as the Factor for *Grazing* and then 8 as the Driver for *Land Use/Diffuse Enrichment* and no other parameter values, you will get just two entries. If on the other hand you had only entered G as a value, you would get eighteen entries.

iv) **TBL_DOCUMENTS** When in this table, you can find all titles that contain a word or part of this word:
So by highlighting the word "*south*" you can also find entries such as southern, southerly or south-facing.

Highlight the word "*south*", Click on top menu bar 'Records', Click on 'Filter', Click on 'Filter by Selection' to get a list of entries. Once you have finished, click on 'X' to close the view and click on 'No' as you do not want to change the design of the table.

A flood defence engineer might wish to find accepted papers that were deemed to have significance to that Management Application (D - Management - flood defence)

A different user might be interested in diatoms, in which case, the best query might be via the use of the word 'diatom' in the summary review field.

DATABASE FORM

Doc No

Title

Author

Reference

Date

Keywords

Status

Summary

Management

Factor	Driver	Type of Study	Basis

APPENDIX 3

a) SNAPSHOT SUMMARY TABLE

Summary of Snapshot Form Information received from Environment Agency Contacts

Region	River	*Ranunculus* Status	Information on *Ranunculus*	Rehabilitation Works
Southern	Nailbourne/ Little Stour	Frequent in middle reaches in last two years but status not know before that	RCS, RHS, Invert Surveys	None
	Darent	Locally dominant in middle reaches for over a decade but status not know elsewhere	RCS, RHS, Invert Surveys	Several, one monitored Ranunculus
	Cray	Abundant in middle reaches for over a decade but status not known elsewhere	RCS, RHS, Invert Surveys	Two but no Ranunculus monitoring
	Great Stour	Locally dominant in upper and middle reaches for over a decade but status not known elsewhere	RCS, RHS, Invert Surveys	Several none monitored Ranunculus
	Ems	Frequent in the winterbourne in last two years status not known before	RCS, RHS, Macrophyte & Invert Surveys	None
	Lavant	Locally dominant in the winterbourne in last two years status not known before	RCS, RHS, Macrophyte Survey, Invert Surveys	None
	Lewes Winterbourne	Status not known	RCS, RHS	None
	Test	Locally dominant and abundant in the 1990s (except status not known in upper reaches) Not known pre 1990s	RCS, Macrophyte survey, Invert Survey	None Known
	Bourne Rivulet	Locally dominant to occasional over the whole river in the last decade. Note known pre 1990s	Invert Survey	Not Know
	Dever and Somborne	Not Known	Not Known	Not Known
	Anton and Pilhill	Occasional in upper Pilhill & Anton, locally dominant to abundant in lower Pilhill & Anton 1998-2000. Not known before	RCS Invert Survey	Not Known

Region	**River**	***Ranunculus* Status**	**Information on *Ranunculus***	**Rehabilitation Works**
	Wallop Brook	Locally dominant but frequent over whole river 1998-2000. Status before not known	Invert Survey	Not Known
	Itchen	Locally dominant to abundant since mid 1990s. Status before not known	RCS, RHS, Macrophyte Survey, Invert Survey	Not Known
	Candover Alre Cheriton	Locally dominant to frequent 1998-2000. Status before not known	Invert Survey	Not Known
	Meon	Frequent in winterbourne and upper reaches, abundant in middle and local dominant in lower reaches 1998-2000. Status before not known	RCS Invert Survey	Not Known
North East	Hayton Beck & tribs, Pocklington Beck & tribs, Settrington Beck & tribs. Scampston Beck & tribs	Rare over whole river 1998-2000. Status before not known	Macrophyte Survey	None
	Tribs of Barlam Beck, Menethorpe Beck & tribs	None over the whole river 1998-2000. Status before not known	Macrophyte Survey	None
	Elmswell Beck	None in the upper reaches, abundant in middle reaches 1998-2000. Status before not known	Macrophyte Survey	One, *Ranunculus* returned
	West Beck	Abundant in upper, locally dominant in middle, none in lower reaches during 1990s. Status before not known	RCS,Macrophyte Survey Invert Survey	Three, *Ranunculus* returned
	Kell or Foston Beck	Not known in upper, abundant in middle and lower stretches in 1990s. Similar status pre 1990s	RCS Invert Survey	One, outcome not known
	Eastburn Beck	Not known in upper, abundant in middle and lower stretches 1998-2000. Status before unknown	Macrophyte Survey Invert Survey	None
	Water Forlorns	Not known	None	None
	Nafferton Beck Southburn Beck	None 1998-2000. Status before unknown	Macrophyte Survey Invert Survey	None

