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Ecohydrological Guidelines for Lowland Wetland Plant Communities

Final Report
December 2004

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Ecohydrological Guidelines for Lowland Wetland Plant Communities

B.D. Wheeler, D.J.G. Gowing, S.C. Shaw, J.O. Mountford and R.P. Money

Final Report Environment Agency - Anglian Region

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Part 1

Introduction and Structure

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1. Introduction

1.1 Objective and Scope of the Guidelines

1.1.1 Objective

Obligations to conserve many of the UK's wetlands have been made through a number of International and European Agreements and Directives relating to the management and conservation of natural resources. These include the Convention on Biodiversity (signed in Rio in 1992), the EC Directive on the Conservation of Natural Habitats and Wild Flora'(the Habitats Directive)[1], the Wild Birds Directive[2], Ramsar[3] and the Water Framework Directive[4].

Wetland communities and species have specific and critical ecohydrological requirements. However, these requirements are in most cases still being researched and hence are not currently generally accessible.

The main objective of the *'Ecohydrological Guidelines for Lowland Wetland Plant Communities'* project is therefore to produce a user-friendly guide containing generic ecohydrological information on the requirements of selected freshwater wetland communities. These guidelines will assist with tasks such as Appropriate Assessments of the effects of Agency permissions and consents required under the Habitats Directive Review of Consents.

1.1.2 Scope of the Guidelines

These guidelines focus primarily on the ecohydrological requirements of communities that contribute to features designated as being of European importance under the Habitats Directive[5] and found in the Anglian Region of the Environment Agency. However, it is likely that as a result of the generic nature of the guidelines they will have wider applicability to other lowland areas of England and Wales where the same communities exist e.g. Somerset Levels and Moors (SW) and Lower Derwent Valley (NE).

Box 1 identifies the freshwater wetland European features, and where applicable the national vegetation classification (NVC) communities (Rodwell, 1991-1995) that are considered to contribute to the features, present in Anglian region. The European features are listed under broad categories for ease of use.

The secondary focus of the guidelines is on plant communities (wet grassland and certain swamp communities in particular) which support breeding or wintering birds of European importance[6]. Where birds are the feature of importance conservation objectives relate to the habitats that support those features. Therefore in this case guidelines have been drawn together primarily for those communities upon which the birds are themselves dependent (e.g. MG9, MG13, S4 and S5).

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[1] Directive 92/43/EEC, amended by Directive 97/62/EC.

[2] Directive 79/409/EEC.

[3] Convention on Wetlands of International Importance, Ramsar, Iran, 1971.

[4] Directive 2000/60/EC.

[5] These European features are identified on Annex 1 of the Habitats Directive.

[6] These are listed on Annex 1 of the EC Wild Birds Directive.

Box 1: Annex 1 Freshwater Wetland European Features in Anglian Region

Wet Grassland

Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Represented by NVC community M24)
Lowland hay meadow (Represented by NVC community MG4).

Fen and Mire

Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae* (Represented by NVC communities M13, S2, S24, S25. PPc which is similar to S24 is also considered to contribute to this feature).
Alkaline fen (Represented by NVC communities M9 and M13).
Transition mires and quaking bogs (Represented by NVC communities M5, M9 and S27).
Depressions on peat substrates of the *Rhyncosporion* (Represented by NVC community M1, M2 and M21).

Ditch Communities

Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation (Represented by NVC communities including A3, A4 and A9).

Wet Heath

North Atlantic Wet Heath with *Erica tetralix* (Represented by NVC communities M14 and M16).

Wet Woodland

Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (Represented by NVC communities W5, W6, W7 and parts of W2).

Guidelines have been produced for those plant communities that the project Steering Group/Panel of Experts (see contributors list at the front of the document) felt there were sufficient data available to have scientific credibility. The communities for which guidelines have been produced are listed in Box 2. In Anglian region one or more of these communities form part of the European feature, or support the European feature, in the following candidate Special Areas of Conservation (cSAC):

- Broads;
- Norfolk Valley Fens;
- Waveney and Little Ouse Valley Fens;
- Roydon Common and Dersingham Bog;
- Fenland;
- North Norfolk Coast;
- Portholme;
- Ouse Washes;
- Nene Washes.

Box 2: Communities for Which Guidelines Have Been Produced to Date

Wet Grassland

MG4	*Alopecurus pratensis-Sanguisorba officinalis* grassland
MG5	*Cynosurus cristatus-Centaurea nigra* grassland
MG7	*Lolium perenne-Alopecurus pratensis-Festuca pratensis* grassland
MG8	*Cynosurus cristatus-Caltha palustris* grassland
MG9	*Holcus lanatus-Deschampsia cespitosa* grassland
MG13	*Agrostis stolonifera-Alopecurus geniculatus* grassland

Fen and Mire

M13	*Schoenus nigricans-Juncus subnodulosus* mire
M24	*Molinia caerulea-Cirsium dissectum* fen meadow
S2	*Cladium mariscus* swamp
S24	*Phragmites australis-Peucedanum palustre* swamp
PPC	*Peucedano-Phragmitetum caricetosum* (Wheeler, 1980)

Swamp and Ditch Communities

S4	*Phragmites australis* reedbed
S5	*Glyceria maxima* swamp
A3	*Spirodela polyrhiza-Hydrocharis morsus-ranae* community
A4	*Hydrocharis morsus-ranae -Stratiotes aloides* community
A9	*Potamogeton natans*

The best information available at the time of reporting has been used to produce prescriptions. There are, however, gaps in the approach, both in relation to the communities for which prescriptions could be produced (i.e. for lowland wet grassland, fen and mire, swamp (including reedbed) and ditch communities), and to the wet heath and wet woodland communities where there is a particular shortage of research. The collection of good-quality time-series hydrological data (e.g. dipwell monitoring of shallow groundwater), and water quality information has been lacking for most wetland sites in England and Wales and this has generally hindered the definition of ecohydrological regime requirements for important wetland communities (both water quantity and quality).

It is important to re-state that the guidelines are *generic* because it is of equal importance to conceptualise how a site works hydrologically and by what mechanism(s) the water needs (quality and quantity) of the communities are met.

To aid understanding of the document a Glossary is presented in Appendix A, English and scientific names for species are presented in Appendix B and a key to the patterns used to represent different substrata in cross-section diagrams is presented in Appendix C.

1.2 Determining Water Requirements

Defining the appropriate hydrological regime is a key step in moving towards achieving ecological objectives for wetlands. Changes in depth, duration, frequency, magnitude and timing of water supply can have significant implications for the type of plants that will grow in a wetland (Wheeler 1995, 1999). Altering the hydrological regime of a wetland changes the assemblage of plants and animals present. Wetlands are dynamic systems, which can be subject to considerable variability in terms of excess of water (floods) and lack of water (droughts, abstraction, land drainage). It is this temporal variability of these factors that affect the well-being of a wetland. Too much water can be as detrimental as too little water, although winter inundation is often a key feature. It is the wetland 'regime' and how it 'works' that is critical for the maintenance of wetland features (i.e. ecological diversity and ultimately whether a feature is considered in favourable condition).

These guidelines are designed to assist with the ability to find out whether a vegetation community on a site is 'out of regime' in terms of both quality and quantity, or is at risk of moving out of regime in terms of its water needs.

Assessment of impacts on wetlands would be considerably easier if the NVC had been developed on a hydrological basis which reflected the water regime (including quality) needs of the key wetland types e.g. fen, bog, wet grassland and wet woodland. However, this was not a driver in the development of the NVC. Nonetheless, in the UK, European features have been identified by English Nature using NVC communities and it can be difficult to relate typologies, such as NVC, directly to hydrological mechanisms which supply the site (for example on groundwater-fed sites). This is because broadly similar, but subtly different, hydrological conditions may support different vegetation communities. Different hydrological conditions may give rise to the same vegetation if other factors, such as soil type, vary. For this reason, **ecohydrological guidelines produced for NVC communities can only ever be considered as a generic indicator of regime needs.** They need to be linked to a thorough understanding of hydrological regimes which supply the site.

The above is further complicated by the fact that the same NVC community can have substantially different species composition in different parts of the country, for example the composition, and consequently the hydrological requirements, of M14 may be different in East Anglia and Devon.

The Habitats Directive and Water Framework Directive provide objectives for various ecosystems. To achieve ecological objectives requires the identification of threshold hydrological conditions. Although thresholds theoretically exist, they are difficult to define in practice as ecosystems are complex. The regime also needs to take account of variability from year to year that maintains stability of the system (including extreme floods and droughts).

The exact hydrological requirements of wetlands may not be known due to lack of intensive research effort. As there is a historical legacy of under-funding of research in this critical area of ecohydrology, the confidence and level of information presented in these guidelines does vary. Much of wetland restoration and conservation has been guided in the past by expert judgement or adaptive management, where the hydrological regime is adjusted as the ecological response of the wetland becomes apparent. In recent years, only limited detailed research has been undertaken by universities (Wheeler and Shaw, 2001; Gowing et al, 2002) and research institutes (Mountford *et al,* 1999). Nevertheless, knowledge of requirements of vegetation communities is based on the assessment of needs in different areas with different hydrological regimes. **As a result of these complexities, this**

report does not provide definitive, absolute figures, but rather indicates the broad range of hydrological regimes that gives rise to specific vegetation communities.

Whilst ecohydrological requirements of wetlands have historically been primarily concerned with time (duration), and water table level relative to the ground surface, these cannot be separated from water quality issues. Wetland ecosystem dynamics are determined by three main environmental gradients (Wheeler and Shaw, 1995):

- acidity: ranging from acid sites on peat soils/substrates to base-rich mires on peat (e.g. coming from a chalk aquifer);
- fertility (availability of nutrients, primarily N and P): ranging from oligotrophic to eutrophic;
- hydrological regime: ranging from highly variable water level(such as floodplains of flashy catchments) to stable water levels fed by groundwater.

It should be noted that the hydrochemical environment, particularly in fens, should be seen as the main critical factor influencing vegetation communities. The presence of groundwater for example can thus impact on wetlands in three ways:

- basic requirement for life (direct effect - too little or too much);
- chemical composition (base, nutrients status and toxins - direct effect); and
- influence on other biological and chemical processes (affected by physiochemical composition, water level fluctuation/flow rate etc - indirect effects).

Other factors may also be extremely important in influencing the hydrological regime of wetlands. For example, land drainage, which affects the whole water budget of a site, and the timing of critical water availability. Secondly, compaction of soils by farm animals and machinery can significantly reduce hydraulic conductivity (i.e. the ease with which water can move through the soil). Consequently, the potential for a wetland to support certain vegetation communities may be compromised, even if water level management in adjacent rivers and ditches is appropriate.

Whether the hydrological requirements prescribed for a plant community can be achieved at a particular site depends upon the natural hydrological regime and on the degree to which this has been altered. Whilst it might be possible to re-instate the required wetland conditions, it is of key importance to work in harmony with natural hydrological processes. This is consistent with the Water Framework Directive, which aims to restore good ecological status in all water bodies. It may be that due to changes at the site or within the catchment or groundwater unit (such as abstraction, diversion, effluent disposal or land use change), the desired hydrological regime can no longer be achieved. For example, wet grassland areas may no longer be flooded due to embankments or dam construction. In such cases it may only be possible, due to current management constraints, to artificially manipulate the hydrological regime of the site to simulate to a more limited degree the appropriate hydrological regime for that location.

1.3 Hydrological Classification of Wetlands

Lloyd *et al* (1993) produced a hydrological classification of East Anglian wetlands which may in the future be used as an aid to assessment of their vulnerability to abstraction. For example, a groundwater-fed site sourced from an unconfined aquifer is more likely to be impacted by nutrient enrichment than in a partially confined situation. The scheme has 7 classes, with groundwater-fed wetlands divided between those supported by confined and unconfined aquifers and classes for wetlands fed by both surface and groundwater (refer to Figure 1.1).

Further details are available in Lloyd *et al,* (1993) on how to use and interpret the classification.

The Lloyd *et al* (1993) classification stressed the need to understand how a wetland works (Lloyd and Tellam, 1995). These ideas have been built upon by Wheeler and Shaw (2000), who developed a classification system called WETMECS. This classification combines landscape situation (e.g. floodplain or valley head), water supply mechanism, topography, base status (pH) and fertility. The WETMEC approach enables the development of a conceptual understanding of the links between the ecological and hydrological characteristics of types within wetlands, based on actual analysis of field data, rather than on subjective considered expert opinion.

Wheeler and Shaw defined a number of WETMEC types, based primarily on water supply mechanism, for example:

- Type 1 Permanent seepage (a type of spring-fed wetland e.g. Badley Moor, Buxton Heath in East Anglia);
- Type 7 Summer ‘dry’ floodplains (this type includes quite large examples of alluvial wetlands such as Woodwalton Fen in East Anglia).

The WETMEC classification helps us to understand the site, however, it doesn't tell us what the impact is upon wetland regimes. The increased understanding that has been derived from basing the classification upon real site data has enabled regimes to be outlined in these guidelines which can help with assessment and prediction of the likely environmental impacts upon particular 'types' of wetland. For this reason, it is likely to be of great use during Stage 4 of the Habitats Directive Review of Consents when the effect of management options upon the site is considered.

1.4 Linkages to Hydrological Models

It is envisaged that the guidelines could be used to examine whether the hydrological regime of a site meets the ecohydrological regime needs of vegetation communities. Additionally, it should be possible to look at predictive scenarios of changes in hydrological conditions, such as those that will result from proposed abstractions, restoration measures or climate change.

Impact assessments are typically undertaken in two stages:

- **Hydrogeological/hydrological impact** studies give an indication of actual hydrological changes in regime (e.g. a 10 cm fall in water tables or a drawdown/cone of depression with certain characteristics).
- **Ecological effect -** a prediction of direct hydrological impact does not necessarily imply an ecological effect. The guidelines try to identify what magnitude of hydrological impact would be likely to have an ecological effect.

Only with these two components together can a predicted hydrological impact be translated into a direct ecohydrological effect. It is at this link stage that extreme care is needed. It is vital that hydrologists and ecologists communicate at the same scale (Hunt and Wilcox, 2003). For example, it is of little use having models which cannot be linked to the same scale at which ecological impact may be occurring (i.e. the surface zone of the wetland itself).

A groundwater model may be considered accurate if predicted water table levels are within 10 cms of observed values, whereas a 10 cm difference in water levels may mark a difference between the condition required by quite different vegetation communities. We must ask the real question; whether hydrological modelling can be undertaken with sufficient resolution as to provide valuable information to link with ecological thresholds. The value of the groundwater model in this case is likely to be in

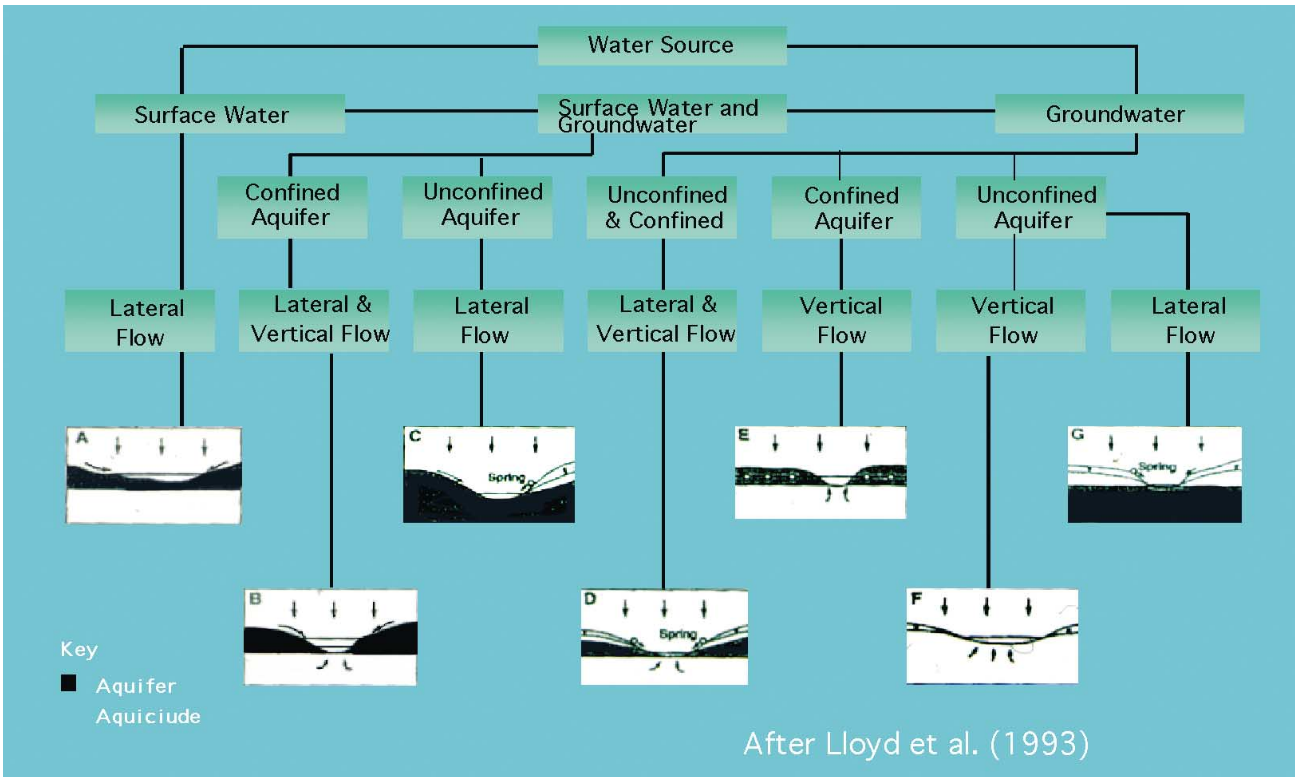

Figure 1.1 Wetland Classification (after Lloyd et al, 1993)

predicting the size of changes in water levels rather than absolute levels.

This is a particularly crucial issue when the hydrological cause and ecological response are at different scales. For example, to model the impact of abstraction on water table level in a large aquifer requires a broad scale groundwater model. The wetland may be very small in comparison, and local changes in water level within the wetland may be influenced by local conditions, such as soil structure that cannot be modelled to a sufficient degree of accuracy with a regional model.

Temporal variability is a key issue in modelling. Many factors influencing the hydrological regime of a wetland, including rainfall, river flow, groundwater levels and evaporation are continually changing; on a minute by minute to a year to year basis. Indeed, it is widely accepted that this variability maintains diversity with the ecosystem. It also suggests that the vegetation may not necessarily be in equilibrium with hydrological regime, but may be recovering from a recent drought or flood. Temporal variability also makes it difficult to identify a “representative period” over which to assess the hydrological regime. Even data collected over several years may not capture frequently experienced conditions.

The type of model used needs to be appropriate to the situation. Guidance on this should be sought, in the first instance, from Hydrologists and Hydrogeologists within the Agency.

1.5 Use of the Guidelines

The primary focus of the guidelines is as a generic tool to assess whether vegetation communities associated with the European-designated features are in or out of regime for the purposes of the Review of Consents. However, they have a range of potential secondary uses:

- Definition of criteria against which to judge WFD monitoring obligations;
- Use by English Nature in refining site specific conservation objectives/favourable condition tables for European Habitats Directive sites;
- Influence on implementation of Water Level Management Plans;
- Catchment Flood Management Plan guidance e.g. influence on management of flood storage areas;
- Use by English Nature, CCW, Wildlife Trusts and other NGOs in management of wetland sites;
- Preparation of wetland restoration and rehabilitation proposals;
- Use in water abstraction licensing technical determination reports to assess impacts of new proposals for groundwater and surface water pumping;
- Application to predict future water resource demands for wetland creation (for use in CAMS).

Three broad groups of applications can be envisaged. These include status assessment, impact assessment and restoration potential and these are further described in Box 3.

Box 3: Broad Applications for the Guidelines

Condition assessment. As part of an audit process, the ecological health of a wetland may need to be assessed. This can either be achieved by direct assessment of ecological objectives, (e.g. presence of target species), (Wheeler, Shaw and Hodgson, 1999) or by assessment of the factors controlling wetland ecology, such as the hydrological regime. This can help to prioritise action at sites or species/communities most at risk.

Impact assessment. The range of ways in which the water regime of a wetland may be changed includes surface and groundwater abstraction, flow diversion and river channelisation for flood defence. Granting of a licence to undertake a proposed activity, such as an abstraction, may depend upon the level of negative impacts this might cause to a wetland. The level of impact on a wetland can be scored by assessing predicted and actual changes in the hydrological regime in relation to ecohydrological guidelines. Reference should also be made to Acreman and Miller, 2004.

Restoration. In many cases, wetlands have been degraded by changes in the hydrological regime. Restoration is the re-establishment of the structure and function of an ecosystem to a more or less natural condition and in this document this includes returning the hydrological regime on a wetland to meet a target defined within these guidelines. Whether the target hydrological regime can be met depends upon the degree to which the alteration that caused the degradation can be reversed or mitigation implemented.

1.6 Case Study on the Use of the Guidelines - The Ouse Washes

An Agency-suggested approach of how to use the guidelines to inform an appropriate assessment is presented here using the Ouse Washes as the example. A detailed case study of the Ouse washes has been developed and is available from the Anglian Region (Paul José). Three further case studies on groundwater-fed fens are currently under development - for further details contact Mark Whiteman.

1.6.1 Context

The Ouse Washes are currently considered to be in unfavourable condition for a number of possible reasons, including eutrophication, summer flooding, abstraction, etc.

The objectives of the study were to:

- *Overall: Determine whether consented activities are having a damaging effect on the site;*
- Identify, for a range of scenarios, a water volume and nutrient loading budget for various units within the Washes;
- Identify whether each unit is within or outside of its target water level regime;
- Identify whether nutrient limits are exceeded and determine the approximate proportion contribution of each upstream nutrient source to the nutrient loadings in the Washes.

1.6.2 Approach

The first step undertaken was to conceptualise how the site worked and to identify the location and type of vegetation units on the site when it was in favourable condition. This is illustrated in Figure 1.2.

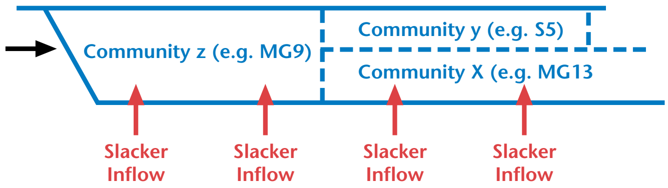

Figure 1.2 Conceptualisation of the Site and Vegetation Units

The next step was to model a range of scenarios:

1. Naturalised flow conditions (altering diffuse pollution). Scenario alters diffuse inputs to a 'natural level'.
2. Naturalised flow conditions (including diffuse pollution).
3. Current abstractions and discharges (with AMP2 phosphate removal).
4. Maximum licensed conditions.

The next step was to compare the results of the scenarios with the guidelines (Figures 1.3 and 1.4) for the wet grassland interest features in order to determine primarily whether the site is in or out of regime in relation to the impact of maximum licensed activities. Scenarios 1 and 2 provide the naturalised platform against which the impact of Scenarios 3 and 4 can be compared. Scenario 4 will provide us with an answer as to whether maximum licensed activities have a water quality or water resource impact on the site. In addition, flood defencerelated activities are being examined to determine whether the site is out-of-regime at higher flows.

Seasons and Variable	Tolerable Amber Range	Not Tolerable beyond Red limit
Spring (Mar-May)		
A Mean Water Table Depth (maximum) /m	**0.3 - 0.55**	**0.55**
B Mean Water Table Depth (minimum) /m	**0.3 - ?**	**-**
C Max duration of surface water flooding episode covering >10% of ar	**-**	**-**
D Cumulative duration of flooding during season/days	**-**	**-**
Summer (June-Aug)		
A Mean Water Table Depth (maximum) /m	**0.8 - ?**	**0.55**
B Mean Water Table Depth (minimum) /m	**0.3 - 0.1**	**0.1**
C Max duration of surface water flooding episode covering >10% of ar	**8 - 20**	**20**
D Cumulative duration of flooding during season/days	**30 - 60**	**60**

Figure 1.3 Variables for MG13 Grassland

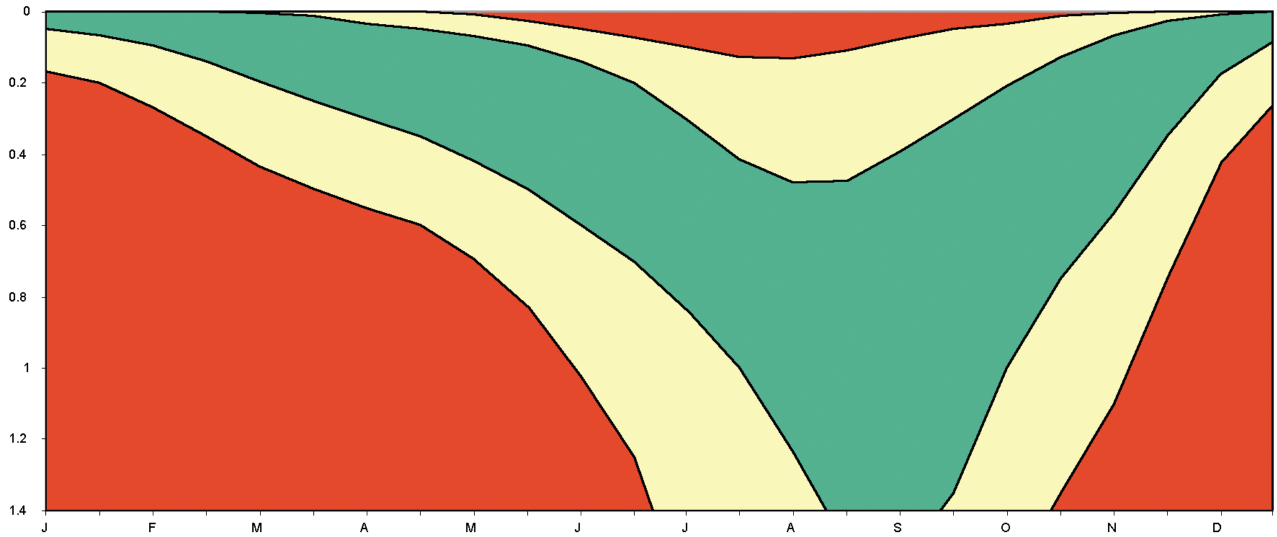

Figure 1.4 Water Table Depth Zones for MG13 Grassland
Water Table zones, illustrating the range of depths that are “desirable” (green) and “tolerable for limited periods” (amber). Values are based on the mean of at least three readings, taken at least 7 days apart, but all within a four-week period.

1.6.3 Outputs

Outputs of the study will include the following (outputs expected October to December 2003):

- Comparison of the annual profile of water table depth across each management unit with water level guidelines required for the target communities defined. Where guidelines are not available, the model output during the naturalised scenario will provide a best available estimate of the ecohydrological guidelines for the target community in question;
- Analysis of the annual flooding inundation duration/frequency/magnitude across each management unit;
- Water budget for each management unit of the Washes based upon the sum of the budgets for each individual field cell. There will be one water budget per model scenario;
- Nutrient budget for each management unit defined in terms of loadings rather than concentrations;
- Analysis of the source apportionment for the nutrient loadings entering the Washes through Earith and the relative importance of Anglian Water’s discharges on nutrient loadings entering the Washes.

1.7 Conclusion

The guidelines provide generic guidance on the hydrological requirements of a plant community that can be applied broadly to any given site. However, although they may be adequate for broad-scale appraisal the guidelines are no substitute for collecting data at a site, particularly where results may be scrutinised in a public inquiry. In this latter scenario it is likely to be appropriate to develop detailed hydrological and ecological guidelines/models solely for that site. For situations between these extremes, it will be appropriate to refine or calibrate the guidelines at a site using local data, especially with respect to soil properties, or a team of experts with local experience. The degree to which this is necessary depends upon a range of factors including the availability of: data; expertise; funds and time and the level of accuracy required.

2. Structure of Ecohydrological Guidelines

2.1 Structure of Each Guideline

Each guideline, which covers only one NVC community, is divided into four parts:

- Context;
- Supply Mechanism and Conceptual Model;
- Regimes;
- Implications for Decision Making.

The **Context** section provides information on the **floristic composition,** and **distribution** of the community. It describes the **landscape situation** and **topography** within which the community is found, and the **substratum** with which it is most commonly associated.

The **Supply Mechanism and Conceptual Model** section presents information on the main water supply mechanisms to the community. A conceptual diagram is generally presented.

The **Regime** section describes the **water, nutrient,** and **management** requirements of the community. A water regime, time-series, diagram has been prepared where sufficient data were available. The green area in these diagrams represents the community's preferred water levels and the amber represents water levels that are tolerable for limited periods. The red zone indicates water levels that will be detrimental to the community in the short term.

The **Implications for Decision Making** section helps the user to make key decisions on future option evaluation (i.e. for Stage 4 of the Habitats Directive Review of Consents). This section covers the **vulnerability** and **restorability** of the vegetation community, and identifies key **gaps** in **scientific knowledge** of the community's ecohydrological requirements.

2.2 Assumptions Made in Data Analysis for the Guidelines

Where possible, and appropriate[7], the guidelines provide quantitative data with respect to water regimes in the format of:

- surface-water depths and durations;
- water-table depths and seasonality.

Surface water depth is usually the major controlling factor determining vegetation type in aquatic and swamp habitats and is therefore the appropriate metric to use. However, for drier habitats, one needs to consider the soil water regime too.

The central assumption made for the terrestrial communities, such as the wet grasslands, is that water table depth is an adequate descriptor of the soil water regime. Such an assumption needs qualification. The water-table depth does not of itself determine the vegetation type. Variables such as soil aeration, soil water potential and nutrient availability are the factors directly controlling competitive interactions between species. However, direct information on the tolerance ranges of different communities with respect to these variables is very limited and directly monitoring such variables is costly and complex. Water-table depth is therefore proposed as the central descriptor for the following reasons:

- It is readily measured using dipwells in suitable soils;
- Historic water-table data and validated models to simulate water-table depths are available for some of the sites of interest (predominantly relates to wet grassland sites);
- It is a relatively easy concept for non-specialists to envisage;
- It is related to the true controlling variables and previous studies suggest it to be an adequate surrogate for them (Silvertown *et al,* 1999).

The relationships between water-table depth and the true controlling variables, though often strong, are sometimes not simple. Other factors will have an influence, primarily soil properties and prevailing climate. How these site-specific factors should be considered in the application of the guidelines is addressed in Section 2.3.

The data on which the quantitative guidelines are based are derived from direct observation of dipwells installed within the communities of interest. The summaries presented often draw on data from more than one site and they give emphasis to those datasets that span many years, thereby reducing any bias due to the vagaries of weather during the monitoring period. The grassland data summaries were compared with much larger data sets generated from hydrological models (Gowing *et al,* 2002) to check they were consistent with a community's tolerance range. Modelled data were not used as the basis for the summaries presented here, except for

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[7] see notes on limitations in the data in Section 2.4.

the section relating to "Other Floodplain-meadow communities," where primary data were not available. In this case quantitative summaries have not been presented but qualitative statements about the communities' requirements listed instead.

The data used in the analysis for wet grasslands were all drawn from communities deemed to be stable. That is there are records going back at least 10 years to suggest there has been no strong directional change in their composition. The wet grassland guidelines therefore aim to describe regimes which would maintain a stable community. It cannot be overstated that simply achieving the target regime will not necessarily result in the target community. There are a large number of other ecological factors at work, not least the need for a source for species not currently present on a site and a means of dispersal. The timescale for community assembly in some cases may be of the order of a few years (e.g. Gilbert, 2000), but more typically measured in decades (e.g. Mountford *et al,* 1996.). It is also possible that where a hydrological change has been engineered to meet a target regime, the vegetation will not respond in a linear way to the change. Most hydrological perturbations initially result in a decline in species richness and may involve the assembly of a distinct transitional community before the target community begins to establish.

2.3 Context for Use of the Guidelines

The guidelines involving water-table depths are of necessity soil and climate specific. The assumptions about soil are stated as part of the guideline and usually reflect the soil type on which that community is most commonly found. If the guideline is to be applied to a site with a distinctly different soil, then an allowance needs to be made for this. Some guidelines contain information about the adjustments that would need to be made to the quantitative data in the context of different soils. If the user is unsure as to the soil characteristics of a site, then guidance should be sought.

Evaporative demand also needs to be considered because sites in regions with warm dry summers will typically require shallower water tables to support the same community as a site with cool wet summers. Within the range of a particular community, this difference may not be sufficient to warrant "versioning " the guidelines for different climates, but in the case of MG4 grassland a table of different scenarios is presented, within which one variable is the typical potential soil moisture deficit in July. This variable reflects the evaporative demand of the region and can be accessed from publications such as Smith and Trafford (1976) or obtained from the Met Office.

The different aspects of all botanical communities requirements (water, nutrients, vegetation management) interact and therefore should not be viewed in isolation. If, for example, the water table depth for a given community were in the zone defined as amber for prolonged periods and even intermittently in the red zone, then one may expect to see some change in community composition. However, if the nutrient regime and management regime for that community were optimal, then changes may be very small or even absent. Conversely if the community is at the edge of its regime in terms of nutrients and management , then a period within the amber zone may be sufficient to precipitate change.

2.4 Limitations in the Data Used

The information presented for the fen and swamp communities comprising M13, M24, S2, S24 and PPC is largely based on that synthesised by Wheeler & Shaw (2001) - itself primarily based on knowledge of wetland sites supporting examples of the communities in eastern England, and other information held within the FenBASE database. The relationships identified between water regimes and the occurrence of specific vegetation types may not necessarily hold good for examples of these communities in regions that are climatically, physiographically and geologically very different to Eastern England. It is proposed that updated accounts, including data from other parts of the UK, should be prepared in 2004.

There are currently virtually no data with which to better inform the temporal water table characteristics of these communities. Most of the information about water levels is derived from 'spot' measurements at a range of sites, rather than time series data from individual sites. Thus, it was not possible to produce graphs of target water table depth zones, as done using 'real' data available for the wet grassland communities.

Similarly, there are currently virtually no data to specify community tolerances to changes in nutrient supply, base status, pollutants etc.

For the grassland communities, the tolerated range of phosphorus availability in the soil is quantified. These tolerances are based on a specific extraction technique, referred to as the Olsen method (MAFF, 1986.). Measuring soil phosphorus availability by other methods (e.g. Truog, 1948) will give results that are not directly comparable with the ranges derived from the Olsen method.

In order to make predictions with respect to the vulnerability of wetland stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at 'representative' sites.

In most cases, possible differences in environmental conditions influencing the different NVC sub-communities have not been explored here.

A better understanding is needed as to the water regime tolerances and interactions with other factors such as soil properties and precipitation inputs of the fen and swamp communities (M13, M24, S2, S24 and PPC) which may be more critical in many instances, than the position of the groundwater table.

The potential for restoring stands of different community-types to dehydrated or derelict sites is largely untested.

Part 2

Lowland Wet Grassland Community Guidelines

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3. MG4 *(Alopecurus pratensis - Sanguisorba officinalis)* Grassland

3.1 Context

The MG4 community corresponds to the "Lowland Hay Meadows" SAC feature.

3.1.1 Floristic Composition

The MG4 community is species-rich, containing up to 18 different grasses plus a few sedges and rushes. The most notable feature of the community is the abundance of broad-leaved herbs, which dominate the community in midsummer. The community is not currently divided into sub-communities.

Species that are particularly characteristic of MG4 in the context of floodplain grasslands are indicated in Table 3.1.

Table 3.1 Species that are Particularly Characteristic of MG4 in the Context of Floodplain Grasslands

Characteristic Species	
Briza media	*Lotus corniculatus*
Centaurea nigra	*Sanguisorba officinalis*
Silaum silaus	*Filipendula ulmaria*

The community typifies the flower-rich meadow, which for many people forms their idyllic representation of the English rural landscape.

3.1.2 Distribution

The extent of MG4 grassland, in terms of geographical distribution and total area, declined substantially during the last century as a result of land-use changes. The remaining range centres on the floodplains of large English rivers with deep alluvial soils and/or gravel terraces (e.g. Thames, Severn, Great Ouse, Trent). The total area of the community remaining in the UK is now less than 1500 ha. Most remaining stands of the community now receive some form of statutory protection and attempts at restoration have begun. The distribution is shown on Figure 3.1.

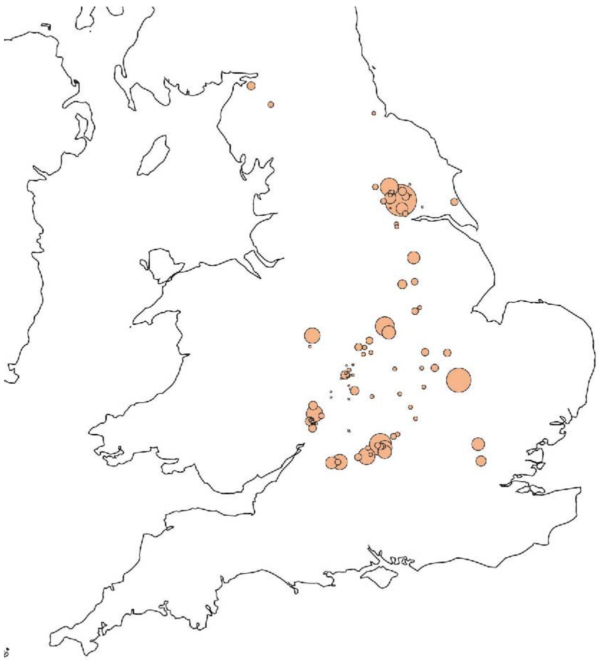

Figure 3.1 The Current Known/Recorded Distribution of the MG4 Community in England. The Size of the Circle Reflects the Relative Area of Each Site on an Arbitrary Scale.

3.1.3 Landscape Situation and Topography

The community is almost exclusively found on floodplains in river valleys. It is not clear however that flood events are an essential part of the hydrological budget for the community. Floods tend to occur in winter when the soil is close to saturation anyway and little surface water is usually retained once the flood recedes, although shallow floods of short duration in early summer may play a role in the water regime of a few sites.

An important landscape feature is the presence of artificial surface drainage systems, designed to remove surface water swiftly from the site. This drainage system typically comprises shallow features connecting to deeper ditches, which then join the main river downstream.

3.1.4 Substratum

MG4 is typically found on fine-textured, but highly-structured soils. The good structure makes them permeable to water and confers on them the ability to store relatively large amounts of water in a form that vegetation can access. As a result, the stored water can meet the demands of the vegetation through the early summer, without its growth becoming limited by water availability.

Many sites are underlain by river-terrace deposits of coarse sand and gravel. These may supply water during the summer months by sub-irrigation and facilitate sub-surface drainage in winter.

3.2 Supply Mechanism and Conceptual Model

A number of water supply mechanisms can support the MG4 community (see Figure 3.2). The arrows on the diagram depict various routes for water movement.

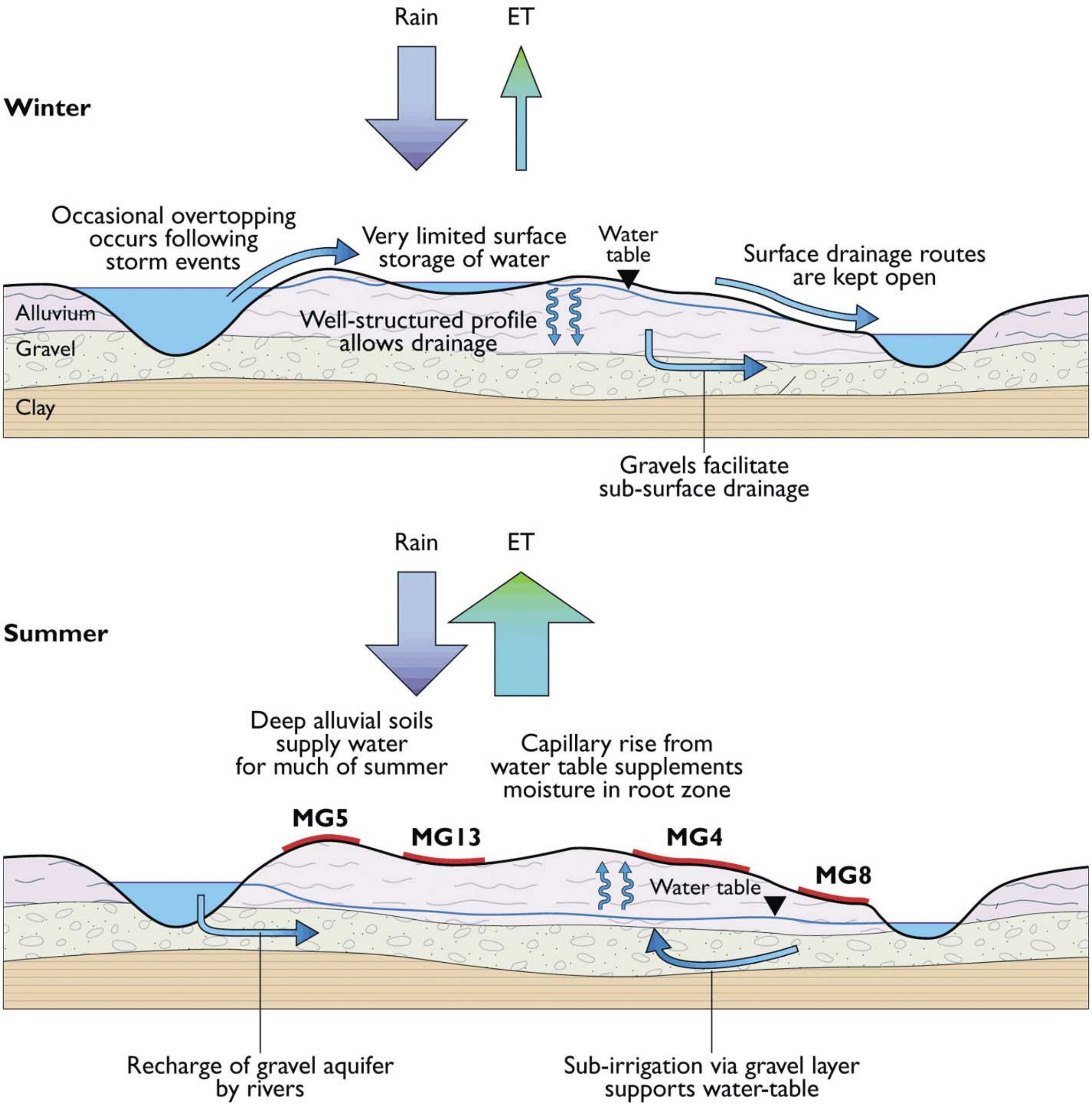

Figure 3.2 A Schematic Representation of the Hydrological Context of MG4 Grassland

Table 3.2 A List of the Different Hydrological Scenarios Under Which MG4 Can Exist

Median Potential Soil Moisture Deficit in July	Coarse Textured Deposits Within 1.2 m of Surface	Soil Texture and Structure	Hydro-logical Type	Example
› 80 mm	Present	Coarser textured loam	A	Not known
		Fine textured alluvium, highly structured to depth	B	Clattinger Farm SAC
		Fine-textured alluvium with poor or shallow structure	C	Achurch meadow SSSI
	Absent	Coarser textured loam	D	Newton Mask SSSI
		Fine textured alluvium, highly structured to depth	E	Long Herdon SSSI
		Fine-textured alluvium with poor or shallow structure	F	Ellerton Ings SSSI
‹ 80 mm	Present	Coarse textured loam	G	Mottey Meadows SAC
		Fine textured alluvium, highly structured to depth	H	Burley Dene SSSI
		Fine-textured alluvium with poor or shallow structure	I	Upton Ham SSSI
SSSI	Absent	Coarse textured loam	J	Kettlewell Meadows
		Fine textured alluvium, highly structured to depth	K	Broad Dale SSSI
		Fine-textured alluvium with poor or shallow structure	L	Not known

The notable features are rapid drainage of surface water and the reliable supply of soil moisture either due to the good storage capacity of the soil profile or via sub-irrigation from water bodies.

The relative importance of the different elements of the water supply mechanism depends upon three factors:

- soil moisture deficit;
- presence or absence of a shallow aquifer; and
- capacity of the soil to retain water in a form available to plants. (This value, known as the soils *Available Water Capacity* can be derived from a soil moisture release curve, generated for a small sample using specialist equipment in a soils laboratory.)

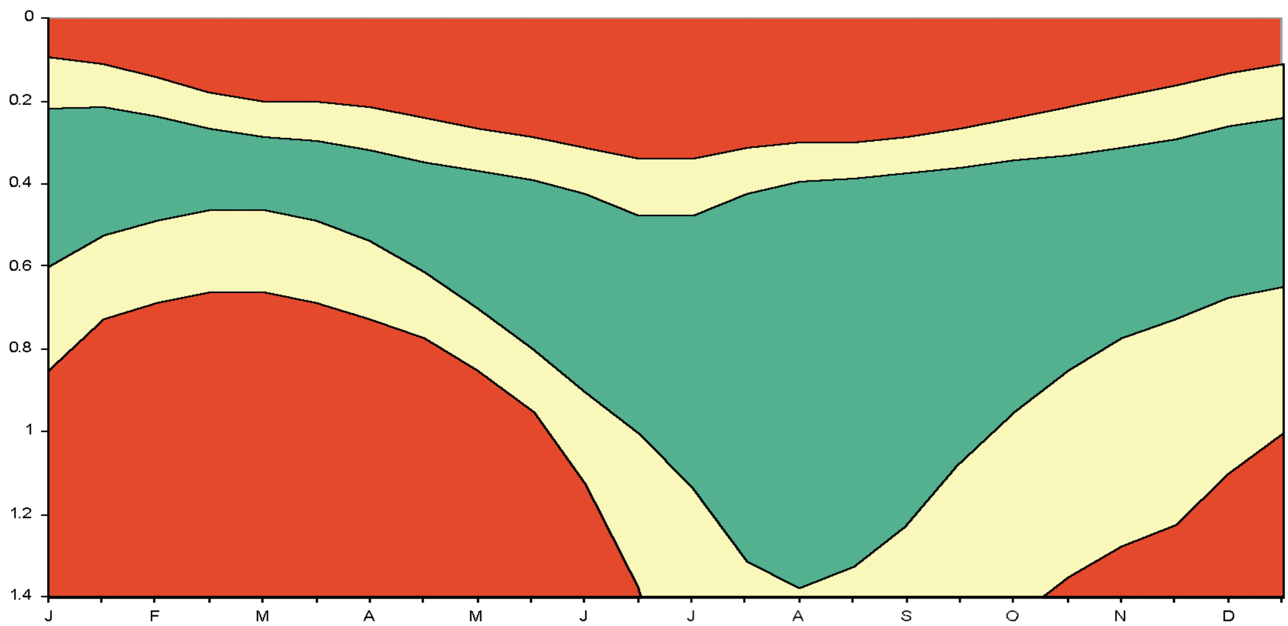

Figure 3.3 Water-Table Depth Zones for Hydrological Type K (refer to Table 3.2 for Type K)

Table 3.3 Water Regime Variables for MG4 Grassland of Hydrological Type B

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)			
A Mean water table depth (maximum)/m	0.35	0.5 - 0.7	>0.7
B Mean water table depth (minimum)/m	0.35	0.11 - 0.08	<0.07
C Max duration of surface flooding episode covering >10% of area/days	5	10 - 18	>18
D Cumulative duration of flooding during season/days	10	35-45	>45
Spring (Mar – May)			
A Mean water table depth (maximum)/m	0.45	0.65 - 0.8	>0.8
B Mean water table depth (minimum)/m	0.45	0.3 - 0.2	<0.2
C Max duration of surface flooding episode covering >10% of area/days	0	7 - 12	>12
D Cumulative duration of flooding during season/days	0	18 - 30	>30
Summer (June - Aug)			
A Mean water table depth (maximum)/m	0.7	1	-
B Mean water table depth (minimum)/m	0.7	0.45 - 0.35	<0.35
C Max duration of surface flooding episode covering >10% of area/days	0	3 - 7	>7
D Cumulative duration of flooding during season/days	0	9 - 14	>14
Autumn (Sep - Nov)			
A Mean water table depth (maximum)/m	0.6	1	-
B Mean water table depth (minimum)/m	0.6	0.3 - 0.2	<0.2
C Max duration of surface flooding episode covering >10% of area/days	3	7 - 12	>12
D Cumulative duration of flooding during season/days	3	16 - 24	>24
E Readily available water in top 0.5 m/mm	65	55 - 45	<45

The green column gives the target values for the community. The amber column gives the range of values which, if experienced in most years, will result in change in the community. The red column gives the threshold which, if breached in 1 year, a change is likely to be experienced.

The various combinations of these factors are listed in Table 3.2 as hydrological types.

Given the scarcity of extant meadows, some scenarios are no longer represented; others have no or scant hydrological data.

3.3 Regimes

3.3.1 Water regime

The MG4 community has two basic requirements:

- an aerated root zone during the growing season; and
- an adequate water supply so as not to limit plant growth in early summer.

Excess water is a more immediate threat to the community than soil dryness.

Figure 3.3 illustrates the water-table regime for MG4 with type K (refer Table 3.2) hydrological regime.

The figure illustrates the range of depths that are "preferred" (green) and "tolerable for limited periods" (amber) by the community. Values are based on the mean of at least three readings, taken in different years, but all within the same four-week period. If a mean value based on three consecutive readings, each at least 14 days apart, falls within the red zone, then there is a high likelihood that the composition of the community will be affected. If they fall in the top red zone the effect may be noticeable within a year, in the lower red zone, it may not reveal itself for several years. The amber region represents a zone in which measured water tables beneath an MG4 community may fall in a particular year during wetter or drier than average periods. Such conditions appear to have no adverse effect on the community providing they do not occur consistently year on year.

In some soils (e.g. type L - refer to Table 3.2 for example), there may be no measurable water table in summer. Table 3.3 gives seasonal requirements for the hydrological type with most available data (type B), while Table 3.4 lists the deviations from this standard that may be expected in other hydrological types.

Table 3.4 Requirements of Other Hydrological Types (a qualitative evaluation of deviations from values in Table 3.3)

Deviation From Regime Documented From Type B	Types
Shallower water tables tolerated in winter/spring	ADGJ
Deeper water tables required in winter/spring	CFIL
Shallower water tales required in summer	A
Frequent transient floods required	D
True water tables may not be present in summer/autumn	EF
Deeper water tables tolerated in summer	HK
Profiles with slightly lower available water capacities tolerated	ADGHIJ

3.3.2 Nutrient Regime

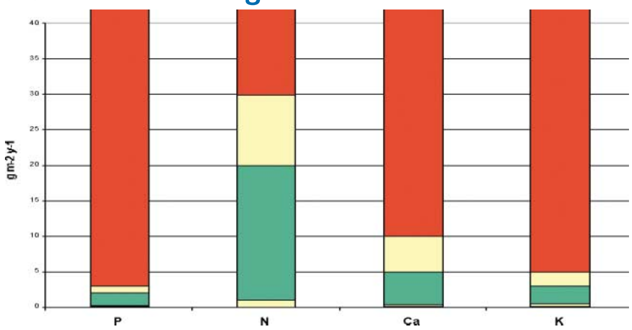

Figure 3.4a Ranges of Acceptable Nutrient Deposition Rate

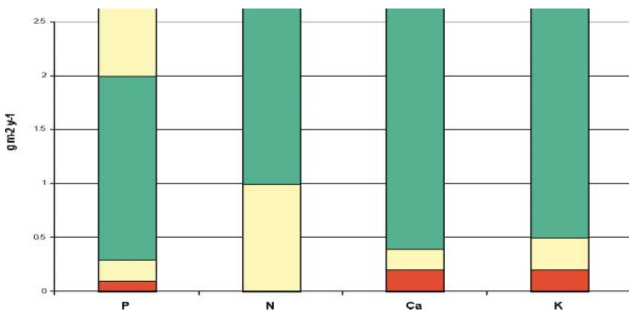

Figure 3.4b Expanded Scale Showing Minimum Deposition Rates Values in the green zone may be safe over the long term, but in the amber zone, they may only be tolerable in the short term.

There has been no focused study of the nutrient limitation of the MG4 community. It is therefore not possible to make a definitive statement as to whether nitrogen, phosphorus or both limit the productivity of these systems.

Most available information relates to phosphorus (P) availability. P-availability can be expressed in a number of ways, dependent on how the nutrient is extracted from the soil prior to measurement. Olsen available P (extracted using Olsen's bicarbonate buffer) is the most widely used and is considered to be the most reliable for neutral semi-natural grasslands, such as MG4. Olsen available P in soils supporting MG4, are normally between 5 and 15 mg per kilogram of dry soil.

Nitrogen availability is less well understood and it is not clear whether it is strongly limiting in these grasslands or not.

MG4 meadows are normally on an active floodplain with a flood return period <5 years. Figure 3.4 gives the range of expected nutrient delivery rates derived from outline nutrient budgets. Empirical data are rather scarce, so the level of confidence attached to specific values is not high.

Another requirement of the meadow is for basic cations (Ca^{2+}, Mg^{2+}, K^{+}) to maintain surface pH. The pH of most sites is close to 6.0 and is maintained by the delivery of base-rich silt to the floodplain. A base-rich groundwater supply may however reduce or even replace the reliance of the system for calcium on flood-derived silt. Estimates for delivery rates of base-rich cations are given in Figure 3.4, but due to a lack of field data these rates are necessarily speculative.

3.3.3 Management Regime

The MG4 community has been traditionally managed by undertaking a summer hay cut followed by grazing of the re-growth in autumn.

Hay cut and removal is important to balance the nutrient budget for the community. Failure to remove the crop may result in eutrophication due to the recycling of nutrients from decaying plant matter, which will accumulate year on year. Cutting later than midsummer in order to allow species to set seed may not be necessary and could be detrimental because nutrients are not so efficiently removed by a late cut and coarser species of grass are favoured.

3.4 Implications for Decision Making for Habitats Directive

3.4.1 Vulnerability

Conservation of MG4 grassland relies on a balance of:

- water-regime;
- nutrient regime; and
- vegetation management.

A stand of the community is vulnerable to a change in either direction of any of these three factors as illustrated in Figure 3.5. Figure 3.6 shows more detail of the community shifts that may occur in response to change in the water or nutrient regimes.

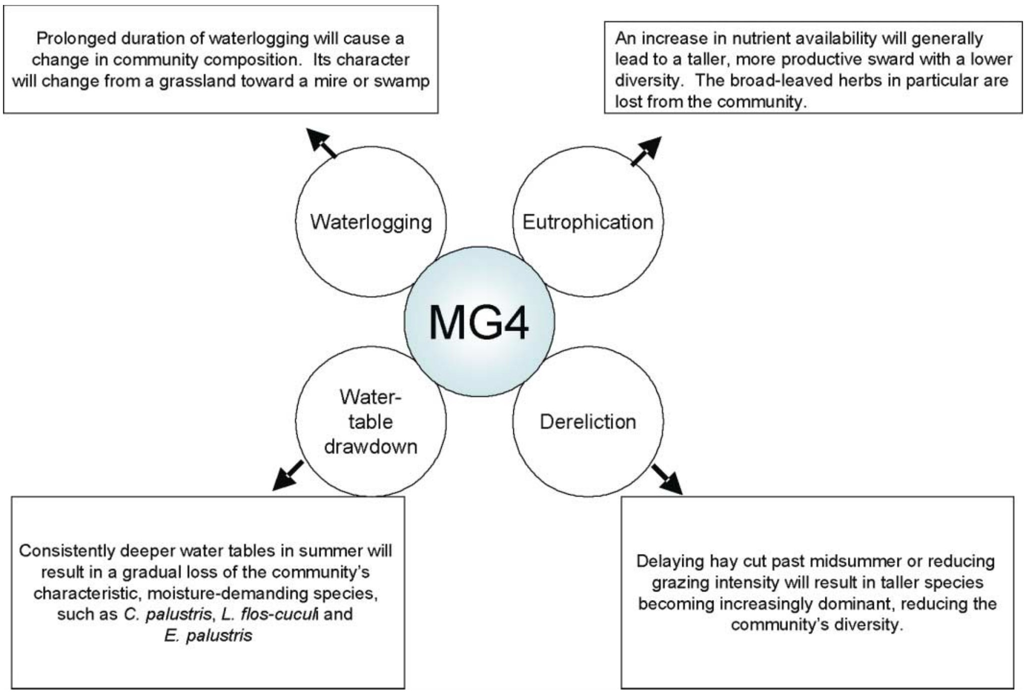

Figure 3.5 The Factors Influencing Community Composition in MG4 Grasslands and Their Effects on Community Composition

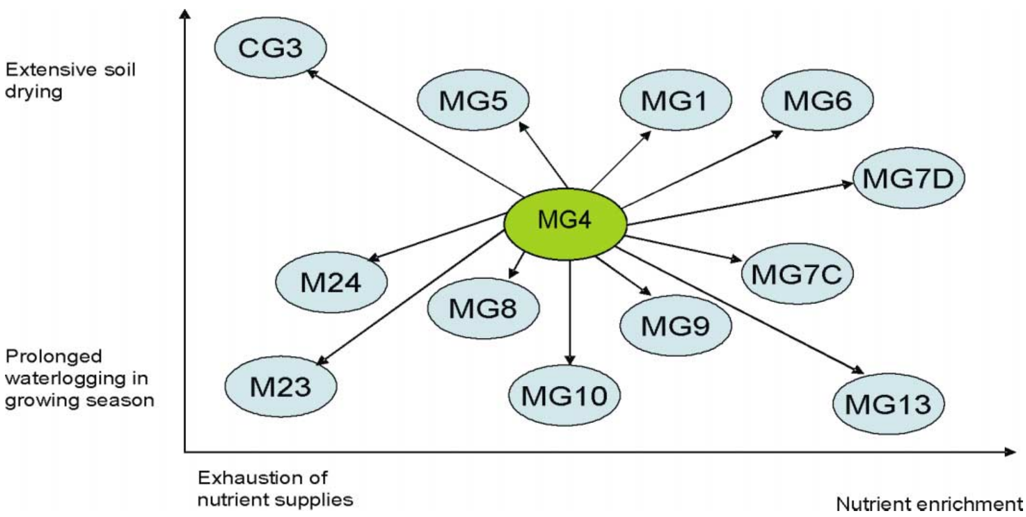

Figure 3.6 The Trajectories of Community Change in Response to Changes in WaterRegime and Nutrient Regime
The arrow implies the direction of change from the studied community. Transitions marked by short arrows may occur in a short time frame and may be reversible. Those with long arrows denote longer-term and more permanent changes.