Region	**River**	***Ranunculus* Status**	**Information on *Ranunculus***	**Rehabilitation Works**
	Gypsey Race	None in the middle and lower reaches 1998-2000. None in the middle but present in lower reaches early1990s. Status before unknown	Invert Survey	None
	Driffield Beck	None in upper, abundant in middle and lower reaches 1998-2000. Status before unknown	Macrophyte Survey Invert Survey	None
	Driffield Trout Stream	Abundant in middle and lower reaches during 1990s. Status before unknown	RCS Invert Survey	None
	Skerne Back	None in river 1998-2000. Status before unknown	RCS, Invert Survey	None
	Watton Beck	Present in middle reaches 1990s. Status before unknown	Invert Survey	None
Anglian	Great Eau	Present in upper & middle reaches 1998-2000. Frequent to abundant in 1990s in upper reaches	Possible RCS Invert Survey	One,some development of *Ranunculus*
	Long Eau	Occasional in upper & middle reaches 1998-2000. Status before unknown	Possible RCS	Not known
	Lymn	Occasional in middle reaches 1998-2000. Status before not known	Possible RCS Invert Survey	Not known
	Bain	Present in upper & middle reaches 1998-2000. Frequent in upper occasional in middle 1990s. Status before not known	Possible RCS Invert survey	Not known
	Waithe Beck	Present in upper & middle reaches 1998-2000. Status before not known	Possible RCS Invert RCS	Not known
	Barrow Beck	Occasional in upper reaches 1998-2000. Status before not known	Possible RCS	Not known
	Bure	Not Known	RCS, Invert Survey, Reports	Not known
	Wensum/Tat	Not Known	RCS, Macrophyte Survey, Invert Survey, Reports/ PhD	One scheme, no monitoring

Region	River	*Ranunculus* Status	Information on *Ranunculus*	Rehabilitation Works
Thames	Colne, Bulbourne, Grade, Ver, Ash, Beane, Rib, Stort	Not Known	RCS	Scheme on Colne- *Ranunculus* returned. Schemes on other rivers but no monitoring
	Misbourne	Not Known	RCS, ALF Monitoring	Not known
	Chess, Mimram	Not Known	RCS, RHS	*Ranunculus* planted in Chess Schemes on Mimram but not monitored for *Ranunculus*
	Quinn	*Ranunculus* not believed to be present	Not Known	Not known
	Loddon, Lyde, Whitewater, Wey, Caker Stream, Mole, Hogsmill, Wandle	Not Known	Invert Survey& MTR on Loddon, Wey, Mole	Not known
South West	Hampshire Avon	Locally dominant in upper reach 1998-2000. Status otherwise not known	RCS, RHS Macrophyte Survey	Not known
	Wylye	Locally dominant in river 1998-2000. Status before not known	RCS, RHS Macrophyte Survey	Not known
	Piddle	Present in the middle reach 1998-2000. Status before not known	RCS, RHS Macrophyte Survey	Not known
	Allen	Locally dominant in river during 1990s. Status before unknown	RCS, RHS Macrophyte Survey	Not known
	Bourne	Locally dominant in whole river 1998-2000. Status before unknown	RCS, RHS Macrophyte Survey	Not known
	South Winterbourne	Present in whole river early 1990s. Status otherwise not known.	RCS, RHS	Not known

Region	River	*Ranunculus* Status	Information on *Ranunculus*	Rehabilitation Works
	Ebble	Dominant in early 1990s. Status otherwise not known	RCS, RHS	Not known
	Frome	Abundant in most of river pre and early 1990s. Current status unknown	RCS, RHS	Not known
	Wey	Dominant in upper reach in early 1990s. Status otherwise not known	RHS	Not known
	Chitterne, Etchilhampton, Fonthill, Nine Mile, Till, Bere Stream, Cerne, Devil's Brook, Empool, Hooke, Sydling Water, Tadnoll Brook, Crane, Gussage, Iwerne, North Winterbourne, Shreen, Tarrant, Bride, Jordan, Osmington	Not enough detail to determine status	RCS, RHS	Not known

APPENDIX 3 continued

b) SNAPSHOT FORM

Loughborough Ecologists
226 Charnwood Road
Shepshed, Loughborough
Leicestershire, LE12 9NR

Tel/Fax : 01509 569670
E mail : lboro.ecols@ntlworld.com
VAT No : 667 3447 05

R & D Project *Ranunculus* in Chalk Rivers. - EA. Snapshot - August 2000

You were very helpful in providing us with information about the Chalk Rivers in your area for Phase 1 of this project. We now need to extend and increase the detail of this information.

You may have provided some of this information before but we need to refine and update our database to make it as comprehensive as possible. As the area contact we need you to liaise with colleagues in other functions to provide us with the most up to date information on the status of *Ranunculus* together with any relevant rehabilitation and research projects.

We want to get a clearer idea of both the distribution and health of *Ranunculus* in the HAP listed Chalk Rivers and the level of knowledge relating to that distribution and health. We are therefore looking to identify:

i) where on the rivers *Ranunculus* distribution is known i.e. upper, middle or lower, as applicable, and
ii) what level of information is available for example RCS, REDS, Macrophytes Surveys, Macroinvertebrate survey notes etc.

Rehabilitation projects can also give a good indication of factors affecting *Ranunculus*. We therefore need to list them and the results of the rehabilitation. Frequently the rehabilitation is done for fisheries or as part of a flood defence scheme but an affect on *Ranunculus* may have been noted.

We are also interested in any research projects you are aware of whether funded by the EA. or not and even work that is to take place later in 2000 or 2001. This information can be added to our database for follow up in the future.

You can help us gather this data by filling in the enclosed form and returning it to us as soon as possible. We will contact you soon to answer any queries you may have.

Thanks again
Ed Darby and Elspeth Cranston

Ranunculus R & D - Snapshot of status for BAP Chalk Rivers

Region ____________________ Area ________________________________

River ____________________ Contact Name (s) ____________________

A) <u>*Ranunculus* Status 1998 - 2000.</u>

River Stretch	**1)** 1998-2000	**2)** cf. early 1990s	**3)** cf. pre 1990s
Winterbourne			
Upper			
Middle			
Lower			
Whole river if <15km			

1) Select one of the following (<u>please do not leave blank</u>):

LD = Locally Dominant, A = Abundant, F = Frequent, O = Occasional, R = Rare, P = Present, abundance not known, N = None, NK = Not Known

2) and 3) Select one of the following (<u>please do not leave blank</u>):

I = Increase, D = Decrease, S = ± Same, NK = Not Known

B) <u>Basis of Assessment of Status (A above)</u>

River Stretch	Survey Data	Research Papers	EA. Staff Observations	Other (state)
Winterbourne				
Upper				
Middle				
Lower				
Whole river if < 15km				

C) Sources of Information on *Ranunculus* held for river (√ as appropriate and list 'other')

River Stretch	RCS	RHS	REDS	Macrophyte survey	Invert Survey	Fish Survey	CEH etc.	Other state
Winterbourne								
Upper								
Middle								
Lower								
Whole river if <15km								

Please state which *Ranunculus* species is present (if known)

Ranunculus R&D - Summary of Habitat Restoration Projects influencing *Ranunculus* and Relevant Research for BAP Chalk Rivers

Region__________________ Area ______________________________

River __________________ Contact Name (s) __________________

D) River Habitat Rehabilitation works potentially influencing *Ranunculus* (e.g. flow restoration, bed raising, channel narrowing, berms, groynes, deflectors, gravel cleaning etc.)