3.4.2 Restorability

If a stand of MG4 has been recently lost, but is still under non-intensive grassland management, then corrective management may rehabilitate the community in the short to medium term (e.g. 520 years). However, if the soil has been disturbed or the P status increased, restoration may require a longer timescale (several decades). Restoration attempts to date have met with limited success.

3.4.3 Gaps in Knowledge

Although water-table depths under stable plant communities are well studied (as represented by the green zone of Figure 3.3), data for the amber zone are less robust and require further investigation. This would entail establishing permanent botanical quadrats in transition zones on sites supporting MG4. Regular recording would enable the trajectory, rate and reversibility of changes resulting from an altered water regime, whether naturally or artificially induced, to be determined.

The data presented on nutrient deposition rates are based on attempts to derive nutrient budgets for meadows. No actual data for nutrient deposition on MG4 exist and hence it is not, with certainty, known which nutrients are growth-limiting.

The effects of surface acidification that may arise as a result of cation leaching by rainwater, following the cessation of silt deposition at a site, also need to be investigated.

Finally, the water holding capacities of a greater range of soils supporting the community need to be characterised to allow a minimum tolerable value to be clearly defined.

4. MG8 *(Cynosurus cristatus - Caltha palustris)* Grassland

4.1 Context

The MG8 community is not specifically listed as a SAC feature, but it represents the most diverse plant community of grazing marshes and provides an important habitat for breeding snipe *(Gallinago gallinago)* whose populations can be important in the designation of Special Protection Areas (SPAs) under the EU Bird's Directive.

4.1.1 Floristic Composition

The community is species-rich, containing numerous grass, sedge and rush species, none of which dominate. Numerous broad-leaved herbs make the community colourful in midsummer. The community is not currently sub-divided, though sub-communities have been proposed. Characteristic species are listed in Table 4.1.

Table 4.1 Species That are Particularly Characteristic of MG8 in the Context of Floodplain Grasslands

Characteristic Species	
Caltha palustris	*Eleocharis palustris*
Carex hirta	*Geum rivale*
Cirsium palustre	*Lychnis flos-cuculi*
Pulicaria dysenterica	

The community's value is its extraordinary diversity (up to 40 species per square metre), its aesthetic appeal, its distinctive place in the landscape and the habitat it provides for wading birds such as snipe and black-tailed godwit.

4.1.2 Distribution

The community has a diverse distribution. The core area was seen as the water meadows alongside the chalk rivers of southern England (Hampshire Avon, Test, Itchen), but substantial areas also occur on the Somerset Moors and in the catchments of the Tyne and Tees in northern England. More scattered examples are found in the Norfolk Broads and the West Norfolk Fens. The community is found on both peat and mineral soils and often occurs as small stands juxtaposed with other grassland communities. The total area of the community remaining in the UK may be as little as 800 ha.

4.1.3 Landscape Situation and Topography

The community is usually found on floodplains in river valleys. In the South of England it is usually reliant on managed hydrological systems based on a dense ditch network, such as in water meadows and the Somerset Moors. Flooding may either be as a result of storm events or artificially induced. In northern England it can be within a more natural context on flat or gently sloping land through which water seeps.

An important landscape feature for the flat lowland sites in southern England is the presence of artificial surface drainage systems, designed to remove surface water swiftly from the site. The drainage system typically comprises shallow features connecting to deeper ditches, which then join the main river downstream.

4.1.4 Substratum

The MG8 community is typically found on well-structured alluvial soils over gravel or chalk or on permeable organic soils with high porosity and high available water capacities. Shallow water tables are supported through most of the year resulting in strongly gleyed mineral horizons. High permeability is the major factor uniting MG8 soils.

Substantial lateral water movement within the soil profile is common. This facilitates subsurface drainage in winter and sub-irrigation in summer.

4.2 Supply Mechanism and Conceptual Model

One of three different supply mechanisms support stands of MG8. The classic water meadow relies on active water management. River water is diverted into small channels known as leats and floats from which it is allowed to run over the grassland surface then into drains and back to the river. The management goal is to keep the water continuously moving to avoid it becoming stagnant and anoxic.

An alternative, less managed mechanism is found in the deep peat soils of Somerset where dense ditch networks maintain relatively constant water tables. Their levels are managed (usually by drop board sluices) to act as drains in winter and irrigation canals in summer. Of the three mechanisms, this is now the most frequently encountered and it is illustrated in Figure 4.1.

The third mechanism is natural hillslope seepage maintaining high water tables in floodplains and flushes in the wetter north of England. In these areas, in addition to high rainfall, the evaporative demand is low and therefore the potential soil moisture deficit (SMD) is much lower than in the south of England.

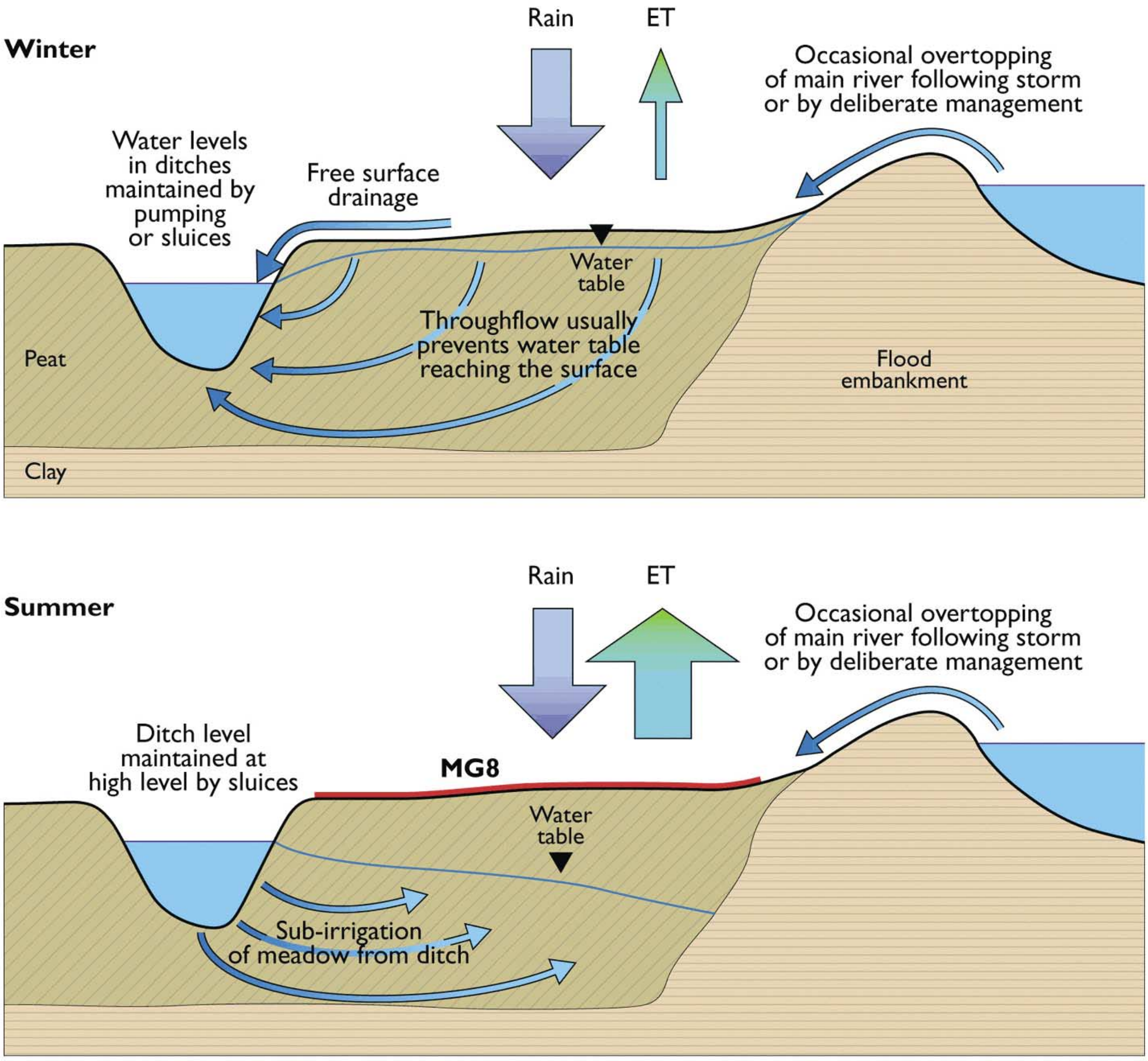

Figure 4.1 A Schematic Representation of the Hydrological Context of MG8 Grassland

4.3 Regimes

4.3.1 Water regime

The MG8 community requires a well-aerated root zone during the growing season plus sufficient water to supply the surface soil throughout the summer. Prolonged waterlogging and prolonged soil dryness both threaten the community, therefore it is found on soils with water tables usually within 0.5 m of the surface and showing relatively little seasonal fluctuation.

Figure 4.2 illustrates the water-table regime for MG8 on a site with the supply mechanism described as the second alternative above.

The figure illustrating the range of depths that are “preferred” (green) and “tolerable for limited periods” (amber). Each value is based on the mean of at least three readings, taken from different years, but all within the same four-week period. If a mean value based on three consecutive readings, each at least 14 days apart, falls within the red zone, then there is a high likelihood that the composition of the community will be affected. The amber region represents a zone in which measured water tables beneath an MG8 community may fall in a particular year during wetter or drier than average periods. Such conditions appear to have no adverse effect on the community providing they do not occur consistently year on year.

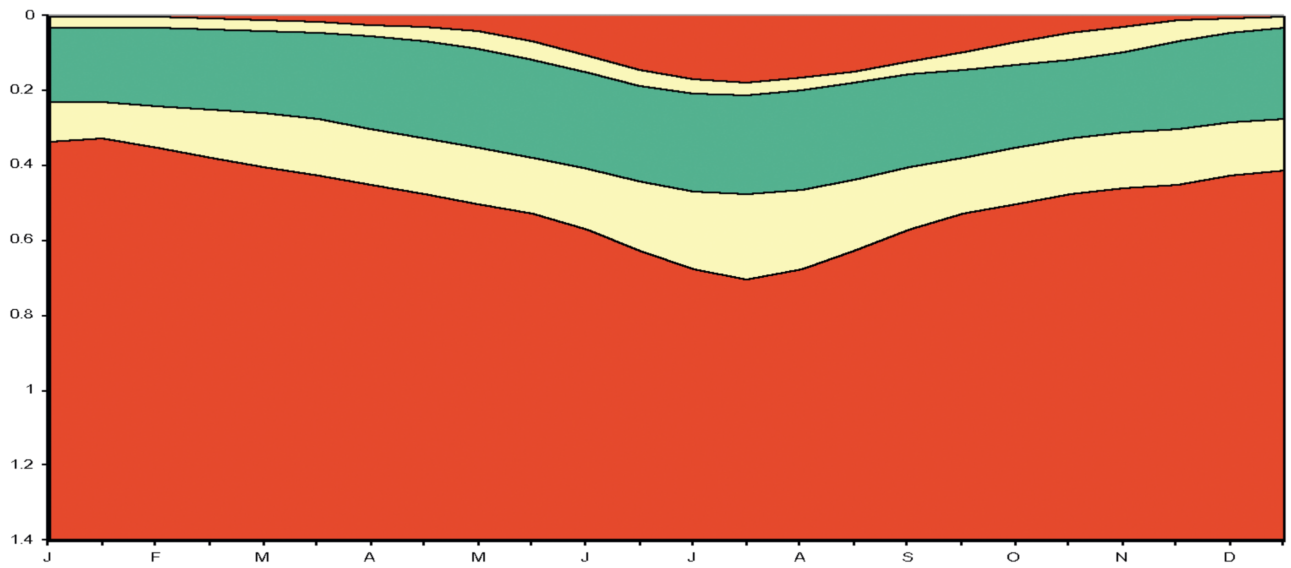

Figure 4.2 Water-Table Depth Zones for the Somerset Moors Hydrological Type

Table 4.2 gives seasonal requirements for the hydrological type found on the Somerset Moors for which most data are available, while Table 4.3 lists the deviations from this reference state, which may be expected in other hydrological types.

4.3.2 Nutrient Regime

Studies using controlled fertiliser application suggest the productivity of grasslands related to MG8 are limited by nitrogen availability, but it is possible that phosphorus may be co-limiting.

Most available information on soil nutrient availability relates to phosphorus (P). Pavailability can be expressed in a number of ways, dependent on how the nutrient is extracted from the soil prior to measurement. Olsen available P (extracted using Olsen's bicarbonate buffer) is the most widely used and is considered to be the most reliable for neutral semi-natural grasslands, such as MG8. Olsen-available P in soils supporting MG8, are normally between 2 and 12 mg per kilogram of dry soil.

Nitrogen availability is less well understood, but has been shown to be strongly limiting in related grasslands.

MG8 meadows often but not invariably receive silt from river water spilling out of channel. Some situations appear to rely on groundwater for their nutrient supply, but may have received organic fertiliser (manure) in the past. No attempt has been made to construct a nutrient budget for this grassland type; therefore it is difficult to estimate quantitative tolerances in terms of nutrient delivery rates.

Another requirement of the meadow is for basic cations (Ca^{2+}, Mg^{2+}, K^{+}) to maintain surface pH. The pH of most sites is 6.0 or above and is maintained by the delivery of base-rich silt to the floodplain. A base-rich groundwater supply may reduce or even substitute the system's reliance on flood-derived silt for calcium however. Furthermore, past agricultural management may have included the application of lime or basic slag.

4.3.3 Management

The typical management that sustains the MG8 community consists of a midsummer hay cut followed by grazing of the re-growth in autumn. The community will persist under year-round grazing provided stocking density is not too high and grazing animals are not allowed to compact the soil in winter. Hay cut and removal can be important for preventing the accumulation of nutrients in the system. Delaying hay cut beyond midsummer could be detrimental because it would allow tall species such as rushes *(Juncus* spp.) to dominate. There is historical evidence that farmers targeted large rush clumps for removal by hand in the past.

4.4 Implications for Decision Making

4.4.1 Vulnerability

Conservation of MG8 grassland relies on a balance of:

- water-regime;
- nutrient regime; and
- vegetation management.

Table 4.2 Water Regime Variables for MG8 Grasslands of Ditch-Drained Permeable Peat Soils, Such as Found on the Somerset Moors

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)			
A Mean water table depth (maximum)/m	0.1	0.25 - 0.4	>0.4
B Mean water table depth (minimum)/m	0.1	0.03	-
C Max duration of surface flooding episode covering >10% of area/days	5	21 - 35	>35
D Cumulative duration of flooding during season/days	15	40 - 60	>60
Spring (Mar - May)			
A Mean water table depth (maximum)/m	0.2	0.3 - 0.45	>0.45
B Mean water table depth (minimum)/m	0.2	0.05 - 0.02	<0.02
C Max duration of surface flooding episode covering >10% of area/days	3	5 - 12	>12
D Cumulative duration of flooding during season/days	9	30 - 45	>45
Summer (June - Aug)			
A Mean water table depth (maximum)/m	0.3	0.45 - 0.65	>0.65
B Mean water table depth (minimum)/m	0.3	0.2 - 0.15	<0.15
C Max duration of surface flooding episode covering >10% of area/days	2	8 - 20	>20
D Cumulative duration of flooding during season/days	5	30 - 60	>60
Autumn (Sep - Nov)			
A Mean water table depth (maximum)/m	0.2	0.35 - 0.5	>0.5
B Mean water table depth (minimum)/m	0.2	0.13 - 0.07	<0.07
C Max duration of surface flooding episode covering >10% of area/days	3	7 - 14	>14
D Cumulative duration of flooding during season/days	12	35 - 55	>55

The green column gives the target values for the community. The amber column gives the range of values which, if experienced in most years, will result in change in the community. The red column gives the threshold which, if breached in 1 year, a change is likely to be experienced.

Table 4.3 Requirements of Other Hydrological Types (a qualitative evaluation of deviations from reference values in Table 4.2)

Mechanism and Soil Type	Deviation from Reference State
Peat substrate supplied by hillslope seepage in a low SMD region	Slightly deeper mean water table depths can be tolerated in summer and autumn
Well-structured alluvial substrate supplied by hillslope seepage in a low SMD region	Slightly deeper water tables required during the spring
Peat soils fed by chalk ground water in a high SMD region	Slightly shallower water tables in spring and summer required
Managed water meadow in southern England on alluvium or peat	Flood durations may be extended at any time of year, providing water is in constant motion through the system

SMD - potential soil moisture deficit.

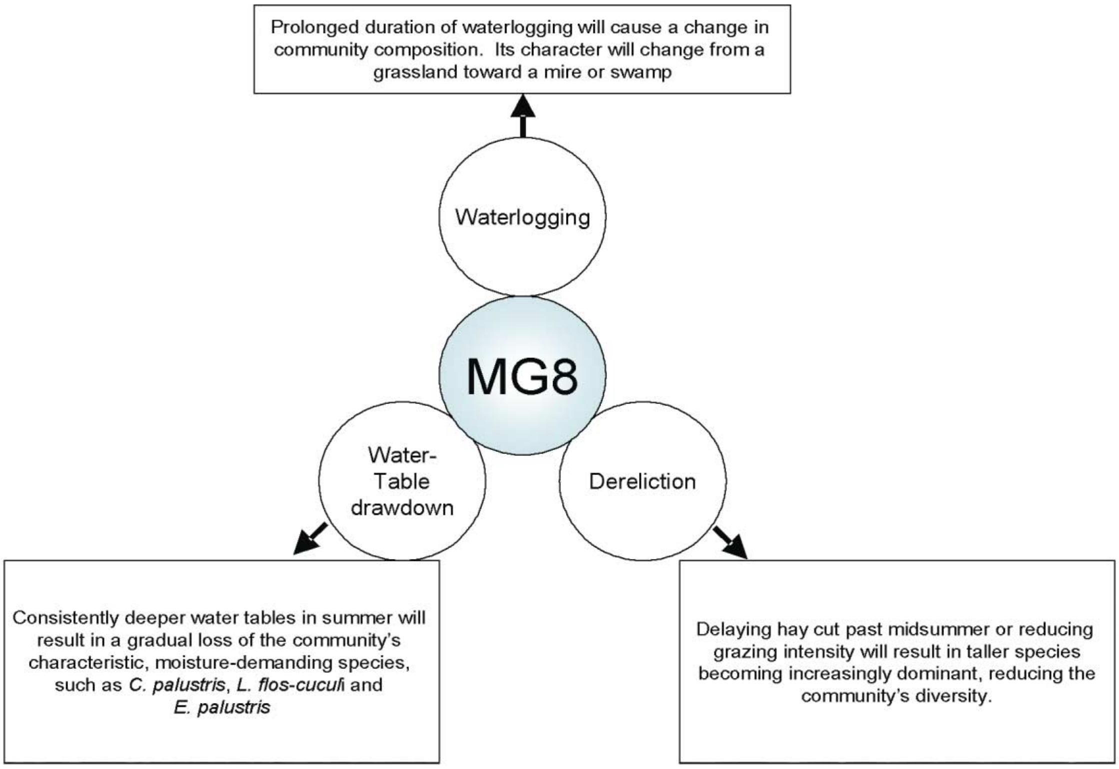

Figure 4.3 The Effect of Environmental Change on Stands of MG8

A stand of the community is vulnerable to a change in either direction of any of these three factors as illustrated in Figure 4.3. Figure 4.4 shows more detail of the community shifts that may occur in response to change in the water or nutrient regimes.

4.4.2 Restorability

Where the community has been recently lost, but is still under non-intensive grassland management, then corrective management may be sufficient to rehabilitate MG8 in the short to medium term. If the

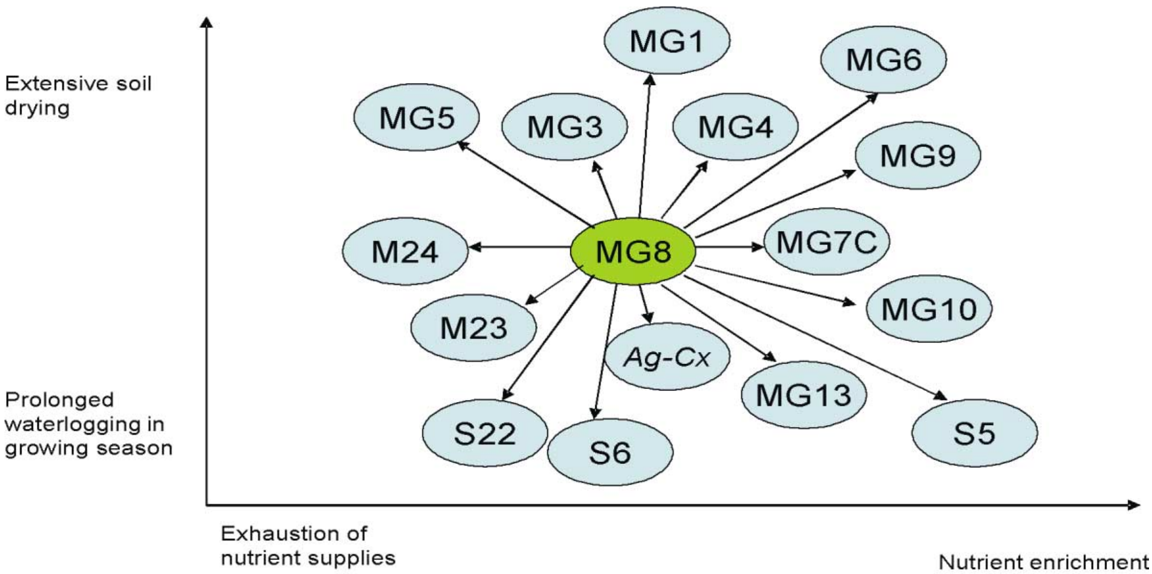

Figure 4.4 The Trajectories of Community Change in Response to Changes in WaterRegime and Nutrient Regime
The arrow implies the direction of change from the studied community. Transitions marked by short arrows may occur in a short time frame and may be reversible. Those with long arrows denote longer-term and more permanent changes. Ag-Cx denotes the Agrostis-Carex grassland not listed in the original NVC, but subsequently recognised as a distinct community type.

soil has been subjected to prolonged drying then the mineralization of nutrients from organic matter may require many years to counteract. If the soil's capacity to transmit water laterally is compromised, again restoration may take decades. There have been no documented attempts focussed on restoring this particular grassland type. Other wet grassland creation efforts have struggled to achieve the level of hydrological control necessary to meet the requirements of the MG8 community.

4.4.3 Gaps in Knowledge

Water regimes have been quite extensively researched for this community, but less is known about its tolerance of varying nutrient deposition rates and therefore no estimates have been made here. A nutrient budget approach spanning a range of water-supply mechanisms would be a useful piece of research for understanding the requirements of MG8 meadows. Experimentation with restoration techniques also needs to be supported.

As a major reason for conserving this community is its provision of suitable habitat for breeding snipe, the relationship between soil moisture status and penetration resistance should be further investigated as this may influence the water management methods.

5. MG13 *(Agrostis stolonifera-Alopecurus geniculatus)* Grassland

5.1 Context

The MG13 community is not specifically listed as a SAC feature, but it represents an important habitat for over-wintering waterfowl and for breeding waders, whose populations can be important in the designation of SPAs under the Bird's Directive.

5.1.1 Floristic Composition

The community is dominated by sprawling grasses with a few, mainly low growing, broadleaved herbs. There are no recognised sub-communities. Characteristic species of the community are listed in Table 5.1.

Table 5.1 Species That Are Particularly Characteristic of MG13 in the Context of Floodplain Grasslands

Characteristic Species	
Alopecurus geniculatus	*Agrostis stolonifera*
Ranunculus flammula	*Oenanthe fistulosa*
Persicaria amphibia	*Rumex crispus*

This community is often not species rich. Indeed it is usually associated with areas of bare mud in spring that are quickly colonised in early summer by a few creeping herbs and grasses. Its conservation value lies in the bird populations, which use it either to overwinter (various wildfowl) or to breed (lapwing, redshank) in spring.

5.1.2 Distribution

The community is widely distributed throughout lowland England with the largest expanses being found in washlands alongside the large rivers of Eastern England (e.g. Ouse, Nene). It is found on both peat and mineral soils and often occurs as narrow strips along old drainage features within other grassland types. Its total UK extent has been estimated at 2000 ha.

5.1.3 Landscape Situation and Topography

The community is usually found within depressions on floodplains. It is normally either within a managed washland used for flood storage, alongside a fluctuating water body such as a pond, or within an old drainage feature (e.g. field gutter.) The surrounding topography is generally flat. Water collects in these areas either as a result of flooding from rivers or through the accumulation of rain from surrounding land.

5.1.4 Substratum

MG13 often occurs on both poorly-structured alluvial soils with low permeabilities, but also on more permeable substrates, including peat. The poor-structured alluvial soils tend to contain relatively little pore-space and therefore they cannot store a lot of water. Water tables may fluctuate considerably over the summer period, as evidenced by the mottled colouring of such soils to considerable depth. The community usually relies on being in a shallow topographic depression, allowing it to capture and retain water. Lateral water movement within the soil profile is not necessarily a major component of the water regime.

5.2 Supply Mechanism and Conceptual Model

Most stands of MG13 can be assigned to a single water-supply mechanism (Figure 5.1). The grassland occurs in shallow depressions within a floodplain, which may capture surface water from a flood event or accumulate excess rainfall draining from other parts of the floodplain. These depressions can vary considerably in scale, from old surface drains less than 1 m wide to entire washlands several hundred metres across.

5.3 Regimes

5.3.1 Water Regime

Surface water is typically 50–150 mm deep by the end of the winter (March). This water is effectively trapped in a depression, due either to the low permeability of the soil or to the lack of a hydraulic gradient for drainage. The water gradually evaporates during spring and summer with the water table typically falling below the surface during May or June. In soils with low porosity, the water table may fall rapidly during July and August and not be readily measurable by the end of the summer. This situation is presented diagrammatically in Figure 5.2.

On more porous soils, however, water tables may remain in the top 0.5 m for the whole year. This may also be true where the grassland is adjacent to a water body that supplies some water through the summer. MG13 is tolerant of sporadic inundation events through the summer, though the community may shift toward a swamp if the surface water regularly persists for more than a week in the height of summer.

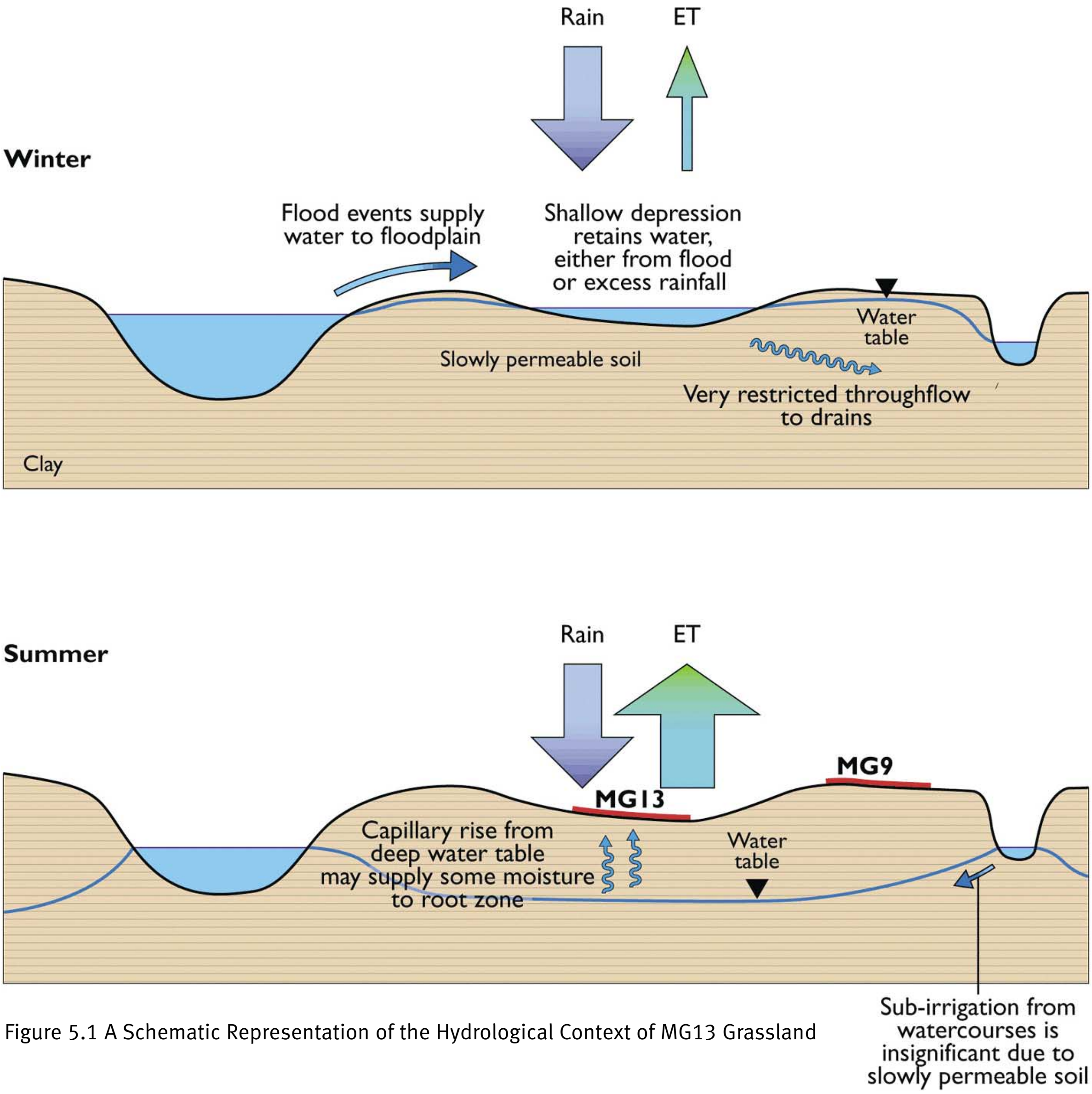

Figure 5.1 A Schematic Representation of the Hydrological Context of MG13 Grassland

The figure illustrates the range of depths that are “preferred” (green) and “tolerable for limited periods” (amber). Each value is based on the mean of at least three readings, taken from different years, but all within the same four-week period. If a mean value based on three consecutive readings, each at least 14 days apart, falls within the red zone, then there is a high likelihood that the composition of the community will be affected. The amber region represents a zone in which measured water tables beneath an MG13 community may fall in a particular year during wetter or drier than average periods. Such conditions appear to have no adverse effect on the community providing they do not occur consistently year on year.

Table 5.2 gives seasonal requirements. Examples of the community on well-structured soil are usually more species-rich and tend to exhibit shallower water tables through the year. Those on poorly structured clays may have no measurable water table for some of the summer months.

5.3.2 Nutrient Regimes

There is available information relating to phosphorus (P) availability on MG13 sites. The community has been shown to tolerate Olsen available P values in the range 6 to 35 mg kg^{-1}. This includes some of the most phosphorus-rich soils under semi-natural grassland on floodplains. Nitrogen availability has not been studied in detail, but is likely to limit the community’s productivity on soils so well supplied with phosphorus.

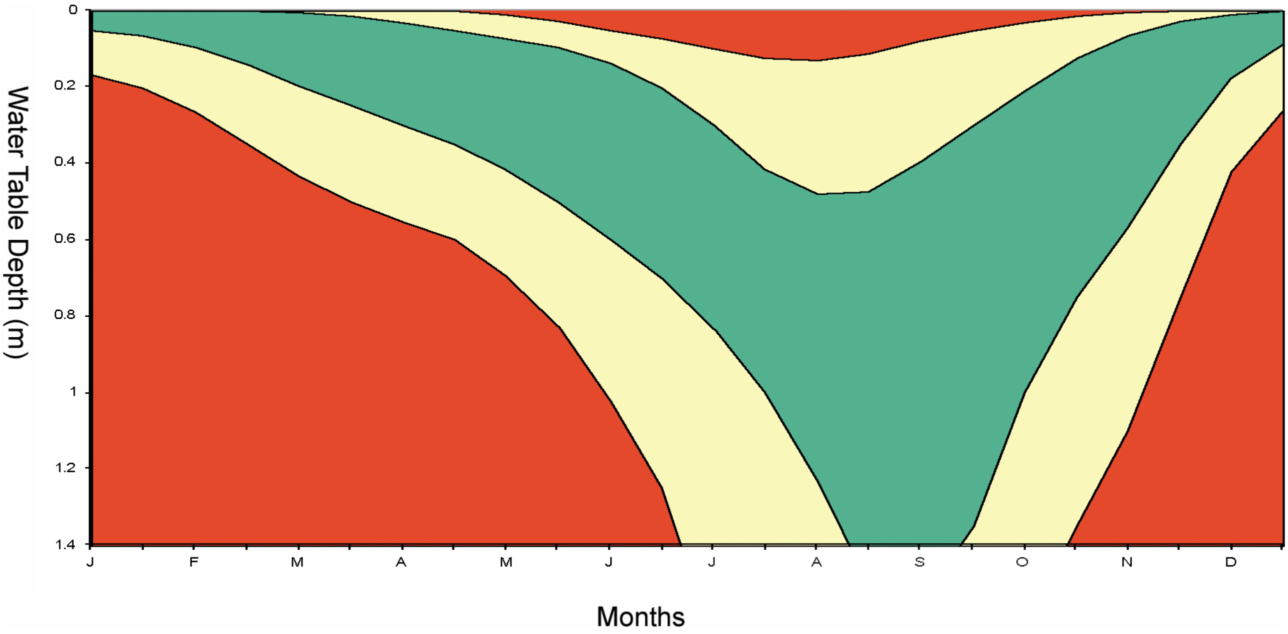

Figure 5.2 Water-Table Depth Zones for MG13 Grassland

Table 5.2 Water Regime Variables for an MG13 Grassland Community on a Poorly-Structured Alluvial Clay Loam

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)			
A Mean water table depth (maximum)/m	0	0.1 - 0.25	>0.25
B Mean water table depth (minimum)/m	0	-	-
C Max duration of surface flooding episode covering >10% of area/days	30	-	-
D Cumulative duration of flooding during season/days	60	-	-
Spring (Mar - May)			
A Mean water table depth (maximum)/m	0.1	0.3 - 0.55	>0.55
B Mean water table depth (minimum)/m	0.1	0.03	-
C Max duration of surface flooding episode covering >10% of area/days	20	-	-
D Cumulative duration of flooding during season/days	40	-	-
Summer (June - Aug)			
A Mean water table depth (maximum)/m	0.4	0.8	-
B Mean water table depth (minimum)/m	0.4	0.3 - 0.1	<0.1
C Max duration of surface flooding episode covering >10% of area/days	4	10 - 20	>20
D Cumulative duration of flooding during season/days	6	30 - 60	>60
Autumn (Sep - Nov)			
A Mean water table depth (maximum)/m	0.4	1	-
B Mean water table depth (minimum)/m	0.4	0.2 - 0.03	<0.03
C Max duration of surface flooding episode covering >10% of area/days	20	-	-
D Cumulative duration of flooding during season/days	40	-	-

The green column gives the target values for the community. The amber column gives the range of values which, if experienced in most years, will result in change in the community. The red column gives the threshold which, if breached in 1 year, a change is likely to be experienced.

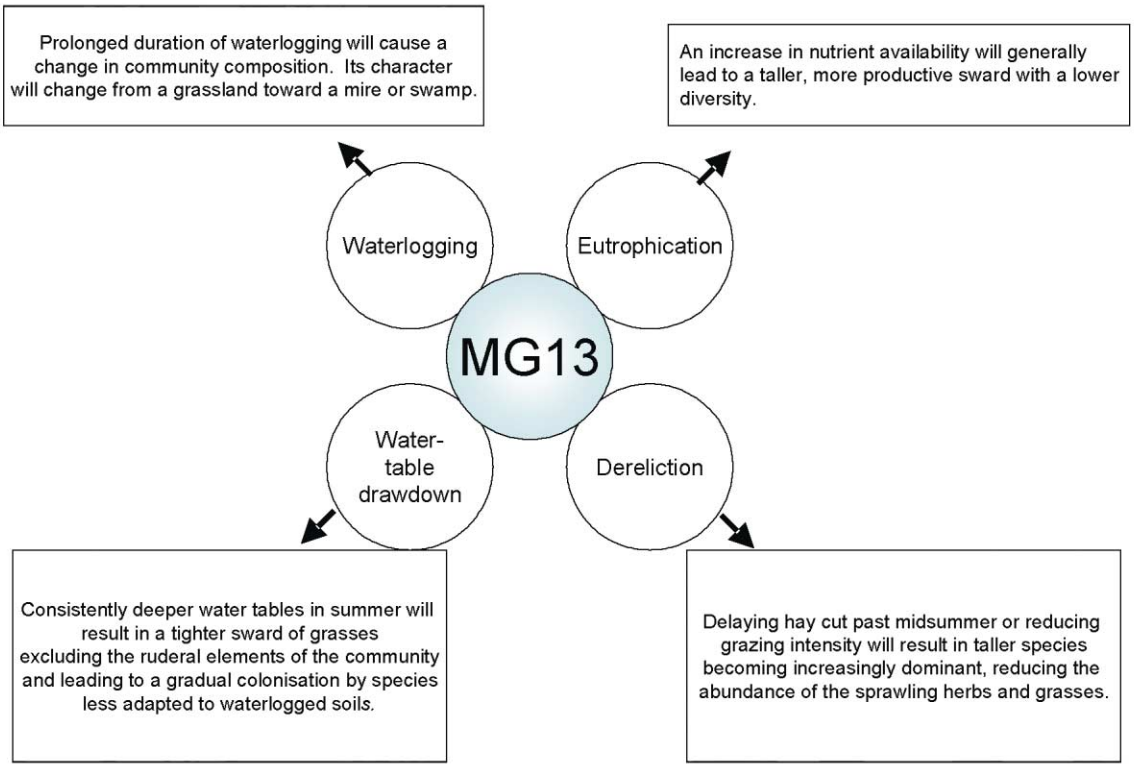

Figure 5.3 The Effect of Environmental Change on Stands of MG13

Many stands of the MG13 community receive silt from river water spilling out of the channel. Indeed silt is preferentially dropped in the floodplain depressions where this community typically occurs. No attempt has been made to construct a nutrient budget for this grassland type, therefore it is difficult to estimate quantitative tolerances in terms of nutrient delivery rates, but it is likely that this community can tolerate higher rates of nutrient input than the more species-rich floodplain grasslands.

5.3.3 Management

The MG13 community may be grazed throughout the year, though stock are often removed during late winter and early spring when the sites tend to be under water for prolonged periods. The community will also persist under a hay-making regime with aftermath grazing. Lack of management tends to result in taller swamp or rush-dominated communities encroaching into areas previously supporting the MG13 community.

5.4 Implications for Decision Making

5.4.1 Vulnerability

Conservation of MG13 grassland relies on a reliable water source either from a water body or a local catchment and regular grazing as illustrated in Figure 5.3. The community will be lost as a result of drainage operations diverting water away. It is considered to be robust in terms of withstanding increased nutrient loading provided sufficiently intensive management is maintained, although species diversity may decline.

Figure 5.4 The Trajectories of Community Change in Response to Perturbations in Water-Regime and Nutrient Regime.

The arrow implies the direction of change from the studied community. Transitions marked by short arrows may occur in a short time frame and may be reversible. Those with long arrows denote longer-term and more permanent changes. Ag-Cx denotes the Agrostis-Carex grassland not listed in the original NVC, but subsequently recognised as a distinct community type.

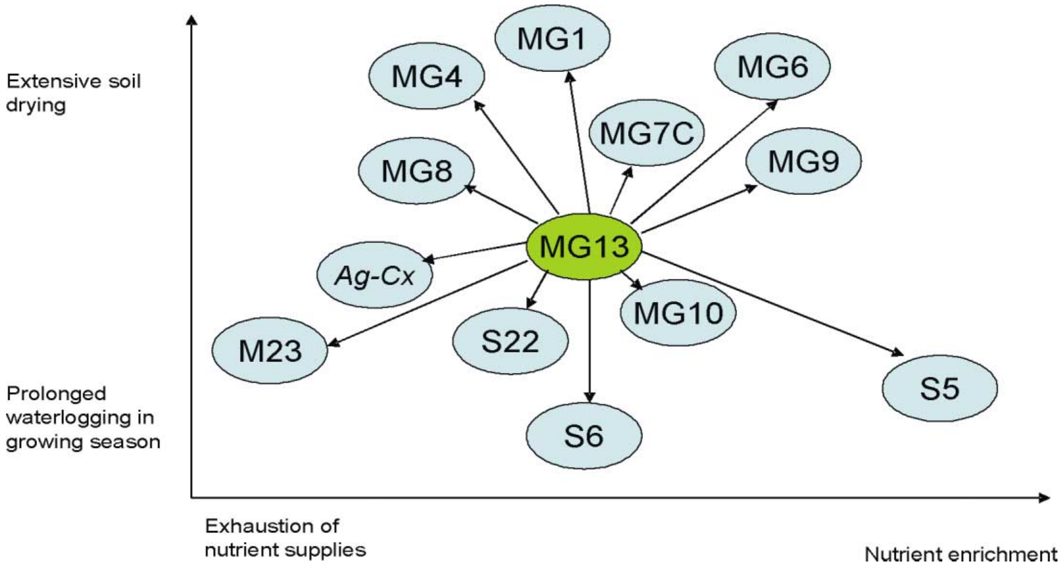

Figure 5.4 shows in more detail the community shifts that may occur in response to changes in the water or nutrient regimes.

5.4.2 Restorability

Restoration of this community is relatively straightforward compared to the more species-rich assemblages. The community by its nature colonises bare ground rapidly, therefore it can be reintroduced to an area simply by broadcasting seeds. Successful restoration schemes have been documented. A sward with reasonable similarity to MG13 can be achieved after just two years. The community is not highly dependent on fragile soil properties or upon low nutrient status and therefore it can be re-introduced wherever a suitable hydrological regime can be established. Species-rich examples of the community would take longer to develop and may rely both on a degree of soil structure development and nutrient availability being at the low end of the community's tolerated range.

5.4.3 Gaps in Knowledge

Water regime information has largely been gathered as a result of studies on neighbouring communities and therefore the full range of MG13 situations has not been addressed. Further monitoring is required to confirm assumptions made above, especially with regard to the range of soils it exploits and the interaction between soil type and species richness. A nutrient budget approach to MG13 grasslands would be a useful adjunct to studies on more species-rich swards.

A useful future investigation would be to study the tolerance of this community to bespoke water regimes imposed for the benefit of attracting and retaining bird species of conservation interest.

6. Other Floodplain - Meadow Communities

6.1 Context

This guideline covers three communities as follows:

- MG5 *(Cynosurus cristatus-Centaurea nigra)* grassland;
- MG7C *(Lolium perenne-Alopecurus pratensis-Festuca pratensis)* grassland;
- MG9 *(Holcus lanatus-Deschampsia cespitosa)* grassland.

These three communities are often found in association with the MG4 floodplain meadow described in Section 3. Although MG7 and MG9 are not as highly prized by conservationists for their botanical diversity as MG5, they may play an equivalent role in terms of providing nesting and feeding habitat for birds.

6.1.1 Floristic Composition

MG5 *(Cynosurus cristatus-Centaurea nigra)* grassland

An often species-rich and relatively unproductive meadow, composed of fine grasses and abundant herbs. It is the *Lathyrus pratensis* sub-community (MG5a) that is most often found on floodplains in association with MG4. Characteristic species of the community are listed in Table 6.1 below.

Table 6.1 Species That Are Particularly Characteristic of MG5a in the Context of Floodplain Grasslands

Characteristic Species	
Cynosurus cristatus	*Plantago lanceolata*
Dactylis glomerata	*Prunella vulgaris*
Festuca rubra	*Rhinanthus minor*
Lathyrus pratensis	*Trifolium pratense*
Leucanthemum vulgare	

MG7C *(Lolium perenne-Alopecurus pratensis-Festuca pratensis)* Grassland

A grass-rich, generally species-poor assemblage, dominated by tall, productive grasses. The main characteristic species, in the context of other floodplain grasslands, is *Festuca pratensis*.

MG9 *(Holcus lanatus-Deschampsia cespitosa)* Grassland

A tussocky grassland of variable species richness, often dominated by the tussocks of tufted hair-grass *(Deschampsia cespitosa),* the community's most characteristic species. However, where the community is regularly mown for hay, this grass may not develop a tussocky habit and be less obvious within a sward of mixed grasses. It is the *Poa trivialis* sub-community (MG9a) that is most often found within the context of floodplain meadows.

6.1.2 Distribution

All three communities are widely distributed throughout lowland England. This guideline focuses on their requirements within floodplains, though it should be noted that all of them can occur within other parts of the landscape. They (like MG4) are generally associated with mineral rather than organic soils.

The MG5 community is of nature conservation interest in its own right in terms of its botanical composition. Its total UK extent (floodplain and non-floodplain situations) has been estimated at ‹5000 ha. Equivalent data have not been collected for the other two communities as their conservation is regarded as of lower priority.

6.1.3 Landscape Situation and Topography

MG5a

Within floodplains, the community is usually found on raised areas with good drainage, such as mounds or on levées bordering water courses. Sites are often sloping, facilitating the shedding of surface water.

MG7C

This community is usually associated with areas within floodplains that are receiving regular silt deposition following floods. It tends to occur on flat or very gently sloping areas, rather than in depressions or on mounds.

MG9a

This sub-community is often associated with areas that retain some surface water in winter though this water is usually neither extensive nor deep. It may also be associated with depressions and runnels forming part of the surface drainage network or on flat areas where soil drainage is slow.

6.1.4 Substratum

The MG5a sub-community normally occurs on fine textured soils, but ones that are well structured, facilitating water movement. There may be some mottling of soil colour at depth, as a result of sub-soil waterlogging, but this does not normally occur within 40 cm of the surface.

The MG7C community also occurs on fine-texture alluvium, but tends to have less developed structure than soils beneath MG4 or MG5 communities. As a result, such soils tend to drain less rapidly.

The MG9a sub-community is again found on fine-texture alluvium, but often where the soil structure has been previously disrupted through tillage or compaction and insufficient time has elapsed to allow it to reform. The drainage of such soils is typically impeded. These less porous soils store less water within their profiles than better structured ones and as a result, water tables may fluctuate considerably over the summer period generating mottled soil colours throughout the profile.

6.2 Supply Mechanism and Conceptual Model

All three communities can occur in the same hydrological setting as that described for the MG4 community (Section 3.2.1, Figure 3.1). Water may be supplied to all three through a combination of precipitation, flood inundation and sub-irrigation, but the soil water regime differs considerably between them.

6.3 Regimes

6.3.1 Water Regime

The MG5a sub-community occurs on better-drained soils than MG4 grassland, alongside which it is often found. This may be a result of higher elevation, the presence of a drainage channel with a freeboard of more than 0.5 m throughout the year, or very rapid drainage being effected by a coarse-textured terrace deposit close to the surface (‹0.5 m deep). These areas are normally only flooded very intermittently and probably do not accumulate much silt due to their elevated position in the floodplain.

The MG7C community in contrast tends to occur on soils that drain less freely than neighbouring ones which support the MG4 community. In some situations it is found at lower elevations than MG4, but in others it appears to be a result of flood-routing across the floodplain resulting in preferential deposition of silt. Areas supporting the MG7C community typically flood in most years and may retain surface water briefly as floods recede. The community is more tolerant of waterlogged soil in spring than is the MG4 grassland. It is not tolerant of prolonged inundation by surface water however.

The MG9a sub-community is less clearly tied to a particular position in the floodplain compared to the other two communities. It is often found around the margins of hollows, where there is some waterlogging in spring but not persistent wetness. The presence of this community on a floodplain is often associated with previous soil disturbance. Soil water-table regimes tend to be characterised by large fluctuations in water table (high in early spring, low in late summer), resulting from low porosity due to the structure having been damaged. It may be that MG9a is a successional stage in the transition from bare ground to the MG4 community following disturbance.

6.3.2 Nutrient Regimes

There is some available information relating to phosphorus (P) availability in soils under each of the communities under consideration, but there are few studies available to indicate which major nutrients are most important in limiting the productivity of these communities.

The MG5a sub-community is distinctive in having very low P availabilities, significantly below those for MG4 grassland. The MG7C community is the opposite, having high P availability, above that for MG4 grassland. On some sites these three communities appear to be arranged across a gradient of nutrient availability linked to rates of silt deposition by flood waters. The MG9a sub-community is less easy to characterise. Phosphorus availability in its soils is very wide ranging and therefore perhaps not an important determinant of this community.

Nitrogen availability is less well understood. The MG5a sub-community often has a high frequency of legumes, suggesting external nitrogen inputs are low. By contrast the MG7C community has few legumes and it may be well supplied with nitrogen from the decomposition of organic matter dropped as litter by floods.

6.3.3 Management

In the context of floodplain meadows, all three communities may receive similar traditional management of a mid-summer hay-cut followed by aftermath grazing. All of them are less demanding in terms of management regime than the MG4 community, as none of the three communities absolutely require the annual hay cut to the degree that the MG4 grassland does. All of them can tolerate year-round grazing in some or even most years. However, shutting up for hay, whilst not essential to maintain the plant community, may be important for maintaining an appropriate habitat for fauna such as ground-nesting birds.

Lack of management, such as late summer cuts or absence of aftermath grazing will result in similar changes to each of the communities, such as colonisation by Arrhenatherum elatius and large umbellifers (e.g. *Heracleum sphondylium*).

6.4 Implications for Decision Making

6.4.1 Vulnerability

The MG5a sub-community is the most vulnerable of the three types discussed here. Any impedance of soil drainage in spring, or increase in nutrient availability, or interruption of traditional management could potentially result in a change in its composition and a change of community type may occur within a few years.

The other two communities are generally more robust with respect to potential threats. The MG7C community could potentially be transformed into an MG4 grassland if its drainage were slightly improved and its nutrient loading reduced. However, if drainage is further impeded and/or nutrient loading further increased, there would be a reduction in species richness and the community may approach in terms of its composition.

The MG9a sub-community is also quite robust, as its characteristic species *(Holcus lanatus* and *Deschampsia cespitosa)* have wide environmental tolerances. The latter can be very long-lived and show considerable inertia, so alterations in community type in the short term are unlikely, unless waterlogging increases markedly which would result in an MG13 inundation grassland or a swamp community as for MG7C above.

6.4.2 Restorability

Restoration of the MG7C and MG9a grasslands, though not documented, would be expected to be relatively straightforward. Both are grass dominated, their characteristic species come readily from seed and nutrient availabilities are not very exacting. The MG5a sub-community in contrast is known to be difficult to restore. The most commonly encountered problem is lowering the soil nutrient availability to an appropriate level. Documented attempts have met with partial success and results suggest restoration requires a long timescale. Species-rich communities such as this are thought to require a timescale of decades to assemble themselves. Recent evidence suggests a diverse soil microflora is an important factor in supporting a diverse plant community and this is difficult to establish artificially.

6.4.3 Gaps in Knowledge

The MG5a sub-community is a well-studied community, but more long-term studies are needed to inform restoration attempts. The MG7C and MG9a grasslands have not been as extensively studied as they have lesser conservation interest. An understanding of the impact of nutrient availability on the promotion of these two communities at the expense of more species-rich communities, such as MG4 or MG5 grasslands, would be valuable.

Part 3

Fen/Mire Community Guidelines

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7. M13 *(Schoenus nigricans - Juncus subnodulosus)* Mire

7.1 Context

Examples of the M13 community have been included within the 'Calcium-rich Spring Water Fed Fens' SAC interest feature. Some also fit the 'Chalk-rich Fen Dominated by Saw Sedge' SAC interest feature.

7.1.1 Floristic Composition

Schoenus nigricans and Juncus subnodulosus usually dominate, with a rich range of associated species (Rodwell (1991) gives the mean number of species per sample as 27, but with a wide range of 7–65). The community is particularly important in supporting several rare species, and other infrequent fen species, in some parts of lowland Britain.

Species which are particularly characteristic of M13, and which help separate it from other communities are listed in Table 7.1. The number of 'M13 Characteristic Species' recorded from a vegetation sample can be used to assess its 'goodness of fit' to M13 (the more, the better). The greater the number of M13 Characteristic species present, the greater the representation of rare and regionally rare species. Species characteristic of M13 are identified in Table 7.1.

Rodwell (1991) recognises three sub-communities of M13: *Festuca rubra-Juncus acutiflorus* sub-community (M13a:); *Briza media-Pinguicula vulgaris* sub-community (M13b); *Caltha palustris-Galium uliginosum* sub-community (M13c).

Table 7.1 Species That Are Particularly Characteristic of M13

Characteristic Species		
Anagallis tenella	*Drepanocladus lycopodioides*	*Pellia endiviifolia*
Aneura pinguis	*Drepanocladus revolvens (s.l.)*	*Philonotis calcarea*
Bryum pseudotriquetrum	*Drepanocladus vernicosus*	*Philonotis fontana*
Campylium elodes	*Drosera longifolia*	*Pinguicula vulgaris*
Campylium stellatum	*Eleocharis quinqueflora*	*Plagiomnium elatum*
Carex dioica	*Epipactis palustris*	*Plagiomnium ellipticum*
Carex hostiana	*Eriophorum latifolium*	*Potamogeton coloratus*
Carex pulicaris	*Euphrasia pseudokerneri*	*Preissia quadrata*
Carex viridula ssp brachyrrhyncha	*Fissidens adianthoides*	*Riccardia chamedryfolia*
Cladium mariscus	*Gymnadenia conopsea*	*Riccardia multifida*
Cratoneuron commutatum	*Listera ovata*	*Sagina nodosa*
Dactylorhiza incarnata	*Moerckia hibernica*	*Schoenus nigricans*
Dactylorhiza praetermissa	*Parnassia palustris*	*Scorpidium scorpioides*
Dactylorhiza traunsteineri	*Pedicularis palustris*	

7.1.2 Distribution

Eastern England and Ynys Môn (Anglesey) are the two main centres for this uncommon vegetation in Britain, with important outliers elsewhere (e.g. Cothill basin, Oxfordshire; North Yorkshire). The distribution of the community, taken from the FenBase database is shown in Figure 7.1.

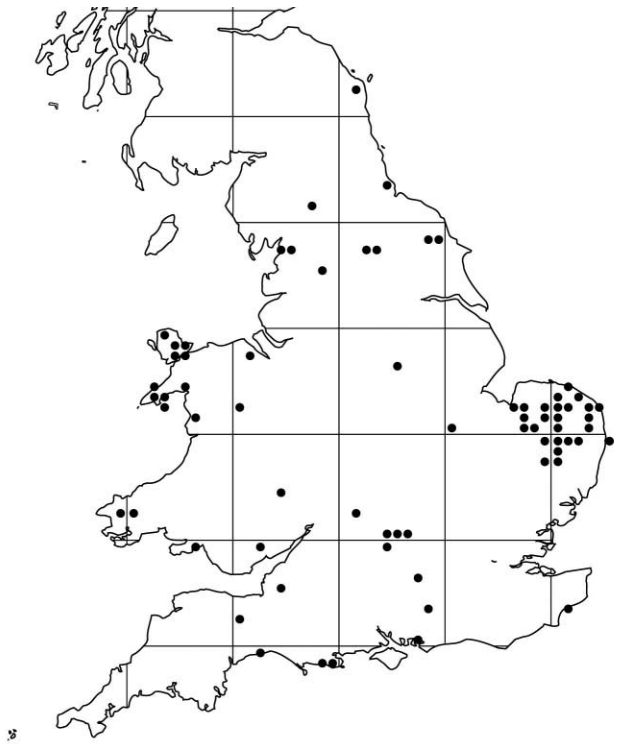


Figure 7.1 Distribution of M13 in England and Wales (from FenBASE database)

7.1.3 Landscape Situation and Topography

The majority of stands occur on sloping ground in valleyhead fens, mostly near the headwaters of small streams, or (occasionally) at floodplain margins.

7.1.4 Substratum

Substratum usually a shallow (<50 cm) organic deposit (sometimes virtually none). Most often overlying permeable sands and gravels or a sandy silt (a less permeable mineral substratum may occur in association with drier stands), but occasionally occurs directly upon the bedrock aquifer at outcrop.

7.2 Supply Mechanism and Conceptual Model

Strongly soligenous often with visibly obvious 'springs'. Fed by lateral or vertical groundwater discharge from a semi-confined or unconfined aquifer (principally chalk or limestone, but sometimes from calcareous drift), typically with a positive piezometric head in supporting aquifer. Some examples strongly artesian (piezometric head >1 m agl), but drier examples also occur, fed by intermittent see pages[8].

Wheeler & Shaw (2001) identified 'Wetmec' types 1, 2 and 5 as supporting M13, although the majority of samples were recorded from Permanent Seepages (Type 1). Types 1 and 2 are illustrated schematically in Figure 7.2: "Permanent Seepage Slope" (Type 1, e.g. Badley Moor (1a) Sutton Bog (1b), Gooderstone Fen (1b), Scarning Fen (1c)) and "Intermittent and shallow sub-surface seepages" (Type 2, e.g. Ducans Marsh (2a)).

7.3 Regimes

7.3.1 Water

Water conditions for M13 are difficult to specify quantitatively, partly due the lack of detailed time series data, but more importantly because different versions of the community are associated with rather different water regimes and because microtopography generates subtle but ecologically important differences in water regime within individual stands. Runnels, lawns and hummocks provide a complex of microhabitats that contributes greatly to the species diversity of high-grade stands. Consequently, **mean water table values have limited value, are potentially misleading and should be interpreted with caution.** Nonetheless, as a guide, mean recorded values for summer water-table associated with stands of M13 in East Anglia are given in Table 7.2 (from Wheeler & Shaw, 2001):

Table 7.2 Mean Summer Water Table for M13 Stands in East Anglia

Variable	N	Mean	ŶSD	Min	Max
Mean Summer Water Table (cm)	19	-9.55	12.4	-38.6	5.0

Specific time-series data for stands of M13 are not available for the majority of sites. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

[8] a seasonally negative piezometric head could result from groundwater abstraction but may also be a natural feature of some systems.