Scheme Title & Location	Length affected	Type of Works	*Ranunculus* monitoring	Date	Contact Details

Please list all enhancement / rehabilitation schemes known in the 1990s that have occurred on the river that could have had an effect on *Ranunculus* (do not need to have had this as a key objective). This could include small- scale fishery enhancements such as deflectors and gravel cleaning. to large scale river narrowing. flow restoration etc. Please indicate if any monitoring undertaken which could show +ve, -ve or neutral effect on *Ranunculus*.

Please state which *Ranunculus* species is present (if known)

Please copy forms if necessary and return to **Loughborough Ecologists, 226 Charnwood Rd, Shepshed, Loughborough, LE12 9NR**. If assistance is required please tel.**: 01509 569670**

APPENDIX 4

REHABILITATION PROJECTS TABLE

Details are presented as given in Information Sources and as supplied by Contacts.

<u>Rehabilitation</u>

Rehabilitation projects undertaken on chalk rivers.

River	Year	Techniques Used	Comment	Monitoring	Info. Source	Contact
Avon		Replanting *Ranunculus*	*Ranunculus* was succesful in strong current			N.Giles
Avon Salisbury	2000	Brushwood mattresses, New river ‘banks’, pseudo meanders	Spectacular return of *Ranunculu*s across whole channel	No formal monitoring		S.Cain
Avon		Placing stone groynes in channel	*Ranunculus* flourished in higher currents			N.Giles
Avon Stratford sub Castle	1996/7	Groynes Fenced both banks	Fisheries. Some *Ranunculus* has come back from very little	Not monitored since first year but *Ranunculus* believed to be present	L Davies	L Davies, RRC
Avon Choulston Bridge		Brushwood mattresses	Over wide. Heavily silted. *Ranunculus* returned.	No formal monitoring		S.Cain
Avon Queensbury Bridge	1997	Brushwood mattresses, Narrowing, Islands	Successful return of *Ranunculus*	Pre and post rehabilitations (1998)	Database doc 284	S.Cain
Avon, Ham Carrier		Narrowing banks, reduction in shade	*Ranunculus* regenerated	No formal monitoring		S.Cain

River	Year	Techniques Used	Comment	Monitoring	Info. Source	Contact
Candover Stream	1976	Augmentation by borehole pumping	The increased rate of flow due to the pumping did not have any noticeable effect on *Ranunculus* growth	Pre and post macrophyte mapping	Database doc 159	Southern Water Authority, EA Southern
Chess, d/s Solesbride Lane		Remove sludge, modify impoundment to improve habitat, water quality, visual amenity and flow characteristics	Increase in gravel, creation of some slight sour and small runs. Channel narrowed. Slight increase in *Ranunculus* possible but long gap between surveys	Pre-RCS 7.91, post-RCS 2.94, Audit 7.99. 1999 RHS post survey but not pre.	A Walker	A. Walker, C. Catling, RRC
Chess, u/s Solebridge Lane		Introduction of gravel & blockstone, hurdle groynes, stone flume, low stone weir, bar faggotting	More varied pattern of flow created with increased flow & riffles, marginal fringes and local scour. Increased extent of *Ranunculus* beds where flow and gravel increased.	RCS 1991 and 1994	A. Walker	A.Walker
Colne Watford		Rock groynes, Gravel, Backwaters	Fisheries	No *Ranunculus* monitoring	RRC Workshop	
Cray Hall Place Five Arches	2000 2001	Stone weirs, Stone Deflectors	Fisheries	No *Ranunculus* monitoring		J.Cave, EA Southern Region
Darent		Four schemes using Stone deflectors, Temporary coir deflectors	Fisheries	No Ranunculus		J.Cave, EA Southern Region