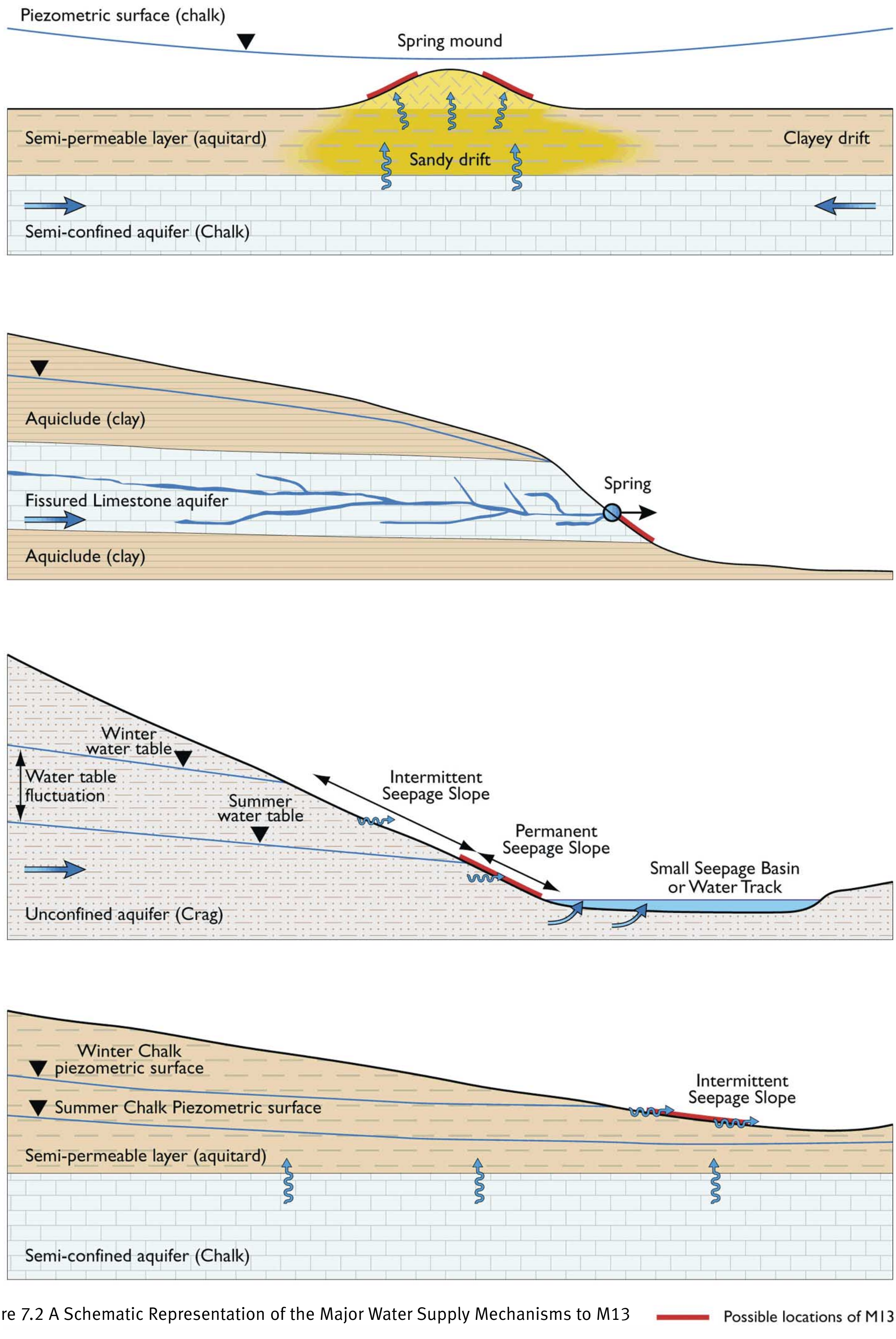


Figure 7.2 A Schematic Representation of the Major Water Supply Mechanisms to M13

Table 7.3 pH, Conductivity and Substratum Fertility Measured in Stands of M13 in Eastern England

Parameter	N	Mean	ŶSD	Min	Max
Soil pH	15	7.17	0.40	6.20	7.52
Water pH	24	6.94	0.45	6.17	8.00
Water Conductivity (µS cm^{-1})	16	648.50	153.82	322.00	834.00
Substratum Fertility((mg phytometer)	15	8.73	4.45	5.00	18.00

Optimal Water Levels

- Most examples of M13 are characterised by winter water tables at or very close to the fen surface (-5 to +1 cm). The richest examples (with ›20 Characteristic species) occur exclusively in locations that exhibit a water table generally at the fen surface in winter and summer. As a rough guide, 'good' examples of M13 mostly occur in sites with visible surface water (but not inundated) or where water oozes from the soil underfoot during the summer months of a 'normal' (non-drought) year. However, a seasonally subsurface water table may be the 'natural' condition of some (less rich) stands occupying intermittent seepages.
- 'Flushing' by groundwater discharge is a feature of most 'high grade' M13 sites. Slopes prevent surface accumulation of water except in small shallow pools that probably experience considerable water throughput.
- The normal range of winter water tables is probably of little importance, except when associated with inundation (see below).

Sub-Optimal or Damaging Water Levels

- Very wet sites (summer water table usually above-surface between tussocks) tend to be less species rich. However, whilst shallow pools and runnels are a natural feature, widespread inundation, particularly in the summer, is likely to be damaging.
- A seasonally subsurface water table may be the 'natural' condition of some (less rich) stands occupying intermittent seepages. It is often difficult to know to what extent 'summer-dry' stands are natural or represent remnants of formerly 'better', wetter M13.
- The highest quality stands do not usually occur at sites where summer water tables are consistently c. 10 cm below ground level (bgl) (often only mediocre or low grade stands (‹10 characteristic species)) are found. However, examples of the community can withstand, or recover from, periodic summer droughts (of at least 3 years duration) when water tables may be 30 cm bgl.
- A long-term reduction of the summer water table beneath high quality stands of M13, to the extent that water no longer oozes underfoot in a non-drought summer, can be expected to result in some loss of botanical interest.
- Summer water tables deeper than 30 cm bgl in non-drought years are associated with particularly 'low grade' stands of M13. In this context, a further reduction in WT is likely to have little impact. This may be the natural condition of some stands or may represent remnants of formerly 'better', wetter M13.

A detailed discussion of the relationships between hydrological conditions and floristic variation within M13 stands can be found in Wheeler & Shaw (2001).

7.3.2 Nutrients/Hydrochemistry

'Flushing' by groundwater discharge is a feature of most 'high grade' M13 sites, but slopes prevent surface accumulation of water except in small shallow pools that probably experience considerable water throughput. Stagnant, strongly reducing conditions have not been encountered even in the wettest examples of the community.

Irrigating waters are typically base rich/high pH and often supersaturated with $CaCO_3$. Substratum is usually base rich as implied by calcite precipitation, which is generally visible, sometimes forming tufaceous concretions (e.g. Badley Moor). Occurrence of ochre is very rare, and usually indicative of water contribution from a drift aquifer. Wheeler & Shaw (1991) report a mean increment (April - September) in dry weight of above ground standing crop of 200 g dry wt m^{-2}. This low productivity reflects the typically low fertility of the substratum.

Table 7.3 presents figures for pH, conductivity and substratum fertility measured in stands of M13 in Eastern England taken from Wheeler & Shaw (2001).

The irrigating waters are typically oligotrophic and P limited (in some cases due to adsorption of P onto calcite particles). SRP concentrations are often below detection limits but concentrations of N are very variable with values in excess of 30 mg l^{-1} NO_3-N in some seepage waters. There is some evidence that,

Table 7.4 Mean Ion Data for Interstitial Water Samples

Limits	pH	Ca^{2+}	Mg^{2+}	K^+	HCO_3^-	SRP	NH_4^+	NO_3^-	SO_4^{2-}
Lower	7.0	97.0	3.0	1.4	285.0	5.0 $\times 10^{-3}$	0.13	0.85	17.0
Upper	7.4	146.0	38.0	3.0	406.0	27.0 $\times 10^{-3}$	0.32	32	73.0

although still oligotrophic, the richest stands are not the most infertile (i.e. very mild enrichment, such as may be associated with natural seral eutrophication or very limited cultural activity, may enhance diversity).

Table 7.4 presents mean ion data for interstitial water samples for a limited selection of sites recorded by Boyer & Wheeler (1989).

All figures (apart from pH) are in mean concentration mg l-1.

7.3.3 Management

The most species-rich examples of M13 are managed, generally by occasional burning, summer mowing or light episodic grazing. Lack of management, or overgrazing, may be detrimental to species diversity, although the effect may depend on the substratum fertility and water table. Management is least important in low fertility, summer-wet stands.

7.4 Implications for Decision Making

7.4.1 Vulnerability

Figure 7.3 indicates the possible floristic impact of changes to the stand environment. However, it should be noted that the concept of 'vulnerability' is complex and is dependent upon the starting conditions (including floristic composition), sensitivity of the stand and the sensitivity of the site to the pressure of change. For example, a wet, species-rich stand of M13 would be particularly sensitive to a fall in summer water table. However, if water supply to such stands is supported by a strong piezometric pressure, the impact of abstraction on water levels may be negligible. In such a context, the stand could be regarded as *sensitive* to change but not necessarily *vulnerable*. For this reason, **accurate assessment of vulnerability is likely to always require careful site-specific investigations.**

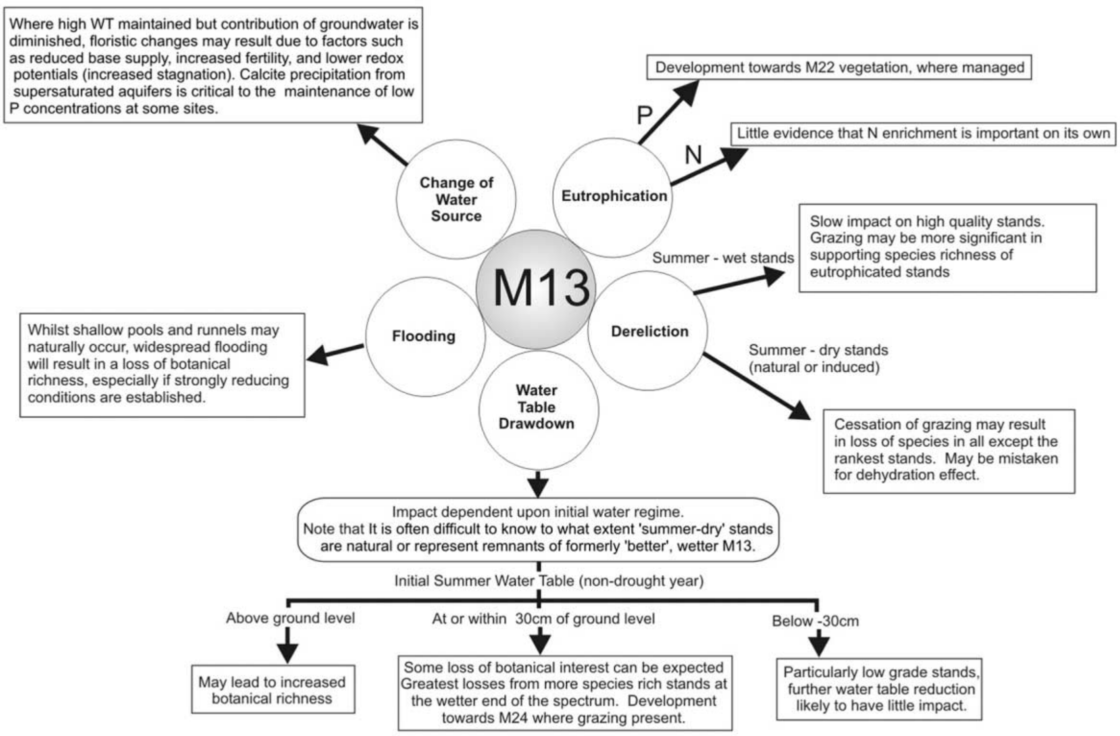


Figure 7.3 The Possible Effects of Environmental Change on Stands of M13

7.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (e.g. numbers of species lost, damage to substratum, degree of enrichment etc). There is limited information available that specifically relates to restoration of M13 stands, but the following observations can be made.

- Vegetation management may increase the representation of certain 'M13 species' in drier stands;
- Scrub removal and re-instatement of vegetation management may help to restore M13 vegetation that has been left unmanaged for a while, provided that other conditions have not changed irreversibly;
- The potential for restoring high grade stands on dehydrated sites through the reestablishment of groundwater supply is unknown. However, it is known that in a few situations M13-like vegetation has developed spontaneously in appropriate, newly-created habitats proximate to a source of appropriate species (e.g. Dry Sandford Pit, Cothill);
- Attempts to increase the wetness of examples of M13 by blocking outflows could be detrimental to the vegetation if they result in the establishment of strongly reducing conditions.

7.4.3 Limitations of These Guidelines and Gaps in Knowledge

The limitations of the information presented here related to M13 include the following.

- The information used is largely based on that synthesised by Wheeler & Shaw (2001) - itself primarily based on knowledge of wetland sites supporting M13 in eastern England, and other information held within the FenBASE database (see Introduction). It is proposed that an updated account, including data from other parts of the UK, should be prepared in 2004;
- There are currently virtually no data to better inform the temporal water table characteristics of M13 stands. Time series of dipwell measurements are required to fill this gap;
- In order to make predictions with respect to the vulnerability of M13 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at 'representative' sites;
- Data on the spatial extent of M13 are lacking;
- Possible differences in environmental conditions influencing the three sub-communities have not been explored here.

8. M24 *(Molinia caerulea - Cirsium dissectum)* Fen Meadow

8.1 Context

Examples of the M24 community have been included within the *'Molinia* Meadows on Calcareous, Peaty or Clayey-silt-laden Soils' and 'Chalk-rich Fen Dominated by Saw Sedge' SAC features. The community can be found in fens and wet grasslands.

8.1.1 Floristic Composition

The M24 community typically comprises much *Molinia caerulea* and *Cirsium dissectum* with a range of other forbs. The vegetation can be fairly species-rich and supports a few rare species. However, the species complement varies very considerably (NVC: mean = 26, range = 9–52 spp per sample (Rodwell, 1995)), and the community is not particularly distinctive in terms of species composition. With the exception of the rare *Selinum carvifolia,* which is primarily associated with this community, all of the typical M24 species also occur in M13, though often at reduced frequency and constancy compared to M13. A number of 'M13 Characteristic Species' (Table 8.1) also occur in M24. Wetter stands contain most mire species and M13 Characteristic species, though there is no comparable increase in the number of rare species.

Rodwell (1991) recognises three sub-communities of M24: *Eupatorium cannabinum* subcommunity (M24a); Typical sub-community (M24b), *Juncus acutiflorus-Erica tetralix* subcommunity (M24c).

8.1.2 Distribution

The community primarily occurs in the warmer parts of Britain. It is widespread in Eastern England but occurs at scattered and infrequent locations (Figure 8.1). The community is much more widespread in parts of southwest England and Wales, but often with a different species composition to the eastern examples.

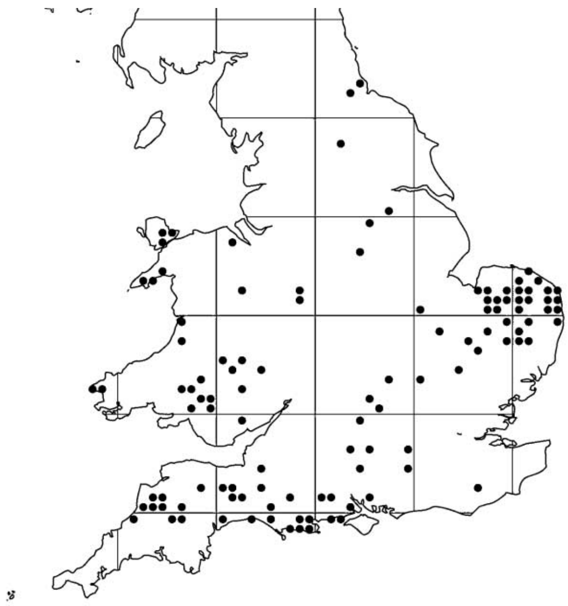


Figure 8.1 Distribution of M24 in England and Wales (from FenBASE database)

Table 8.1 Species That Are Particularly Characteristic of M13

Characteristic Species		
Anagallis tenella	*Drepanocladus lycopodioides*	*Pellia endiviifolia*
Aneura pinguis	*Drepanocladus revolvens (s.l.)*	*Philonotis calcarea*
Bryum pseudotriquetrum	*Drepanocladus vernicosus*	*Philonotis fontana*
Campylium elodes	*Drosera longifolia*	*Pinguicula vulgaris*
Campylium stellatum	*Eleocharis quinqueflora*	*Plagiomnium elatum*
Carex dioica	*Epipactis palustris*	*Plagiomnium ellipticum*
Carex hostiana	*Eriophorum latifolium*	*Potamogeton coloratus*
Carex pulicaris	*Euphrasia pseudokerneri*	*Preissia quadrata*
Carex viridula ssp brachyrrhyncha	*Fissidens adianthoides*	*Riccardia chamedryfolia*
Cladium mariscus	*Gymnadenia conopsea*	*Riccardia multifida*
Cratoneuron commutatum	*Listera ovata*	*Sagina nodosa*
Dactylorhiza incarnata	*Moerckia hibernica*	*Schoenus nigricans*
Dactylorhiza praetermissa	*Parnassia palustris*	*Scorpidium scorpioide*
Dactylorhiza traunsteineri	*Pedicularis palustris*	

8.1.3 Landscape Situation and Topography

The majority of stands in eastern England are associated with valleyhead wetlands, where they usually occupy a zone between wetter fen communities and drier grassland and heath.

Examples in undrained floodplain wetlands often occupy a narrow, marginal zone alongside the main stands of fen vegetation.

Some of the most extensive examples of the community are found in partly drained sites, particularly on rather flat valleyhead fens and in some floodplain fens. In part-drained situations the community has usually replaced a wetter fen vegetation type (which may include M13).

8.1.4 Substratum

M24 is most often found over organic or strongly humic soils (Rodwell, 1991). Where M24 is located at the margins of fens the community is usually underlain by a relatively shallow (less than 50 cm) depth of organic soil and peat. The community can be found on deeper peat in locations with impeded drainage, for example, in groundwater-fed basins (e.g. Banham Great Fen) or on floodplains (e.g. Woodwalton Fen).

8.2 Water Supply Mechanisms

A number of water supply mechanisms can support the M24 community. The main source of water to the substratum supporting this vegetation is usually primarily groundwater in valleyhead sites (notably through intermittent seepages) and surface water in the floodplains, though some floodplain examples may also receive groundwater seepage inputs, either directly or distributed through the surface water system. The occurrence of narrow zones of M24 along the rising margins of floodplain fens is sometimes attributed to groundwater seepage although this should not be assumed.

Wheeler & Shaw (2001) identified several different 'Wetmecs' as supporting M24. The main types are illustrated schematically in Figure 8.2: "Intermittent and shallow sub-surface seepages" (Type 2, e.g. Royden Fen, Foulden Common), "Summer 'Dry' Percolating wetlands" (Type 5, e.g. Limpenhoe Meadow, Poplar Farm Meadow), "Summer 'Dry' Floodplains" (Type 7, e.g. Wicken, Woodwalton and much of Broadland).

8.3 Regimes

8.3.1 Water

Mean recorded values for summer water-table associated with 'fenny' stands of M24 in East Anglia are given by Wheeler & Shaw (2001) and presented in Table 8.2 below.

Table 8.2 Mean Summer Water Table for M24 Stands in East Anglia

Variable	N	Mean	ŶSD	Min	Max
Mean Summer Water Table (cm)	10	-24.85	17.15	-53.33	-10.00

The M24 community characteristically occurs on sites with subsurface water tables, at least during summer. Some stands occupy areas with intermittent seepage, with winter water levels at or near the surface, but in others the water table is permanently subsurface. Sites with relatively high summer water tables tend to show the greatest affinity towards M13.

Specific time-series data for stands of M24 are not available for the majority of sites. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal Water Levels

- M24 may occupy a broad band of subsurface summer water tables. Sites with a relatively high summer water tables tend to show the greatest affinity towards M13. Winter water tables may be more or less at the surface in some sites;
- A relatively deep subsurface water table may be a perfectly natural feature of some sites. It is often difficult to know to what extent relatively dry stands are natural or represent remnants of formerly wetter M24;
- M24 is not normally associated with inundation, except to a very minor degree in the winter at particularly wet sites.

Suboptimal or Damaging Water Levels

- A summer water table at or near the surface is likely to generate vegetation closer to M13 than M24;
- Prolonged inundation in winter or summer is likely to lead to species losses;
- Strongly subsurface winter and summer water tables are probably outside of the normal range of this community. Precise tolerances are not known but it can be speculated that this will lead to a loss of wetland interest and increased representation by 'dryland' species;

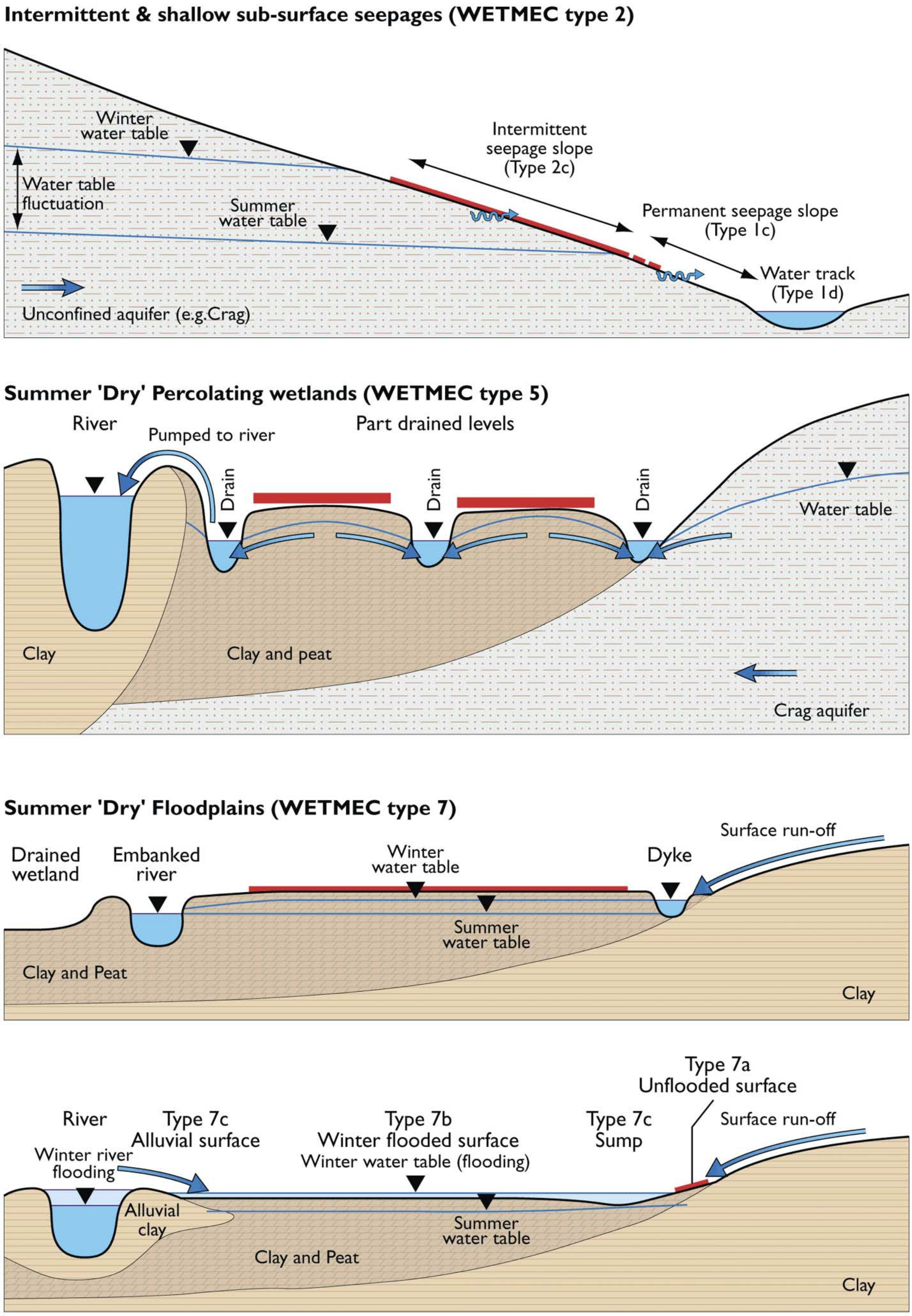


Figure 8.2 A Schematic Representation of the Major Water Supply Mechanisms to M24

Possible locations of M24

- The potential for restoring M24 through rewetting of strongly dehydrated sites is largely untested.

8.3.2 Nutrients/Hydrochemistry
pH values of soils supporting M24 are rather variable, ranging from mildly acidic to base rich. The fertility of the soils is also variable, ranging from oligotrophic to mesotrophic. Deeper peats of drained floodplains tend to provide a relatively more acidic and more fertile substratum than the shallower peats at the fen margins.

Wheeler & Shaw (2001) give the following figures for pH, conductivity and substratum fertility, measured in stands of M24 in eastern England. These are presented in Table 8.3 below.

8.3.3 Management
M24 appears to be primarily a secondary vegetation-type, with no 'natural' analogues. In all sites maintenance of this vegetation-type depends upon some form of management - either mowing or grazing. The community can establish following woodland clearance and/or fen drainage on sites with a tradition of annual grazing and/or mowing for 'litter'.

8.4 Implications for Decision Making

8.4.1 Vulnerability
M24 is particularly vulnerable to reduction in water-table, flooding and dereliction. The probable impact of changes to the stand environment related to these three factors are identified in Figure 8.3.

For relatively wet examples of M24, a reduction in water table will result in the loss of some mire species and 'M13 characteristic' species. If the conservation objective is preservation of characteristic M13 species then this may be considered undesirable. However, if the objective is the protection of the M24 community then such losses are arguably less important. Conservation objectives for M24 are clearly important in this context and the assessment of their relative importance needs to be made on a site-by-site basis.

It is important to note that M24 stands are generally associated with relatively low summer water tables, and attempts to make them wetter may have unexpected and undesired effects. For example, there is some evidence that high dyke water levels at Chippenham Fen (Cambridgeshire) have resulted in an increase in *Agrostis stolonifera* in the vicinity of some dykes. Likewise, it seems quite likely that the speciality of Chippenham Fen, *Selinum carvifolia,* which is found in M24 in continental Europe, may be adversely affected by water table increase.

Strongly subsurface winter and summer water tables are probably outside of the normal range of this community. Precise tolerances are not known but it can be speculated that lowering water levels would lead to a loss of wetland interest and increased representation by 'dryland' species.

Dereliction of traditional vegetation management practices is likely to lead to development of a tall rank and botanically impoverished sward. Such trends may sometimes be mistaken for evidence of dehydration (and/or enrichment). Derelict stands will be prone to scrub invasion and woodland succession. Species typical of M24 e.g. *Cirsium dissectum* are not woodland species and are likely to be intolerant of closed canopy shading.

8.4.2 Restorability
Reinstatement of a regular vegetation management regime can be expected to improve stand quality. Whilst vegetation management is likely to be the most critical factor, a degree of rewetting may be required in severely drained situations in order to generate appropriate water conditions (though such measures are untested with respect to M24 restoration).

As with all restoration measures, the likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (e.g. numbers of species lost, damage to substratum, degree of enrichment etc).

Table 8.3 pH, Conductivity and Substratum Fertility Measured in Stands of M24 in Eastern England

Variable	N	Mean	ŶSD	Min	Max
Water pH	6	6.55	0.69	5.25	7.30
Water Conductivity (µS cm-1)	5	646	131	413	731
Soil pH	9	6.31	0.84	5.40	7.42
Soil Fertility[9] (mg phytometer)	9	10.33	7.33	5.00	22.00

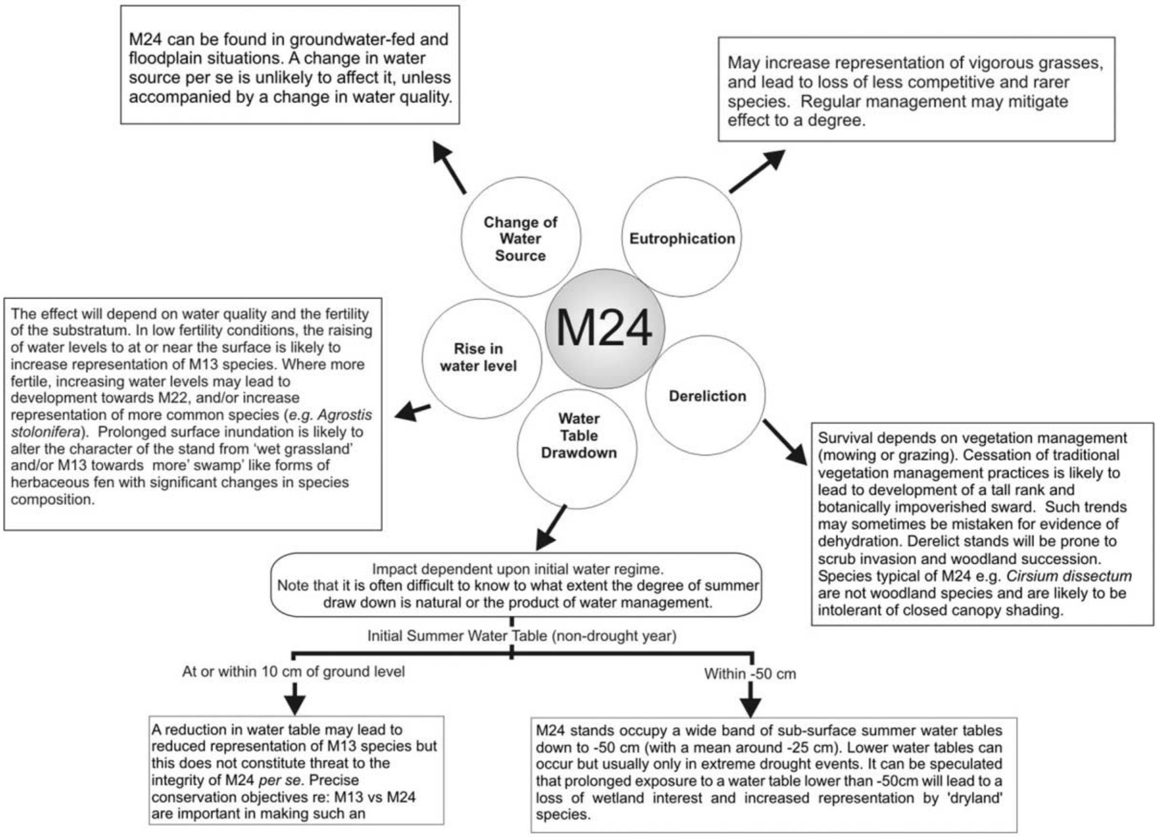


Figure 8.3 The Possible Effects of Environmental Change on Stands of M24

8.3.3 Limitations of These Guidelines and Gaps in Knowledge

The limitations of the information presented here related to M24 are as follows:

- The information presented here is largely based on that synthesised by Wheeler & Shaw (2001) - itself primarily based on knowledge of wetland sites supporting M24 in eastern England, and other information held within the FenBASE database. No attempt has been made to collate/examine environmental information relating to this vegetation-type from sites supporting 'drier' examples, or from western examples (e.g. culm grasslands in the south-west and Rhôs pastures in Wales);
- There are currently virtually no data to better inform the temporal water table characteristics of M24 stands. Time series of dipwell measurements are required to fill this gap;
- In order to make predictions with respect to the vulnerability of M24 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at 'representative' sites;
- A better understanding is needed as to the water regime tolerances of M24. As it is often associated with sub-surface water tables, soil properties and precipitation inputs may be more critical in many instances, than the position of the groundwater table;
- Data on the spatial extent of M24 are lacking;
- Possible differences in environmental conditions influencing the three sub-communities have not been explored.

9 Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of Phytometry (measuring the biomass of test species (Phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); Low fertility = ‹8 mg, High fertility›18mg.

9. S2 *(Cladium mariscus)* Swamp

9.1 Context

Examples of the S2 community have been included within the 'Chalk-rich Fen Dominated by Saw Sedge' SAC feature.

9.1.1 Floristic Composition

A tall sedge community of wet fens and swamps characterised by the dominance of *Cladium mariscus*. The community is typically species-poor (NVC: mean = 7, range = 1–12 spp per sample (Rodwell, 1995)), and supports few uncommon species. The absence of species found in drier fens and the occurrence of species of shallow water and swamp *(e.g. Sparganium minimum)* help provide positive characterisation. [Note that *Cladium mariscus* swamp (S2) and *Carex elata* swamp (S1) are not clearly distinguishable from each other, because of the intergradation of dominance of the two defining species, both in the field and between the abstract units.]

Rodwell (1995) recognises two sub-communities of S2: *Cladium mariscus* sub-community (S2a); *Menyanthes trifoliata* sub-community (S2b).

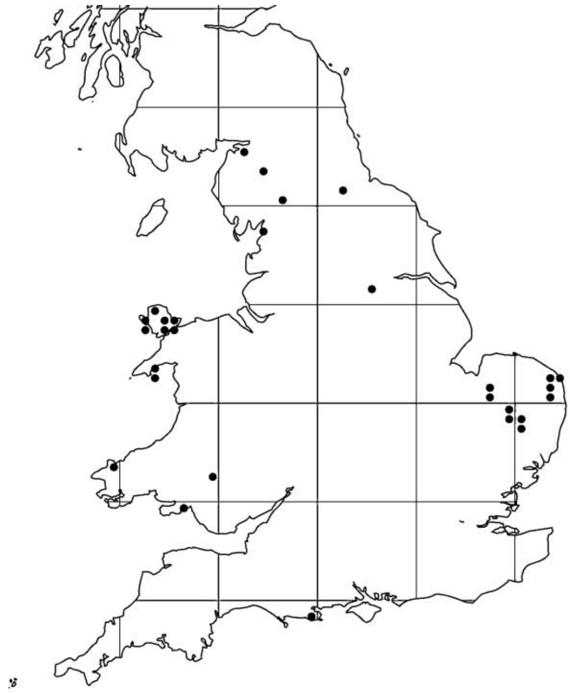


Figure 9.1 Distribution of S2 in England and Wales (from FenBASE database)

9.1.2 Distribution

Eastern England provides most of the British localities for this community (Figure 9.1).

S2 is especially characteristic of many of the wet ground hollows in central and western Norfolk, and can also occur in overgrown ditches and reflooded peat pits (in particular it is an important recolonist species of some reflooded turf ponds in Broadland). Outside of eastern England it is very infrequent, but Ynys Môn (Anglesey) provides an important centre for S2 and it is also found around pools in the West Midlands, NW England, Yorkshire and parts of Scotland (particularly in the west).

9.1.3 Landscape Situation and Topography

Most of the examples in valleyhead situations are in shallow ground hollows, some of which may be pingos or other ground ice depressions, whilst the floodplain examples are all in reflooded peat workings, mostly in turf ponds but also around the margins of a few Broads. Examples may occur in occluded ditches.

9.1.4 Substratum

The community may form semi-floating root-mats but most examples are rooted in fen peat or in muddy basin and dyke sediments.

9.2 Supply Mechanism and Conceptual Model

In the valleyhead fens, stands of S2 are primarily groundwater fed. Examples forming part of the swamp fringe around Barnby, Martham and Upton Broads also appear to receive groundwater inputs, at least in part, but some turf pond examples in Broadland appear to be primarily fed by surface water.

All of the ground depressions in the valleyhead sites are situated upon a chalk bedrock, and for most sites the chalk aquifer is considered to be unconfined - though in some sites upward flow from the chalk may be retarded by putty chalk and perhaps by silty layers in the drift, which can result in (temporarily) perched conditions in wet periods. Most of the S2 depressions do not appear to be associated with strong springs, but their wetness seems to be determined by the intersection of the topography with the water table (there is lack of visible evidence for springs or for Ŷ permanent, or even any, outflow streams). However, the source of the groundwater supply to the ground depressions in the valleyhead fens (i.e. chalk water versus drift) is not well understood and may vary within individual sites.

Wheeler & Shaw (2001) identified 'Wetmecs' 3, 4, and 6 as supporting S2. These are illustrated

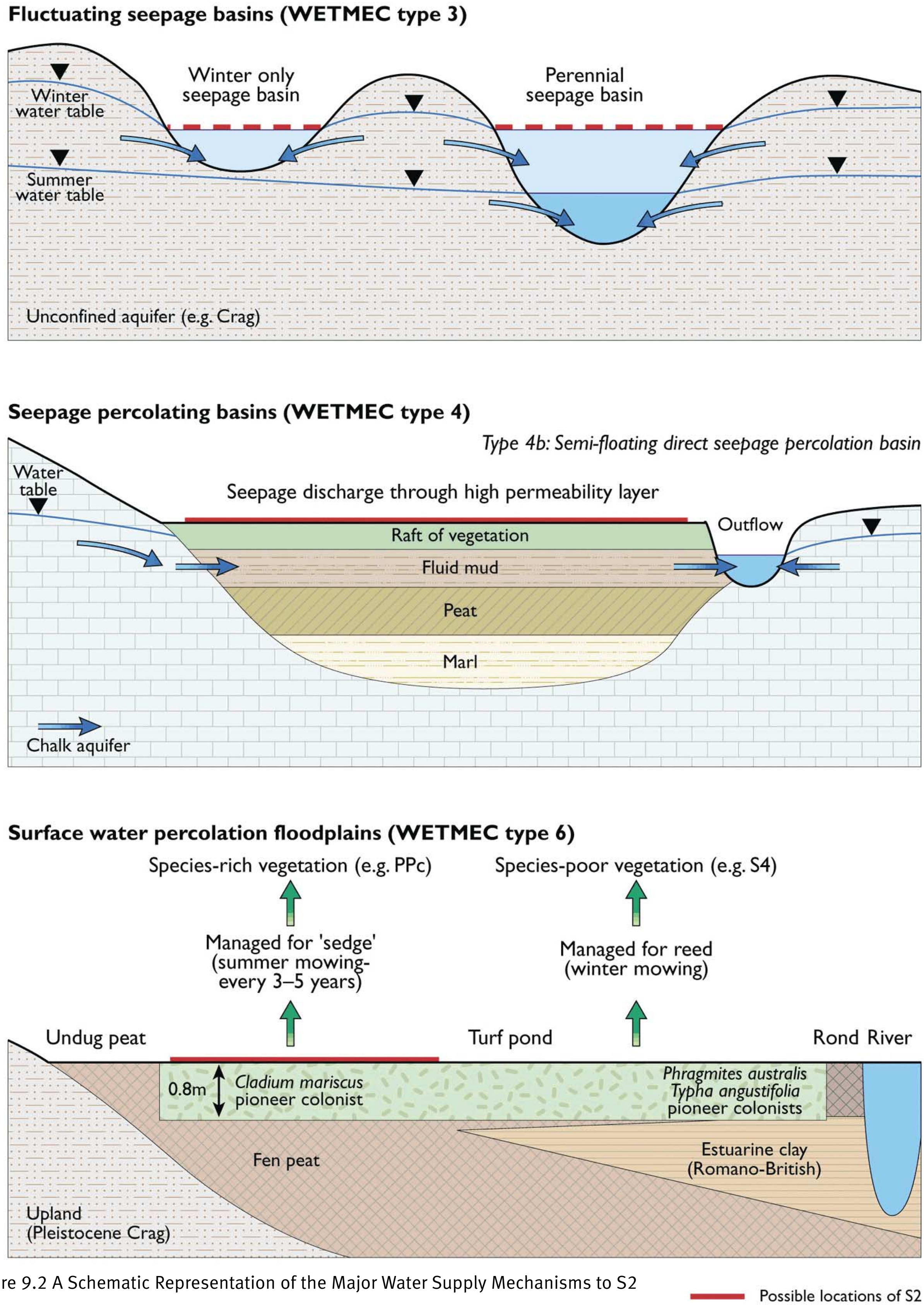


Figure 9.2 A Schematic Representation of the Major Water Supply Mechanisms to S2

schematically in Figure 9.2: Fluctuating Seepage Basins (Type 3 - e.g. Foulden Common); "Seepage percolation basins (Type 4 - e.g. East Walton Common); "Surface Water Percolation Floodplains" (Type 6 - e.g. Catfield Fen).

9.3 Regimes

9.3.1 Water

Water levels associated with S2 are well above the surface for some, sometimes all, of the year. In a few cases the vegetation is semi-floating, but most examples are rooted to (often soft) underlying muds and, in the case of some of the deeper hollows, the outer edge of the community appears to be depth limited and grades into open water.

In some valleyhead fens, gauge board readings point to water level fluctuations in some ponds of up to about 2 m, indicating periodic deep flooding or subsurface water tables (or both). Although good comparative data do not exist, there is strong reason to suspect that the development of aquatic macrophytes (e.g. *Hydrocharis morsus-ranae, Sparganium minimum)* in association with S2 is related to the degree to which they 'dry out'. [The impact of water level fluctuation does, of course, depend upon the position of the water table relative to the surface. For example, whilst the water table remains above the surface, even quite substantial changes in level (e.g. 50 cm) may have only limited impact upon the vegetation provided they remain within the depth tolerances of the main species. However, a comparable reduction of water level below the surface can have much greater repercussions, especially on the survival of aquatic species.]

Examples of the S2 community can occupy a quite wide range of conditions, from wet 'swamp' to relatively dry sedge beds. In addition, specific time-series data for stands of S2 are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal Conditions

- Water levels associated with S2 are typically well above the surface for some, sometimes all, of the year. *Cladium* apparently grows best when the water table remains between c. 15 cm below ground and 40 cm above, and standing water in winter may help to protect the growing point from frost damage (Conway (1942) - see Rodwell, 1995).
- S2 stands associated with water tables at or above the fen surface all year round are likely to support greater numbers of aquatic macrophytes.
- Where the vegetation is semi-floating, there is greater accommodation of water level fluctuation than when it is rooted to a solid substratum.

Sub-Optimal and Damaging Conditions

- *Cladium* seems to be limited by water depth. Protracted subsurface water tables or inundation ›c. 40–50 cm may lead to a loss of *Cladium* vigour.
- Where the vegetation is semi-floating, ongoing hydroseral processes may lead to development of *Peucedano-Phragmitetum caricetosum* (PPc), with an increase in species diversity. [This may not be considered 'damaging'.]
- Deep inundation will result in loss of sedge cover and generation of open water.
- Populations of aquatic macrophytes will be absent from stands that are summer dry for protracted periods.
- Subsurface winter water tables and strongly subsurface summer water tables will lead to a loss of *Cladium* and increased representation by 'dryland' species.
- Peat drying and degradation may lead to development of rank fen, rapidly becoming wooded without management.

9.3.2 Nutrients/Hydrochemistry

Typically base rich and oligotrophic to mesotrophic. Surface water from a stand of S2 at Foulden Common yielded a pH of 7.75 and EC 834 (µS cm^{-1}). Wheeler and Shaw (2000) report a mean EC of 284 µS cm^{-1} (Ŷ 3.4) and relatively low mean substratum fertility[10] of 8.5 mg phytometer (Ŷ 1.2) for S2 stands in East Anglia.

Wheeler & Shaw (1991) report that Cladium dominated stands have a high April standing crop (›250 g m-2) compared with other tall herbaceous fen types but a surprisingly modest April September standing crop increment (at around 600 g m^{-2}). This reflects the winter-green, long-lived character of *Cladium* foliage, and the relatively low fertility conditions.

9.3.3 Management

S2 tends not to receive any specific management except where it occurs alongside or within S24 and PPC communities traditionally mown for sedge and reed. Timing of management, if it occurs, is critical - winter floods can significantly inhibit re-growth if *Cladium* is mown too late in the year and cut stems are subsequently submerged. Where relatively dry, repeated summer cutting may result in development towards mixed sedge/litter fen or fen meadow, (e.g. S24, S25, M24).

9.4 Implications for Decision Making

9.4.1 Vulnerability

Figure 9.3 outlines some of the possible impacts of changes to the stand environment. The principal vulnerabilities are probably to water level change - either drawdown or flooding - and eutrophication. Many stands are unmanaged, but the dereliction of wider vegetation management practices may result in some stands of S2 becoming rank with litter accumulation. Eutrophication without drying, may lead to invasion by *Typha* and *Phragmites,* whilst peat drying and degradation may lead to loss of certain 'wetter' vegetation components e.g. aquatic macrophytes (where they occur), followed by development of rank fen, rapidly becoming wooded without management.

9.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (e.g. numbers of species lost, damage to substratum, degree of enrichment etc). The potential for restoring stands of S2 to dehydrated or derelict sites is largely untested (most pertinent fen restoration trials are at a relatively early phase), though the propensity for Cladium swamp to spontaneously colonise re-flooded turf ponds in the past is encouraging.

9.4.3 Limitations of These Guidelines and Gaps in Knowledge

The limitations of the information presented here related to S2 include the following:

- The information presented here is largely based on that synthesised by Wheeler & Shaw (2001) - itself primarily based on knowledge of wetland sites supporting S2 in eastern England, and other information held within the FenBASE database (see Introduction). It is proposed that an updated account, including data from other parts of the UK, should be prepared in 2004;
- There are currently virtually no data to better inform the temporal water table characteristics of S2 stands. Time series of dipwell (or gaugeboard) measurements are required to fill this gap;
- In order to make predictions with respect to the vulnerability of S2 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at 'representative' sites;
- The potential for restoring stands of S2 to dehydrated or derelict sites is largely untested;
- Data on the spatial extent of S2 are lacking;
- Possible differences in environmental conditions influencing the two sub-communities have not been explored here.

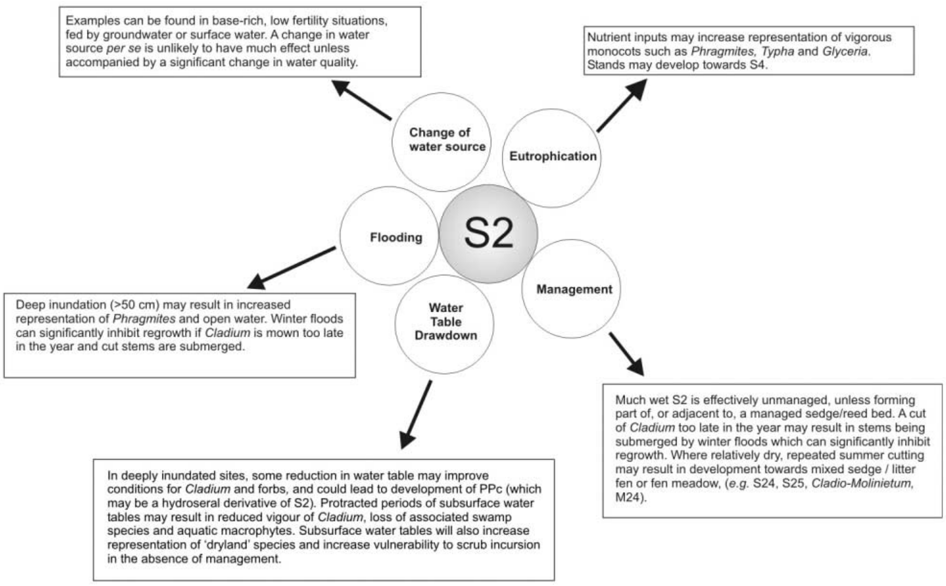


Figure 9.3 The Possible Effects of Environmental Change on Stands of S2

10 Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of Phytometry (measuring the biomass of test species (Phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); Low fertility = ‹8 mg, High fertility›18 mg.

10.S24 (Phragmites australis-Peucedanum palustre) Tall-herb Fen

10.1 Context

Examples of the S24 community have been included within the 'Chalk-rich Fen Dominated by Saw Sedge' (Ref H6410) SAC feature (although note that not all stands of S24 necessarily support *Cladium mariscus*).

10.1.1 Floristic Composition

Tall herbaceous fen community with monocotyledons, notably *Phragmites australis* and *Cladium mariscus,* providing the major structural component. Variable in composition (NVC: range = 14–39 spp per sample (Rodwell, 1995)) with a wide range of associated tall forbs e.g. *Lysimachia vulgaris, Eupatorium cannabinum* and *Filipendula ulmaria*. The community is given cohesiveness by the recurrence of such species as *Calamagrostis canescens, Carex elata, Peucedanum palustre* and *Thelypteris palustris*. The community supports several rare species, and other infrequent fen species. It is the main community supporting *Peucedanum palustre,* the food plant of the rare swallow-tail butterfly.

Rodwell (1995) recognises six sub-communities of S24: *Carex paniculata* sub-community (S24a); *Glyceria maxima* sub-community (S24b); *Symphytum officinalis* (S24c); typical subcommunity (S24d); *Cicuta virosa* sub-community (S24e), *Schoenus nigricans* sub-community (S24f).

10.1.2 Distribution

The S24 community is very localised and primarily based in Broadland (where it is widespread and quite extensive), with outliers in a few other East Anglian sites (such as Cranberry Rough and Swangey Fen). It also occurs at Wicken Fen, though in a form which is close to M24, and impoverished examples can be found at Woodwalton Fen. The community occurs fragmentarily in the Somerset Levels and rather similar species assemblages occur in various other places (e.g. Crymlyn Bog, Wales) though their taxonomic relationship to S24 remains to be clarified.

The distribution of the community is shown in Figure 10.1.

10.1.3 Landscape Situation and Topography

The majority of examples occur in floodplain situations - they form the main herbaceous vegetation over much of the Broadland fens. Some variants occur in basin and valley head situations.

10.1.4 Substratum

S24 usually occurs on solid fen peat or else on a semi-floating turf pond infill over fen peat.

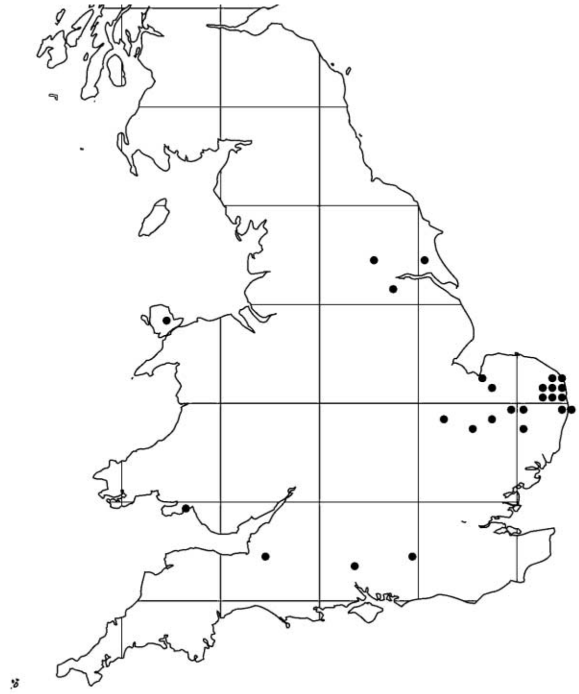


Figure 10.1 Distribution of S24 in England and Wales (from FenBASE database)

10.2 Supply Mechanism and Conceptual Model

The majority of stands of S24 appear to be surface-water fed, primarily through periodic river flooding. However, the community also occurs where similar conditions are created by groundwater inputs (e.g. East Ruston Common and Upton Fen). In some other cases (e.g. Sutton Broad, Swangey Fen) some groundwater contribution is suspected but is not known. In some sites (e.g. Wicken Fen) the surface of the peat appears now to be fed just by precipitation, creating the paradox of an 'ombrotrophic fen' in which the base-rich peat can be prone to surface acidification.

Wheeler & Shaw (2001) identified 'Wetmecs' 4, 5, 6 and 7 as supporting S24. The two main types are illustrated schematically in Figure 10.2: "Surface Water Percolation Floodplains" (Type 6, e.g. Sutton Broad (6a), Catfield Fen (6b), Cranberry Rough (6d)) and "Summer 'dry' Floodplains" (Type 7, e.g. Wheatfen, Strumpshaw, Catfield Fen).

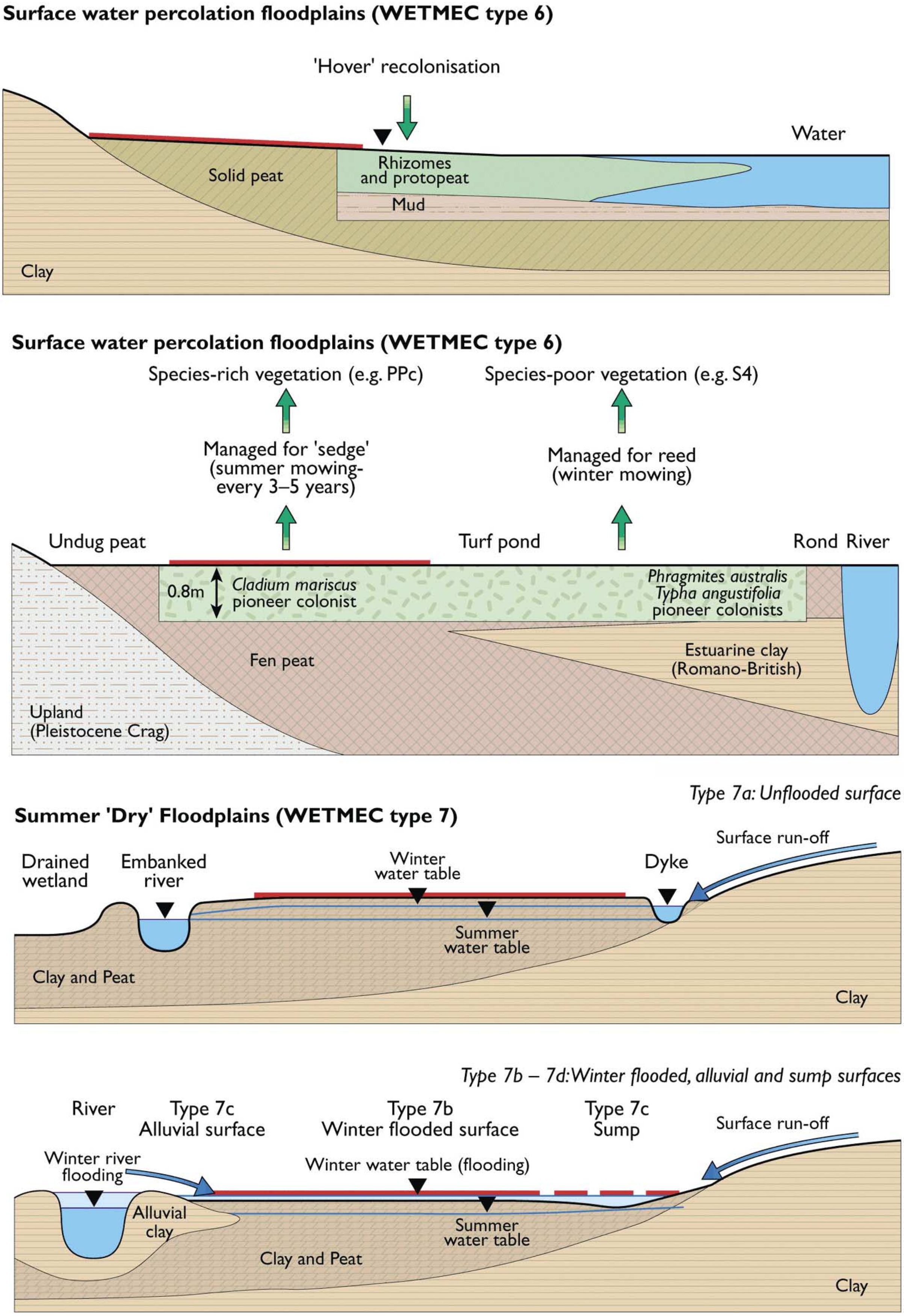


Figure 10.2 A Schematic Representation of the Major Water Supply Mechanisms to S24

Possible locations of S24

10.3 Regimes

10.3.1 Water

S24 is a highly variable vegetation type and it can be difficult to untangle the significance of water regime to vegetation composition from the influence of other factors such as management and substratum fertility. Mean values for summer water table measured in stands of S24 in eastern England (Wheeler & Shaw, 2001) are given in Table 10.1.

Table 10.1 Mean Summer Water Table for S24 Stands in East Anglia

Variable	N	Mean	ŶSD	Min	Max
Mean Summer Water Table (cm)	30	-16.70	20.11	-78.40	+3.80

It is also clear that different sub-communities tend to be associated with rather different sets of conditions (See Table 10.2).

Those sub-communities particularly associated with 'solid' peat tend to have the lowest mean summer water tables. Considering all stands of S24, the mean summer water table associated with examples in reflooded peat workings was -9.1 cm, whilst that of examples on 'solid' peat was -23.3 cm. The low water tables associated with 'solid' peat may reflect constraints of recharge from surface water during the main growing period.

Specific time-series data for stands of S24 are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal Water Levels

- The summer water level is typically around 15 cm bgl. However, relatively deep subsurface water table in the summer may be a perfectly natural feature of some sites. It is often difficult to know to what extent 'summer-dry' stands are natural or represent remnants of formerly wetter S24;
- The sub-community most often associated with a water table at or near the surface all year round (S24e) on average supports the greatest number of rare species (see table above). These tend to occur on semi-floating rafts on infilled turf pond. However, stands of the 'drier' sub-communities may still support a good number of rare species where soil fertility is relatively low and the vegetation is properly managed;
- Winter inundation is a natural feature of many S24 stands. The normal range of winter water tables is probably of little importance, except when associated with prolonged spring inundation, which may reduce species diversity.

Suboptimal or Damaging Water Levels

- Strongly subsurface winter and summer water tables are outside of the normal range of this community. It can be speculated that this will lead to a loss of wetland species and increased representation by 'dryland' species. Peat drying and degradation would lead to development of rank fen rapidly becoming wooded without management;
- Very wet sites with widespread summer inundation are likely to be less species rich than those where the summer water table is sub-surface;
- Winter inundation is a natural feature of many S24 stands. However, deep inundation in the spring or summer months is likely to kill some species and lead to development of less diverse swamp communities.