River	Year	Techniques Used	Comment	Monitoring	Info. Source	Contact
Darent, nr Shoreham	1998	Temporary structures consisting of blocks and lintels	Aim to restore the in-river environment. The final monitoring was disrupted by Flood Defence operations but *Ranunculus* was observed to have increased during the study from none before.	Observation only	Database doc 283	J Cave, EA Southern Region
Dun		Narrowing, island creation	*Ranunculus* returned			A.Driver, RRC
Dun, North Standen		Weir lowering and channel narrowing, introduction of blockstone, construction of bars, groynes and stone flume	More varied pattern of flow created with increased flow & riffles, marginal fringes and local scour. Increased extent of *Ranunculus* planted but eaten by swans. Gravel remained bare. No *Ranunculus*.	RCS 11.94, Audit 10.96	A.Walker	A.Walker
Great Eau Manby	1993	Steep embankment removed Riffles installed, 3 km	Ad hoc *Ranunculus* development maintained	No formal monitoring		P.Smith
Elmswell Beck	1999	Groynes	Fisheries. *Ranunculus* disappeared from site in the past. Now returned	*Ranunculus* seen on post project photos for Invertebrate survey	Caroline Essery	K.Tait
Frome		Loose gravel in old dredged areas				D.Kite
Gade Cassiobury Park		Partly dredged Alteration of weir levels		No apparent monitoring of macrophytes	RRC Workshop	

River	Year	Techniques Used	Comment	Monitoring	Info. Source	Contact
Gade Gadebridge Park		Replace material of previous works, Notch 5 weirs, Cut meander channel, Import gravel	Intertebrate sampling Mention of *Glyceria* and Water-cress but not *Ranunculus*	No formal monitoring	RRC Workshop	
Gade, Picotts End		Weir lowering, construction of groynes, stone flume, geotextile bar, introduction of blockstone	Cover of Ranunculus 60-80% along enhanced reach. Increase in *Ranunculus* in places, decrease in others. Some limited new establishement; overall slight increase	RCS 10.95, Audit9.96. Also RHS and visual estimate of cover	A.Walker	A.Walker
Itchen Ovington	1997	Narrowing with underwater nattress of woven hazel sticks	Fisheries. *Ranunculus* flourished	No formal monitoring		S.Cain, RRC
Kell or Foston Beck	1997	Deepening		No monitoring	Caroline Essery	A. Mullinger
Upper Kennet	1999-	River narrowing, installation of deflectors, planting *Ranunculus* in snowshoes	Aim to provide conditions for sustained *Ranunculus* growth. Very high discharge affected post works monitoring but there was good establishment in 'snowshoes' except where shallow water allowed grazing by swans	Macrophyte surbey pre and post works	Database docs 41, 42, 43	N.T.H. Holmes
Kennet, nr. Savernake	1970s	Current deflectors, planting marginal vegetation, cutting willows and laying in river	Aim to increase velocity to improve conditions for *Ranunculus* growth. Most of *Ranunculus* occurred near the current deflectors where velocity was increased. Despite the measures the occurrence of *Ranunculus* was very low	Macrophyte mapping pre and post adoption of management measures using some long term monitoring sites	Database doc 133, 137	Wright J.F *et al*.

River	Year	Techniques Used	Comment	Monitoring	Info. Source	Contact
Lambourn, Winterbourne Stream	1975	Augmentation by borehole pumping	The impact of the augmentation on the macrophytes was somewhat obscured by seasonal succession and the subsequent drought (1976).	Macrophyte mapping of intermittent, upper perennial, lower perennial sites	Database doc 12	Wright J.F, Berrie A.D.
Lyde, Andwell		Partial dredging, island creation, shoal creation by introduction of blockstone, groynes, hurdle flumes, timber& stone bars	Slight increase in *Ranunculus* from none, large beds downstream in another open reach that was not surveyed before enhancement.	RCS 5.96, Audit 10.97 & 7.98. Also RHS.	A.Walker	A.Walker, RRC
Misbourne	1997	Repositioning of weir, Groynes	Flow restored to majority of channel, macrophyte composition restored but no mention of *Ranunculus*	No macrophyte monitoring	RRC Workshop	
Nadder		Repair to islands, restoration of flows	*Ranunculus* regeneration			R.Archer, RRC
Pang, Tidmarsh		Improvement of flows through restoration of flows to Upper Pang. Dredging	The works maintained an open channel. Slight increase in *Ranunculus.*	RCS 10.97, Audit 5.99		A.Walker, RRC
Piddle/ Devil's Brook		Fencing of cattle	Regeneration of *Ranunculus*			N.Giles
Great Stour		Four Schemes (12 more in 2001) Range of deflectors	Fisheries	No *Ranunculus* monitoring		J.Cave, EA Southern Region
Little Stour Littlebourne	1997	Handcutting of existing channel vegetation to create local scour	Increased velocity, *Ranunculus* replaced some Water-cress and Bur-reed	Photographic record	Rob Mungovan	