10.3.2 Nutrients/Hydrochemistry

Typically base rich and, particularly where subject to periodic river flooding, conditions are generally mesotrophic - eutrophic. In Broadland, more fertile

Table 10.2 Mean Summer Water Table for Sub-Communities of S24

Sub-Community of S24	n	Total spp (spp 4 m^{-2})	Rare spp (mean) (spp 4 m^{-2})	Rare spp (max) (spp 4 m^{-2})	Water Table (cm)	% in Wet Peat Cutting
S24b *Glyceria maxima*	14	26.2	3.1	6	-26.1	21%
S24c *Symphytum officinalis*	15	27.4	4	7	-47.5	0%
S24d Typical	34	21.3	3.9	6	-14.3	61%
S24e *Cicuta virosa*	24	25.1	5.4	10	-3.4	100%
S24f *Schoenus nigricans*	22	22.1	4.7	9	-14.5	45%

Table 10.3 pH, Conductivity and Substratum Fertility Measured in Stands of S24 in Eastern England

	n	Mean	ŶSD	Min	Max
Soil pH	15	7.17	0.40	6.20	7.52
Water pH	31	6.46	0.37	5.46	7.00
Water Conductivity (µS cm-1)	28	1896.39	1680.08	451.00	5354.00
Soil Fertility1 (mg phytometer)	30	16.63	9.07	5.00	37.00

examples tend to be found in the Yare valley, whilst less fertile examples occur in the northern valleys. Figures for pH, conductivity and substratum fertility measured in stands of S24 in eastern England are presented in Table 10.3, taken from Wheeler & Shaw (2001).

Wheeler & Shaw (1991) report a mean increment (April - September) in dry weight of above ground standing crop of 681 g dry wt m-2 (range: 381–1097 g. dry wt m-2).

Different sub-communities tend to be associated with rather different fertilities, which appears to have some relationship with species richness. Measurements in sub-communities of S24 in eastern England are presented in Table 10.4, taken from Wheeler & Shaw (2001).

10.3.3 Management

S24 appears to be a completely 'artificial' vegetation-type, derived either by the clearance of carr or the management of drained swamp. Where appropriate stratigraphical data are available, it is clear that the fens where it occurs have been occupied by fen woodland for much of the post-glacial period.

Management is essential to maintain species richness, and is principally by mowing for marsh 'litter', and harvesting reed and sedge for thatching. The timing and frequency of management can profoundly influence vegetation composition, for example, winter floods can significantly inhibit regrowth if *Cladium* is mown too late in the year and cut stems are submerged. Abandonment of traditional marsh crop harvesting has lead to problems of scrub encroachment across large areas of Broadland.

10.4 Implications for Decision Making

10.4.1 Vulnerability

The principal vulnerability is to scrub encroachment through dereliction of traditional vegetation management practices, although the degree to which this has a significant botanical effect depends upon the sub-community type. The wide range of habitat conditions associated with S24 makes it difficult to assess vulnerability to drying and eutrophication. Figure 10.3 outlines some of the possible impacts of changes to the stand environment.

Table 10.4 Species Rarity and Substratum Fertility Measured in Stands of S24 in Eastern England

Sub-Community of S24	n	Total spp (spp 4 m-2)	Rare spp (mean) (spp 4 m-2)	Rare spp (max) (spp 4 m-2)	Fertility (mg phyto-meter)[11]
S24b *Glyceria maxima*	14	26.2	3.1	6	23.7
S24c *Symphytum officinalis*	15	27.4	4	7	9.5
S24d Typical	34	21.3	3.9	6	20.6
S24e *Cicuta virosa*	24	25.1	5.4	10	13.5
S24f *Schoenus nigricans*	22	22.1	4.7	9	7

11 (Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of Phytometry (measuring the biomass of test species (Phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); Low fertility = ‹8 mg, High fertility›18mg.

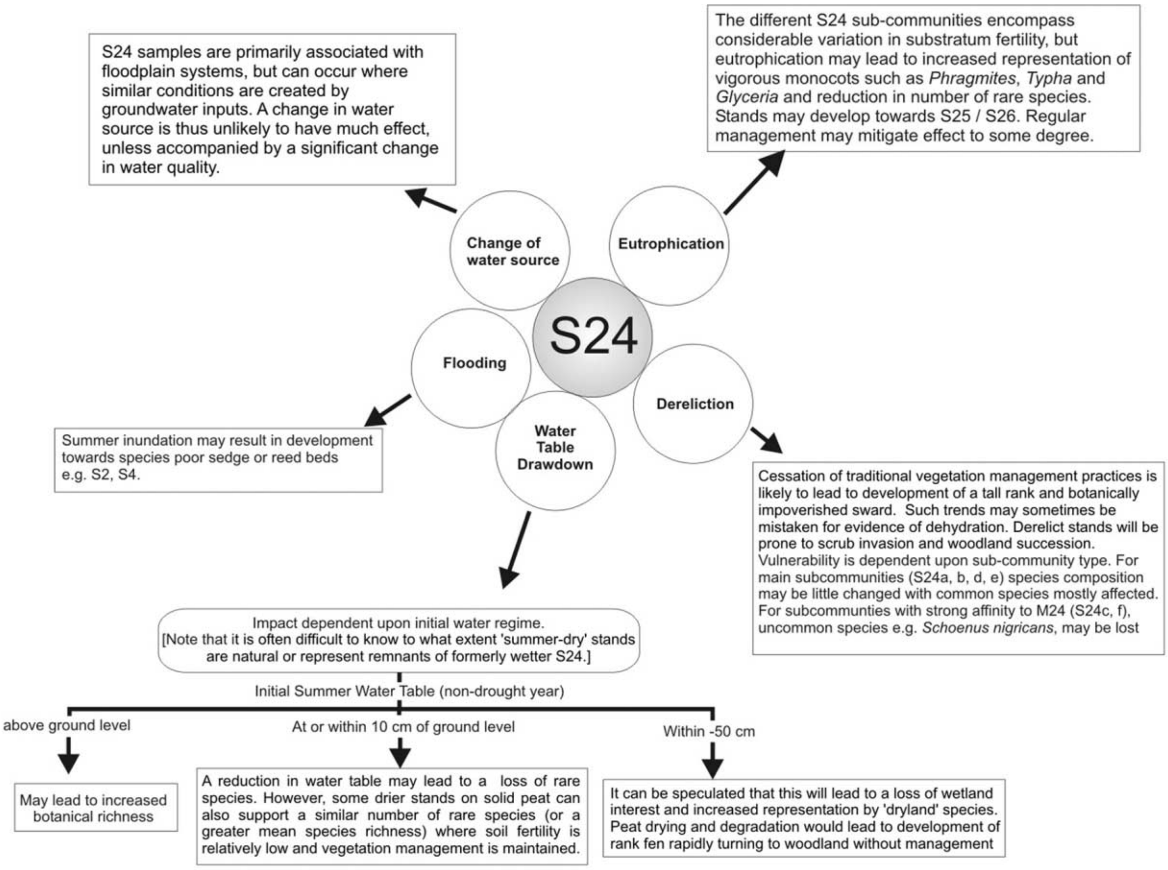


Figure 10.3 The Possible Effects of Environmental Change on Stands of S24

10.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (e.g. numbers of species lost, damage to substratum, degree of enrichment etc). There is limited information available that specifically relates to restoration of S24 stands, but the following observations can be made.

- Scrub removal and reinstatement of a regular vegetation management regime can be expected to improve stand quality;
- The potential for restoring high grade stands to dehydrated sites through re-wetting is largely untested (most pertinent fen restoration trials are at a relatively early phase).

10.4.3 Limitations of These Guidelines and Gaps in Knowledge

The limitations of the information presented here related to S24 include the following:

- The information presented here is largely based on that synthesised by Wheeler & Shaw (2001) - itself primarily based on knowledge of wetland sites supporting S24 in eastern England, and other information held within the FenBASE database. It is proposed that an updated account, including data from other parts of the UK, should be prepared in 2004;
- There are currently virtually no data to better inform the temporal water table characteristics of S24 stands. Time series of dipwell measurements are required to fill this gap;
- In order to make predictions with respect to the vulnerability of S24 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at 'representative' sites;
- S24 is very localised in Britain, but the habitat that it typically occupies appears to be considerably wider than the distribution of the community. The reason why apparently suitable habitats do not support S24 is not known;
- Data on the areal extent of S24 are lacking;
- Possible differences in environmental conditions influencing the six sub-communities have not been explored in detail here.

11. PPc *(Peucedano-Phragmitetum - caricetosum)* Community

11.1 Context

Examples of the PPc community have been included within the 'Chalk-rich Fen Dominated by Saw Sedge' SAC interest feature.

11.1.1 Floristic Composition

An uncommon herbaceous fen community, characteristically species rich (28–42 species per m^2) with an abundance of small sedges and brown mosses, and particularly notable for supporting populations of the internationally-rare fen orchid *(Liparis loeselii)* in Broadland. The community is floristically transitional between M9 and S24 and not is adequately represented by the NVC.

11.1.2 Distribution

The community is confined to Broadland where, currently, it is known from the valleys of the Ant (Broad Fen (Dilham), Sutton Broad and Catfield Fen) and Bure (Woodbastwick Fen, Ranworth Broad and Upton Fen). There are former records for what appears to have been this community from Decoy Carr (Acle), Strumpshaw Fen and Shallam Dyke.

The distribution of the community is shown in Figure 11.1.

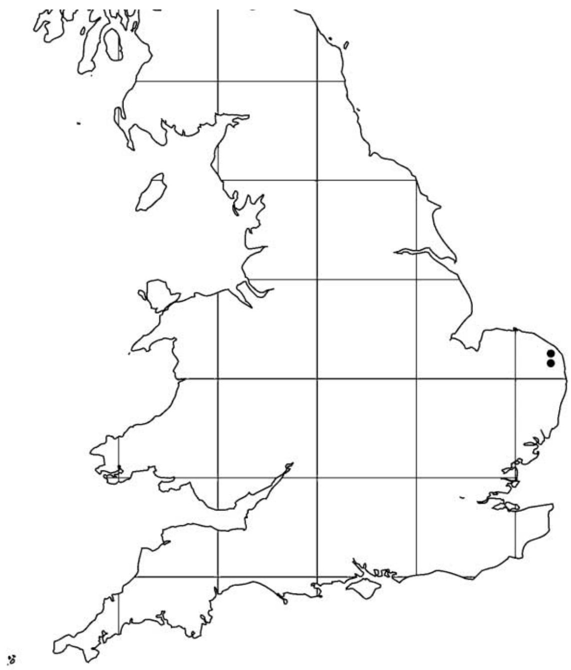


Figure 11.1 Distribution of PPc in England and Wales (from FenBASE database)

11.1.3 Landscape Situation and Topography

All examples of PPc occur in flood-plain fens. Stands are usually very localised. Many of them are located close to the upland margin of the fen (but normally just as discrete patches - only at Sutton Broad do they form a (discontinuous) band along parts of the margin). However, stands at Woodbastwick (and some former stands elsewhere) are located deep into the fens.

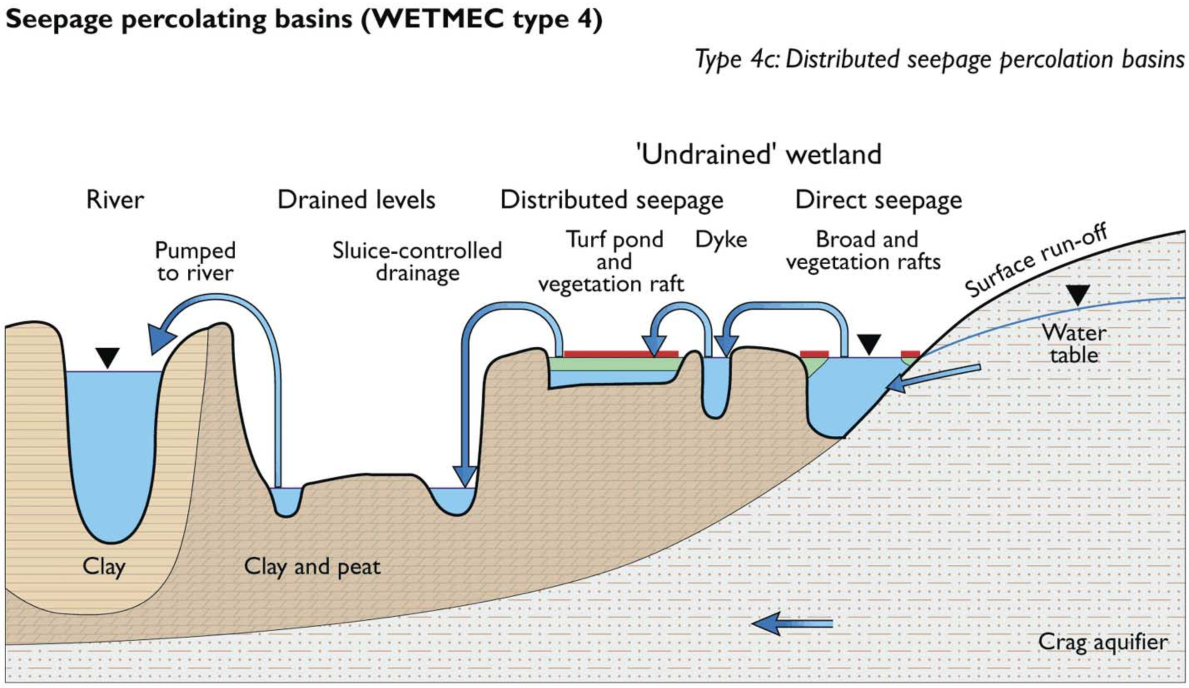
11.1.4 Substratum

All of the stands are located in reflooded peat workings, either the deep medieval excavations (the Broads) or shallower 18–19th Century turf ponds, where they form a quaking, hydroseral mat. In a few stands the peat has been removed almost to the underlying mineral ground (Sutton Broad), but in most there are some 2–5 m of peat (mostly dense brushwood peat) below the floor of the peat cutting. In some sites (e.g. Great Fen, Catfield) the peat is separated from the underlying Crag by a layer of soft grey clay. As is reflected in the relatively low values of water conductivity (see below), in no cases known is the peat cutting underlain by estuarine clay of the Romano-British transgressive overlap - turf ponds underlain by estuarine clay support a quite different vegetation, normally dominated by *Phragmites australis or Typha angustifolia* (illustrated in Figure 11.2).

11.2 Supply Mechanism and Conceptual Model

Wheeler & Shaw (2001) identified recorded stands of the PPc as being restricted to *'Percolating Fens',* fed either by groundwater (Wetmec Type 4 - e.g. Upton Fen) or surface water (Wetmec Type 6 - e.g. Catfield Fen) (or both) (see Figure 11.2).

The identity of the main water sources to stands of PPc has attracted some attention, partly because there has often been an informal presumption that stands of PPc are groundwater fed. This is because of their very localised occurrence, their frequent association with the upland margin and the occurrence of 'seepage indicator species' within the vegetation (i.e. species which occur in some valleyhead fens and are believed to be diagnostic for groundwater inputs). In fact, hydrological investigations at selected sites found little evidence of direct groundwater input and instead emphasised the importance of the surface water system as a primary water source (some stands undoubtedly



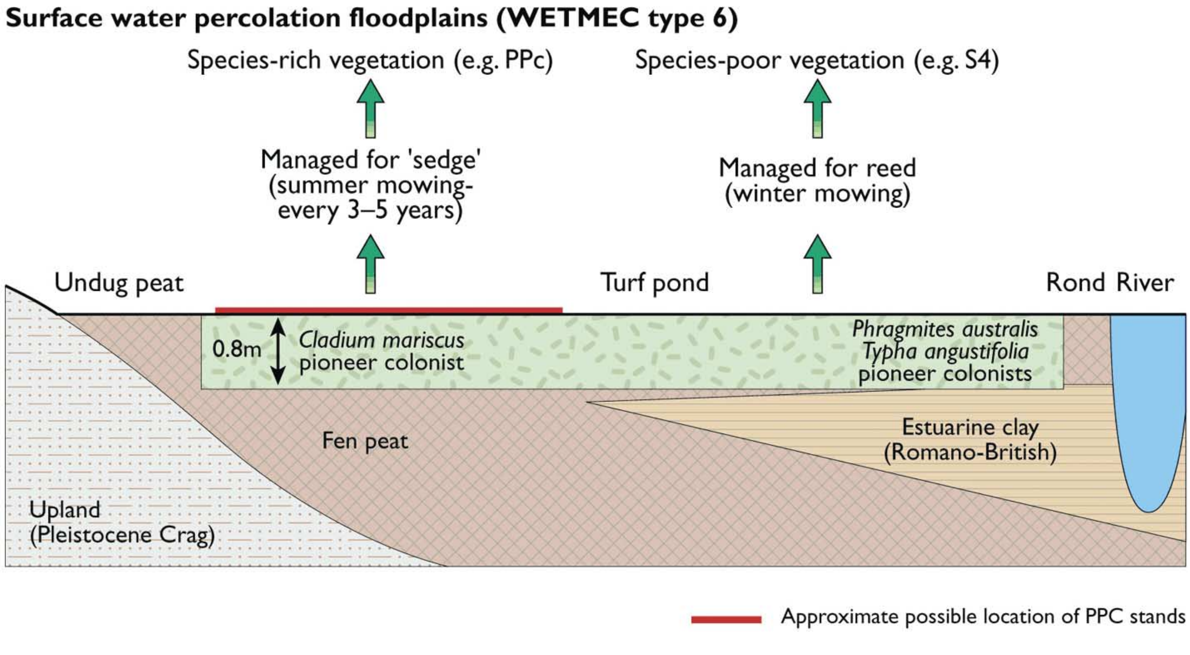


Figure 11.2 A Schematic Representation of the Major Water Supply Mechanisms to PPc

receive groundwater but via the surface water system) (Van Wirdum *et al,* 1997). The role of groundwater *versus* land drainage water and river water sources requires quantification, but there is little doubt (a) that some sites receive river water inputs, apparently stripped of nutrients; and (b) that in some sites this seems to be the primary source of telluric water. It would appear that, providing the water is fairly base rich, but not rich in nutrients or sea salts, its exact provenance is unimportant. In most, perhaps all, stands the summer water is supplied by lateral flow through very loose peat beneath the quaking mat from nearby sources e.g. feeder dykes.

11.3 Regimes

11.3.1 Water

Summer water tables do not show much variation between stands, and are consistently near or at the fen surface. However, the microtopographical variation found within most stands makes the specification of a mean water table difficult and potentially misleading. In many stands it is possible to find hollows with standing water in the summer and low hummocks/tussocks ‹20 cm above the water level. Indeed, the variation in conditions provides a complex of microhabitats that contributes greatly to the species diversity of high-grade stands. The semifloating nature of turf pond infill gives the fen surface a degree of vertical mobility and hence hydrological stability (though in winter and spring, sites with river connections can become inundated).

Mean recorded values for summer water table associated with stands of PPc in Broadland are given in Table 11.1 (from Wheeler & Shaw, 2001).

Table 11.1 Mean Summer Water Table for PPc Stands in Broadland

Variable	n	Mean	ŶSD	Min	Max
Mean Summer Water Table (cm)	7	-7.29	9.95	-26.20	+3.20

Specific time-series data for stands of PPc are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Optimal Water Regime:

- Most often associated with an average water table at or near the surface all year round. Its confinement to semi-floating turf pond infill provides vertical mobility and thus hydrological stability.
- Episodic flooding, including relatively deep inundation, may occur in the winter at riverconnected sites.

Sub-Optimal or Damaging Water Regime:

- Deep inundation in the summer months is likely to lead to development of less diverse swamp communities.
- Floating mats provide a permanently-saturated surface, which is thought to be critical in determining the distribution of PPc. Consequently, subsurface water tables (except as a consequence of natural microtopographical variation) are not generally a feature and tolerance of protracted water table drawdown is probably very limited.

11.3.2 Nutrients/Hydrochemistry

The substratum (i.e. the fen mat) is always of rather low fertility (oligotrophic or low mesotrophic). This contrasts with the mats over estuarine clay which are normally mesotrophic or eutrophic and which support other vegetation-types. Where a PPc stand occurs close to eutrophic river, it is presumed that either the river water does not penetrate/flood the stand, or that a process of nutrient-stripping is operating.

Mean water pH is 6.4, which is below the threshold at which calcite precipitation can occur. Highest pH values have been measured at Upton Fen, where biogenic calcite precipitation has been observed in some fen pools (which here generally have pH values some 0.5 units higher than within the fen mat).

pH, conductivity and substratum fertility measured in Broadland stands of PPc are given in Table 11.2 below, taken from Wheeler and Shaw (2000).

Wheeler & Shaw (1991) report a mean increment (April - September) in dry weight of above ground standing crop of only 299 g dry wt m-2, which reflects the low substratum fertility.

Table 11.2 pH, Conductivity and Substratum Fertility Measured in Stands of PPc in Broadland

Variable	n	Mean	ŶSD	Min	Max
Water pH	7	6.40	0.17	6.19	6.8
Water Conductivity (µS cm-1)	7	676	197	486	1067
Soil Fertility (mg phytometer)12	7	6.57	1.81	5.00	10.00
Soil pH	7	6.62	0.36	6.26	7.3

12 Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of Phytometry (measuring the biomass of test species (Phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); Low fertility = ‹8 mg, High fertility›18mg.

11.3.3 Management

Management is necessary for the long-term persistence of the community, but it can withstand several years of dereliction without serious floristic consequences (probably on account of the low substratum fertility). Management is principally by mowing for marsh 'litter'. PPc stands are prone to scrub invasion where management is abandoned.

11.4 Implications for Decision Making

11.4.1 Vulnerability

Conservation management involves ensuring low fertility and relatively base-rich conditions, periodic vegetation management (summer mowing), and (ultimately) maintenance of hydroseral conditions (peat excavation). Figure 11.3 indicates the possible floristic impact of changes to the stand environment.

Terrestrialisation

All examples of PPc represent a transient phase of turf pond terrestrialisation. Terrestrialisation is manifest in two ways: (i) elevation of the surface, by growth of hummock/tussock-forming species and accumulation of decomposing litter; and (ii) root peat accumulation. The rate of the first of these processes can be considerably reduced by regular mowing (and removal of the mown material); the rate of the second is much less affected by this. Continued growth of rooting structures and formation and consolidation of peat is likely to be detrimental to the water supply mechanism for this vegetation, viz reduction of the vertical mobility of the quaking mat and reduction of transmissivity of the peat infill. It can be predicted that examples of PPc will gradually 'dry out' and become similar to the vegetation of the uncut peat surfaces (a process for which there is some stratigraphical evidence). Conservation of this vegetation-type may therefore ultimately require rejuvenation of the hydroseral conditions (i.e. re-excavation of turf ponds).

Acidification

This can also be considered to be a form of terrestrialisation, but occurs when the fen mat ceases to be inundated by base-rich water, but remains sufficiently wet to support *Sphagnum* species. It occurs particularly on buoyant fen mats and can therefore sometimes occur at an earlier stage in the terrestrialisation process than do changes induced by subsurface solidification. Acidification is extremely localised in those examples of PPc that are periodically inundated by river water (patches are known at Catfield) but is extremely prevalent at Upton Fen where there is little flooding with telluric water.

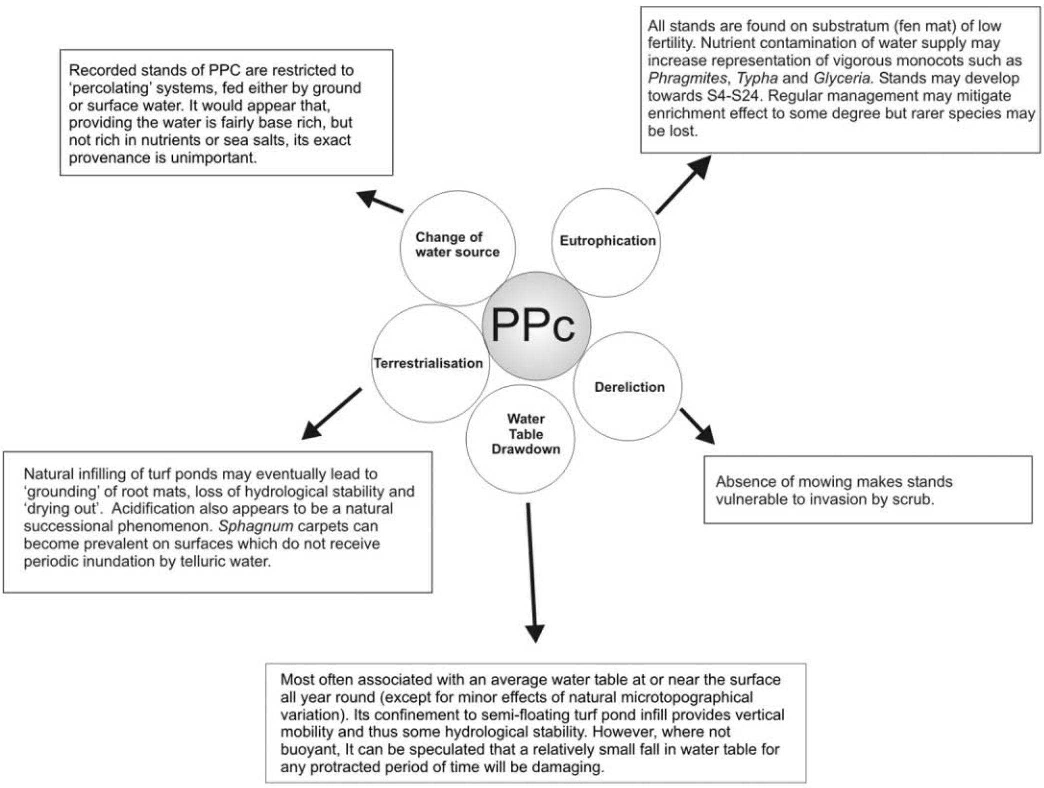


Figure 11.3 The Possible Effects of Environmental Change on Stands of PPc

Nutrient Enrichment
The low fertilities typically associated with this community mean that stands are potentially vulnerable to nutrient enrichment, especially those irrigated in part by river water. In general, there is little evidence for enrichment from river sources, either because nutrients are stripped from the water during summer sub-irrigation or because winter floodwaters are dilute. However, the PPc at Sutton Broad is separated from the river by a rather narrow band of reed that may offer only limited protection from penetration by river water. The possible interaction between sub-surface transmission of river water versus any groundwater inputs at this site is not known, but could be important.

Groundwater Abstraction
The impact of groundwater abstraction on this community is difficult to predict with present information:

- for many sites the exact importance of groundwater to the maintenance of the summer water table is not known, especially as any supply appears to be indirect (it is, for example, possible to envisage situations in which a reduction of groundwater input beneath the stands was inconsequential because of very low rates of water exchange, whilst reduction of more distant inputs could reduce lateral inflows through the surface water system);
- in river connected sites, other water sources may be able to compensate for any reduction of groundwater inputs, though such sources will be only be suitable for the community if they are naturally nutrient poor or if nutrients are stripped from them by passage through the peat/rhizome mixture (i.e. direct input of river water *via* dykes would be damaging);
- even in sites which are exclusively groundwater fed, a small reduction of water level can probably be mitigated by a compensatory movement of the peat mat.

11.4.2 Restorability
As with all restoration measures, their likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (e.g. numbers of species lost, damage to substratum, degree of enrichment etc). There is limited information available that specifically relates to restoration of PPc stands, but the following observations can be made.

- To ensure the longevity of PPc in Broadland it is necessary to provide new or re-excavated turf ponds so that hydroseral conditions can be maintained. However, the potential for restoring PPc is largely untested - turf pond restoration trials have been undertaken by the Broads Authority in the Broads but are at a relatively early phase;
- In river connected sites, other water sources may be able to compensate for any reduction of groundwater inputs, though such sources will be only be suitable for the community if they are naturally nutrient poor or if nutrients are stripped from them by passage through the peat /rhizome mixture (i.e. direct input of river water *via* dykes would be damaging);
- Scrub removal and re-instatement of vegetation management may help to temporarily restore PPc vegetation that has been left unmanaged for a while.

11.4.3 Limitations of These Guidelines and Gaps in Knowledge
The limitations of the information presented here related to PPc are as follows:

- The information presented here is based on that synthesised by Wheeler & Shaw (2001) - itself primarily based on knowledge of wetland sites supporting PPc in Broadland, to which this community is apparently confined. This account may be updated in 2004, should further information (e.g. water level data) become available;
- There are currently virtually no data to better inform the temporal water table characteristics of PPc stands. Time series of dipwell measurements are required to fill this gap;
- In order to make predictions about the vulnerability of PPc stands to water resource management and water quality in the wider environment it will be necessary, on a site specific basis, to investigate the key water supply mechanisms to PPc stands and to establish the relative importance of groundwater *versus* land drainage water and river water;
- Data on the areal extent of PPc are lacking;
- The potential for restoring PPc is largely untested (although some trials have begun).

Part 4

Ditch and Swamp Community Guidelines

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12. Ditch Communities

12.1 Overall Context

Within the *Environment Agency's* Anglian region, the standing water feature identified for SACs as being of interest is 'Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation'. Such vegetation survives in the Broads themselves, which are not natural lakes but peat cuttings of ancient artificial origin. Natural lakes per se were eliminated by the middle of the 19th century with the draining of the Fenland meres. However, closely related plant communities with many of the same biota are widespread in the region within surface drainage channels. Since these are the standing water habitat with which most EA staff will deal, these guidelines focus almost exclusively on such channels. Note that these guidelines do not cover the flora of the fluctuating meres in the Breckland cSAC even though the meres are considered to support flora consistent with the 'Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation' feature.