River	Year	Techniques Used	Comment	Monitoring	Info. Source	Contact
Test		Bed raising	Colonization by *Ranunculus*			P.Marshall, T. Holzer
Ver, u/s Shafford Mill		Restoration of flows to Upper Ver, improvement of flows to Lower Ver. Narrowing by construction of geotextile bars, and fagotting. Dredging.	Narrowing improved flow, dredging cleared a central strip but this became silted again. Extensive recolonization by *Ranunculus*. Cessation of abstraction also had a major impact.	Pre-project RCS 91, post-project RCS 3.95, Audit 10.99	A.Walker	A.Walker, RRC
Ver, headwaters	1993-1995	Cessation of abstraction (1993) and channel works.	Ver on list of low flow rivers. Loss of *Ranunculus* due to abstraction. Inference that cessation of abstraction combined with the natural end of the drought caused first Pond Water-crowfoot and then Brook Water-crowfoot to return well.	Macrophyte surveys	Database docs: 30, 35, 171, 236, 255, 281	N.T.H. Holmes
West Beck	1995/7	3 schemes involving, Groyne, Meanders, Raking gravel	*Ranunculus* returned	Checked 2000	Caroline Essery	K.Tait
Wensum	2000 (eventually 25 schemes)	First schemes, Riffle replacement Meander loop connection	Fisheries	No macrophyte monitoring so far		Simon Johnson, RRC

River	Year	Techniques Used	Comment	Monitoring	Info. Source	Contact
South Wey, Frensham		Contrustion of groynes, work on weirs, introduction of blockstone & gravel	Increased variety and speed of flow and scour. Increased extent of gravel. Very little increase in *Ranunculus* in first audit although good Callitriche. Incrase in *Ranunculus* by second audit but still overshadowed by big increase in Callitriche.	RCS 10.92, Audit 9.94 & 7.96	A.Walker	A.Walker
Wye, Kingsmead, High Wycombe		Introduction of gravel, re-profiled banks, marginal shelves and flood relief channels	Increased riffles, retention of gravel on concrete lined bed. Good increase in *Ranunculus* in some reaches but no comparable pre-project survey. Reduced abstraction and increased rainfall also had major influences.	RCS 4.98, Audit 8.99. Also RHS & visual estimate of cover	A.Walker	A.Walker, R. Green, RRC
Upper Wylye	1999	Augmentation above Kingston Deverill	Augmentation had a positive effect on the flora of the upper reaches, but more variable results futher downstream	Use of historic photographic information and surveys together with new macrophyte monitoring sites	Database docs 134, 257	NTH Holmes, G. Green
Wylye, Hunt Stream, Four Copses	1998	Narrowing Bank Revetment	*Ranunculus* came back at Hunt Stream. *Ranunculus* planted at Four Copses.	No formal monitoring		S.Cain
Wylye		Narrowing, Deflectors, New gravel riffles	Recolonising *Ranunculus*			N.Giles
Wylye	1989-1991	Cleared silt, Sluices removed, Narrowing	*Ranunculus* planted using stones, Flow increased, Clean gravel	No formal monitoring		S. Cain

Gaps = Lack of information or information not provided