12.1.1 NVC Communities of Interest

At its richest, the drainage channel flora comprises an intimate mixture of at least three structural elements i.e. emergent, floating and submerged species, though the emergent macrophytes often tend to form a marginal zone. Drainage channels, especially those of coastal and floodplain grazing marshes, do not fit neatly into the *NVC* system, where aquatic and swamp community descriptions are based mainly on larger semi-natural water bodies (rivers and lakes). The smaller scale of drainage channels, together with their management cycle, tends to make for a "compressed" structure and a composition intermediate between several *NVC* types. Most described *NVC* communities also focus on a single element of the ditch vegetation (e.g. the floating duckweed mat), and thus are mainly species-poor with one or two overwhelming dominants. Background information is available both on alternative classifications of such vegetation and those species typical of the habitat, ranked in terms of their indicator power for channel habitat quality. For the purposes of these ecohydrological guidelines, the most important (in biodiversity terms - NOT extent) NVC communities that occur in the drainage channels of the EA Anglian region are:

- A3 *Spirodela polyrhiza-Hydrocharis morsus-ranae community;*
- A4 *Hydrocharis morsus-ranae -Stratiotes aloides community;*
- A9 *Potamogeton natans community.*

12.1.2 Distribution of the Drainage Channel Habitat

Figure 12.1 (after Marshall *et al* 1978) depicts those parts of England and Wales that are dependent upon surface drainage channels for effective farming and flood defence. These areas not only correspond to the jurisdiction of the IDBs, but also indicate the core distribution of the plant communities dealt with in these guidelines - especially in the EA Anglian Region. It will be noted that the drainage channel habitat is most extensive within this part of England and Wales.

Figure 12.1 Distribution of the Drainage Channel Habitat

A3 *Spirodela polyrhiza-Hydrocharis morsus-ranae*

12.2 Context

12.2.1 Floristic Composition

The community mainly comprises a dense floating mat of mixed duckweeds and frogbit *(Hydrocharis morsus-ranae)*. Common duckweed *(Lemna minor)* and Fat duckweed *(L. gibba)* are common, but the most distinctive species is greater duckweed (Spirodela polyrhiza). Below this mat grow submerged rigid hornwort *(Ceratophyllum demersum)* and waterweeds *(Elodea canadensis* or *E. nuttallii)*, mixed with ivy-leaved duckweed *(L. trisulca)*. Some emergent species are frequent, but usually occur as floating, or even semi-submerged, plants within the duckweeds. The main species present in the community are shown in Table 12.1.

Table 12.1 Major Species of A3 Greater Duckweed and Frogbit Community in Eastern England

Characteristic Species	
Berula erecta	*Lemna gibba*
Ceratophyllum demersum	*Lemna minor*
Elodea canadensis	*Lemna trisulca*
Glyceria fluitans	*Spirodela polyrhiza*
Hydrocharis morsus-ranae	

12.2.2 Distribution

Although potentially present throughout lowland England, A3 is almost confined to the main grazing marshes of the warmer lowlands of southern and eastern England i.e. the Somerset Levels and Moors, the North Kent and Romney Marshes, and (within the Anglian region) the Norfolk Broads and the Fens (Figure 12.2). The chief species of the community are largely limited to that part of Britain where the mean annual maximum temperature is >28°C. There is evidence of a recent contraction in distribution.

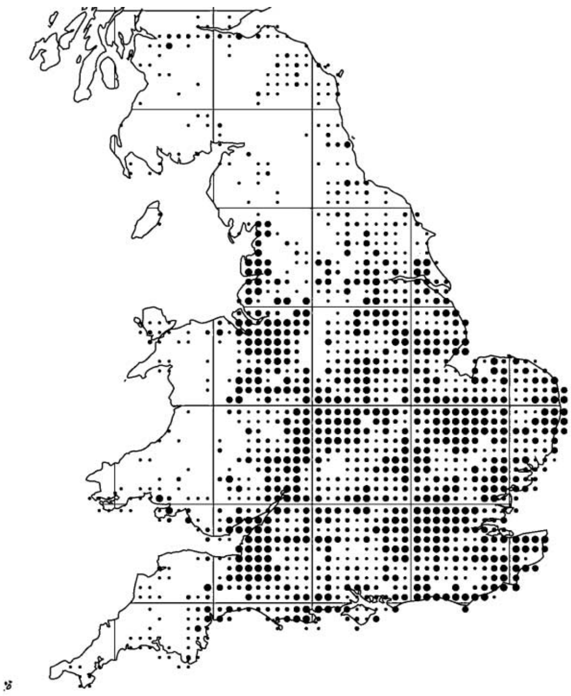

Figure 12.2 Map of A3 *Spirodela polyrhiza-Hydrocharis morsus-ranae* Community (botanically this illustrates co-occurrence of the main constants).
Map indicates those areas where the most characteristic species of the community are recorded in the same region, and suggests that although A3 could potentially occur throughout lowland England, there are clear strongholds in the Anglian region on the Broads and the Fenland, as well as the Humberhead Levels.

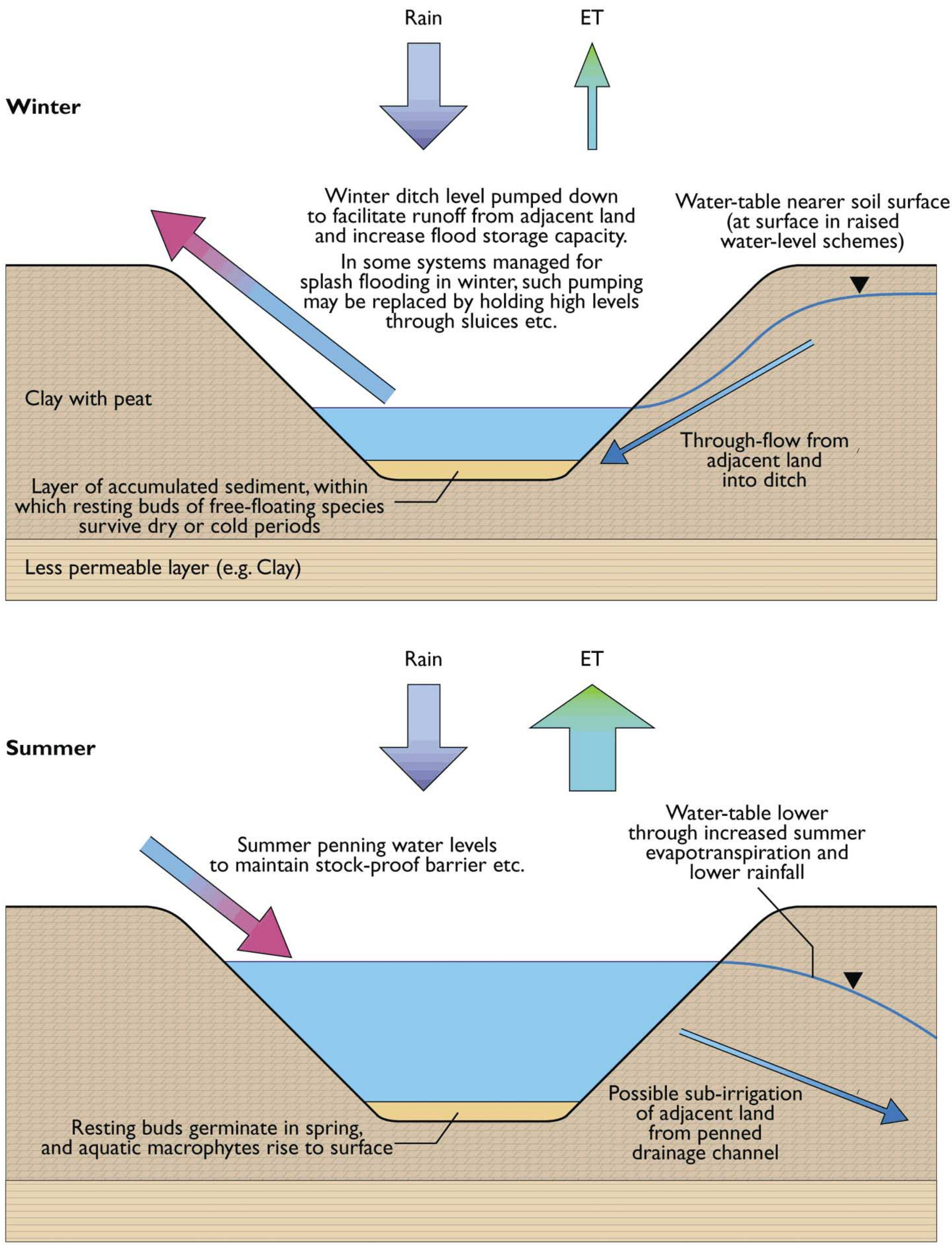

Figure 12.3 Conceptual Diagram of Major Water Fluxes in A3, A4 and A9 Drainage Channels

12.2.3 Landscape Situation and Topography

A3 is typical of the lowest lying parts of Britain, especially coastal and floodplain grazing marshes at altitude of <10 m AOD (mean ca 5 m AOD), where topographic variation is minimal. A3 is commonest in artificial habitats created by the draining of the floodplains i.e. drainage channels and ponds. In most instances, A3-dominated ditches lie between grassland fields, and only occasionally with one of the two banks under arable farming (or a road/drove). A3 is also known from those canals within the same region with little or no boat traffic.

12.2.4 Substratum

Through this association with floodplains, the A3 drainage channel vegetation tends to occur primarily on groundwater gleys (both alluvial and humic-alluvial), and more rarely on loamy peats. Since the greater part of the vegetation is free-floating, the ditch bottom with its frequently deep organic ooze has much less direct influence on the floristic composition than the water quality.

12.3 Supply Mechanism and Conceptual Model

In the great majority of sites, the water supply for this aquatic community is sustained by a combination of rainfall and runoff from the higher-lying land surrounding the grazing marsh, and regulated by sluices and pumps to achieve the desired level (Figure 12.3). The runoff may supply the ditch network directly through diversions from the main rivers, seepage and overland flow from the surrounding land, or through pumping. The level adopted depends upon the water-management needs (for nature conservation, agriculture and/or housing) that apply locally. Lower winter levels will be maintained to enhance flood storage capacity, whereas higher spring and summer levels might be adopted to encourage waterfowl and waders. In many grazing marshes, summer penning levels are high, either to maintain the stock-proof barrier or to provide water-supply to the adjacent wet grassland habitat. In contrast to A4, there is little evidence that the greater duckweed and frogbit community (A3) is associated with a particular water-supply mechanism within the grazing marsh landscape. Such drainage channel communities frequently occur between fields supporting lowland wet grassland or mire communities - consult equivalent guidelines for a description of the water supply mechanisms in these varied terrestrial communities

Table 12.2 Water Regime Variables for A3 Drainage Channels

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)			
Mean water depth (maximum)/m	1.5	1.75	2.0
Mean water depth (minimum)/m	0	0	0
Maximum duration - single exposure event i.e. drying out of channel	10	20	30
Cumulative duration of exposure (drying out of channel)	30	40	50
Spring (Mar - May)			
Mean water depth (maximum)/m	2.0	2.0	2.0
Mean water depth (minimum)/m	0.2	0	-0.2
Maximum duration - single exposure event i.e. drying out of channel	<5	<7	<10
Cumulative duration of exposure (drying out of channel)	<10	<12	<15
Summer (Jun - Aug)			
Mean water depth (maximum)/m	1.25	1.75	2.0
Mean water depth (minimum)/m	0.5	0.2	0
Maximum duration - single exposure event i.e. drying out of channel	5	<7	<10
Cumulative duration of exposure (drying out of channel)	10	<12	<15
Autumn (Sep - Nov)			
Mean water depth (maximum)/m	1.5	1.75	2.0
Mean water depth (minimum)/m	0.2	0.2	0
Maximum duration - single exposure event i.e. drying out of channel	<5	<7	<10
Cumulative duration of exposure (drying out of channel)	<10	<12	<15

Note: 1) Water depth values given relative to soil/sediment surface; and 2) these values are based on published sources cited in references I and IV, augmented with unpublished data for drainage channels collected by the authors of these guidelines.

12.4 Regime

12.4.1 Water

Typical of unshaded, clear standing water and occurring throughout the hierarchy of drainage channels from minor field-ditches to main drains (width 1.0–6.0 m and depth 0.4–1.0 m), A3 is however typical of the larger field ditch (width 2–4 m and maximum depth 0.75–1 m). Since the NVC community is overwhelmingly composed of free-floating species, there is very wide tolerance of pump-induced flow and level fluctuation (e.g. summer draw-down). In addition, the apparent upper depth limit has less to do with light attenuation at depth, and more to do with turbulence in deeper water-bodies restricting growth of the submerged component. The community will even tolerate very brief periods when the ditch dries out, especially when turions (resting buds) of key species are protected by a continuously wet substrate. However, in winter the turions may be prone to frost damage. A3 is very uncommon where there is continuous flow, though the submerged component will benefit from periodic aeration through pumping and through less shade as the free-floaters are swept away. Water regime variables for A3 are presented in Table 12.2 below.

12.4.2 Nutrients

Ditches and ponds with A3 generally lie in basins surrounded by calcareous rocks and base-rich clays, and the water-supply is consequently base-rich. A3 occurs in mesotrophic to naturally eutrophic water that is non-turbid, unpolluted and may be relatively calcareous or slightly saline. Detailed studies of A3 vegetation in English grazing marshes (based on >100 samples) provide the following typical values for certain key chemical parameters of the water:

1 mean *pH*	=	6.6–6.8 (range 4.2 to 8.6);
2 mean *electrical conductivity*	=	486.5 _S/cm at 25°C (range 57 to 943);
3 mean *Redox value*	=	+33.3 mV (range -159 to +148).

12.4.3 Vegetation Management

A3 is found in unshaded to lightly shaded (i.e. <20% shade) ditches and ponds. The vegetation recovers well from ditch cleaning operations and indeed requires such periodic intervention to arrest succession to a tall-emergent cover of reeds etc. Between cleaning events, continued cover of A3 is favoured by marginal grazing (obviously dependent on stock having easy direct access to the water). In contrast to main drains, such channels are more infrequently cleaned/dredged since they do not perform an arterial function, and hence sediment accumulation is normally ca 0.45–0.55 m (corresponding main drain values 0.2–0.25 m). There is evidence of variation within the community with respect to management regime, with frogbit especially prevalent in field ditches, whilst greater duckweed *Spirodela* makes a greater contribution to the floating carpet in drains managed by the Environment Agency or IDBs.

Summary information on the preferred management of drainage channels supporting *A3* vegetation at time of survey (with variation where *Spirodela* dominant - §)

Mean freeboard	0.63 m (to >1.1 m in more major drains)
Banks fenced off from field	6% of banks
Channel cleaned/dredged annually	3% (to 30% §) of ditches
Channel cleaned/dredged in previous year	12% (to 58% §) of ditches
Channel cleaned/dredged >1 year before survey	35% (down to <15% §) of ditches
Channel vegetation cut	6% (to 15% §) of ditches
Banks (and channel margins) grazed	>60% of banks
Banks mown	1–3% of banks
No management evident at time of survey	% of ditches

12.5 Implications for Decision Making

12.5.1 Vulnerability

A3 represents a stage in aquatic successions, and its conservation requires intervention to prevent progression to terrestrial conditions. In most British grazing marshes, management to maintain the efficient drainage through the channels provides such intervention. Management of adjacent land has a strong impact on the ditch vegetation, especially in narrow channels where increased shade from terrestrial species rooted on the bank can affect the aquatic community. Rationalisation of the drainage network can lead to the elimination of sites. Though A3 occurs over a quite wide range of water-quality, eutrophication can degrade the duckweed mats, and saline intrusion markedly alters their composition. Those factors that most threaten the continued occurrence of A3 are listed below, together with a figure (Figure 12.4) depicting the main trajectories of community change where such threats are uncontrolled:

- Eutrophication and increased turbidity;
- Altered salinity;
- Elimination following abandonment of ditch/drain maintenance;
- Excessive shade from overgrown hedges and marginal vegetation;
- Uncontrolled succession to emergent reed etc;
- Fencing of ditches and prevention of access for stock;
- Unsympathetic management e.g.:
  - over-deepening e.g. through severe use of JCB back-bucket;
  - re-grading to produce very steep banks;
  - aquatic herbicides.

Succession leads to reed-swamp (S4) or marginal emergent vegetation, sometimes through a stage of deeper water swamp (S12, S13, S16). Re-engineering of the channel can produce deep water more favourable to water-lilies (A7, A8) or bistort (A10). Succession under more nutrient-rich conditions may favour S5. Eutrophication may simply degrade the duckweed carpet (A1, A2) or produce a fennel pondweed community (A12). The latter vegetation also arises under increased salinity, conditions that can lead to communities of hornwort (A6), water-crowfoot (A21) or eventually to a club-rush swamp (S21).

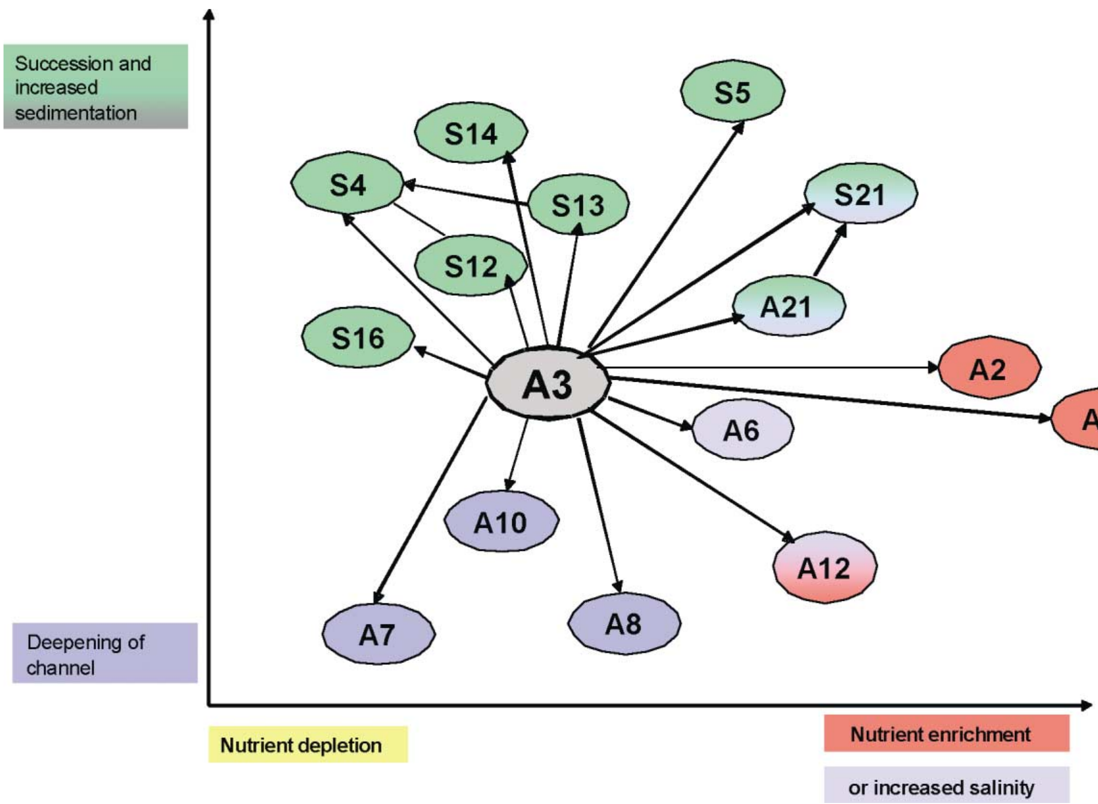

Figure 12.4 Trajectories of Community Change in Response to Altered Water Depth (through succession or over-deepening) and Changes in Water Chemistry

12.5.2 Restorability

Provided the water quality is toward the optimum this vegetation is relatively easily restored in open drainage channels and ponds. Some regular management to arrest succession will be necessary, and introduction of certain more local species may be required. However, there appear to be no marked technical or scientific problems in the successful restoration of the A3 Spirodela polyrhiza-*Hydrocharis morsus-ranae* community.

12.5.3 Limitations on the Use of These Guidelines and Gaps in Knowledge

Some of the proposed trajectories of change are rather speculative, and research may be required in order to prescribe management regimes that either favour or prevent particular successions. The preferred nutrient and depth/flow regimes of the component species are not always well quantified. Finally, there is some concern as to the value of strictly phytosociological approach in describing ditch vegetation. The same management regime may actually lead to the apparent coexistence of a number of aquatic and swamp communities within a relatively short length of drainage channel.

A4 *Hydrocharis morsus-ranae -Stratiotes aloides*

12.6 Context

12.6.1 Floristic Composition

This luxuriant vegetation comprises three primary layers. At the surface is a mixed floating mat of Common Duckweed and Frogbit, accompanied by the rosettes of various-leaved waterstarwort *(Callitriche platycarpa)* and sometimes by yellow water-lily *(Nuphar lutea)* and amphibious bistort *(Persicaria amphibia)*. Immediately below the surface is a layer of ivyleaved duckweed and water-soldier *(Stratiotes aloides)* that floats in the upper levels of the water. Deeper still is a diverse submerged component composed mainly of profusely branched species with finely divided leaves. Finally there is a varied emergent component, occurring especially at the margins of the channel or pond, but its cover is very limited, and no species can be said to be particularly characteristic. The major species found in the A4 community are listed in Table 12.3.

Table 12.3 Major Species of A4 Frogbit and Water-Soldier Community in Eastern England

Characteristic Species	
Berula erecta	*Callitriche platycarpa*
Ceratophyllum demersum	*Ceratophyllum submersum*
Elodea canadensis	*Hottonia palustris*
Hydrocharis morsus-ranae	*Lemna minor*
Lemna trisulca	*Myriophyllum verticillatum*
Nasturtium officinale	*Nuphar lutea*
Oenanthe aquatica	*Persicaria amphibia*
Potamogeton obtusifolius	*Potentilla palustris*
Sium latifolium	*Sparganium erectum*
Stratiotes aloides	*Utricularia vulgaris*

12.6.2 Distribution

Although A4 may occur in Holderness and could develop where *Stratiotes* is introduced (Figure 12.5), the known extant British sites are all within the Broadland area covered by the Anglian region of the Environment Agency. Until about 1970, there were sites in Fenland (Anglian Region), and some areas of the Witham levels (Lincolnshire) may still support A4. As a native, water-soldier has declined, being only known where the annual maximum temperature is ›28°C, but there are many instances of its occurrence as a naturalised alien elsewhere in Britain, resulting in a net increase.

12.6.3 Landscape Situation and Topography

The Broadland localities are in drained coastal/floodplain grazing marshes below 5 m AOD, and this community is found primarily in artificial habitats (especially ditches) created by the draining of the floodplains, where there is minimal topographic variation. A4 is almost entirely restricted to ditches with unfenced, summer-grazed grass fields on both sides, although occasionally it can be found within rich fen complexes. Research in Norfolk showed that A4 was especially characteristic of the ditch network cut off from the tidal rivers, and close to the margins of the floodplain.

12.6.4 Substratum

Most of the luxuriant A4 vegetation is free-floating, and not rooted in the organic sediment that accumulates on the ditch bottom. The coincidence of this type with lowland river floodplains results in an apparent predilection for groundwater gleys (alluvial and humic-alluvial), and loamy peats. The clear preference for the edges of these floodplains results in an association with a more mineral substrate, in contrast to the deeper peats that frequently characterise the centre of the site.

Figure 12.5 shows those areas where the most characteristic species of the community are recorded in the same region, and suggests that the potential distribution of A4 is localised, with the main areas where it can occur being the Broads and the Fenland.

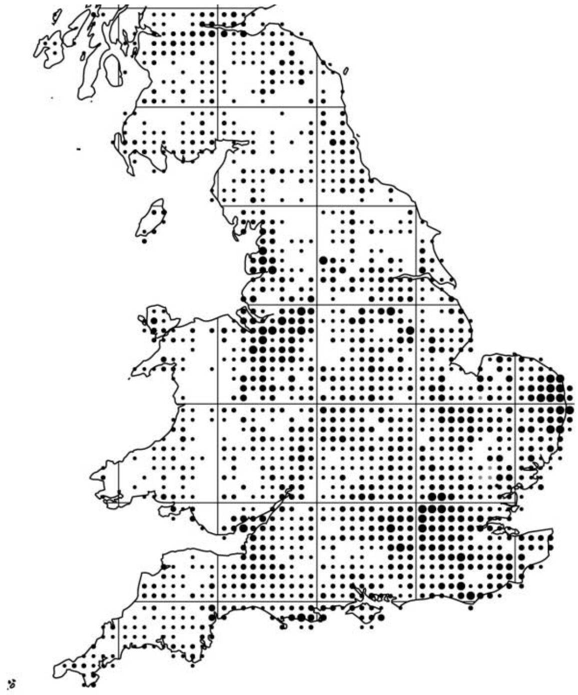

Figure 12.5 Map of A4 *Hydrocharis morsus-ranae- Stratiotes aloides Community* (botanically this illustrates co-occurrence of the main constants)

12.7 Supply Mechanism and Conceptual Model

In the great majority of sites, the water supply for this aquatic community is sustained by a combination of rainfall and runoff from the higher-lying land surrounding the grazing marsh, and regulated by sluices and pumps to achieve the desired level (Figure 12.3). The runoff may supply the ditch network directly through diversions from the main rivers, seepage and overland flow from the surrounding land, or through pumping. There is evidence that the A4 community is most common around the margins of the grazing marsh, where land-drainage water from neighbouring farmland may have a marked influence. The level adopted depends upon the water-management needs (for nature conservation, agriculture and/or housing) that apply locally. Lower winter levels will be maintained to enhance flood storage capacity, whereas higher levels might be adopted to encourage waterfowl and waders. In many grazing marshes, summer penning levels are high, either to maintain the stock-proof barrier or to provide watersupply to the adjacent wet grassland habitat. Such drainage channel communities frequently occur between fields supporting lowland wet grassland or mire communities - consult equivalent guidelines for a description of the water supply mechanisms in these varied terrestrial communities.

12.8 Regime

12.8.1 Water

Frogbit-Water Soldier vegetation is most often found in quite deep, clear standing water, but within minor ditches (width ca 2–3 m and depth 0.5–1.0 m). Detailed information on the depth requirements and response to flow or water-level fluctuation is sparser than for A3, but the general pattern appears similar, with a wide tolerance to such variation, provided the ditch does not suffer prolonged drying out during the summer. Winter dry periods (often due to pumping) can be withstood through the production of resting buds that remain dormant but viable in the wet substrate (although are prone to frost damage in the winter). The apparent depth limit seems to be determined by the incidence of turbulence (and hence turbidity) in deeper waterbodies, which restricts the growth of the diverse submerged component. In Broadland, A4 is prevalent near the “upland” margins of the grazing marsh, where there is a direct (or indirect) influx of land-drainage water. Water regime variables for A4 are presented in Table 12.4 below.

12.8.2 Nutrients

Water draining the uplands into the Broadland floodplains is often, though by no means always, base-rich especially where the parent material is chalky clay. However, a more acidic supply arises from soils derived from the Norfolk Red Crag, and most notably where marine sediments containing sulphides become decalcified following drainage and oxidation, resulting in pH values <3.5 (e.g. the Ant valley). Studies in the River Ant system have produced an excellent description of both water and sediment chemistry for drainage channels where A4 occurs. The community prefers mesotrophic to locally eutrophic waters, which are calcareous (high levels of calcium and magnesium) with relatively high values for both inorganic nitrogen concentration and Redox potential.

Table 12.4 Water Regime Variables for A4 Drainage Channels

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)Winter (Dec - Feb)			
Mean water depth (maximum)/m	1.5	1.75	2.0
Mean water depth (minimum)/m	0	0	0
Maximum duration - single exposure event i.e. drying out of channel	10	20	30
Cumulative duration of exposure (drying out of channel)	30	40	50
Spring (Mar - May)			
Mean water depth (maximum)/m	2.0	2.0	2.0
Mean water depth (minimum)/m	0.2	0	-0.2
Maximum duration - single exposure event i.e. drying out of channel	‹5	‹7	‹10
Cumulative duration of exposure (drying out of channel)	‹10	‹12	‹15
Summer (Jun - Aug)			
Mean water depth (maximum)/m	1.25	1.75	2.0
Mean water depth (minimum)/m	0.25	0.15	0
Maximum duration - single exposure event i.e. drying out of channel	5	‹7	‹10
Cumulative duration of exposure (drying out of channel)	10	‹12	‹15
Autumn (Sep - Nov)			
Mean water depth (maximum)/m	1.5	1.75	2.0
Mean water depth (minimum)/m	0.2	0.2	0
Maximum duration - single exposure event i.e. drying out of channel	‹5	‹7	‹10
Cumulative duration of exposure (drying out of channel)	‹10	‹12	‹15

Note: 1) Water depth values given relative to soil/sediment surface; and 2) these values are based on published sources cited in references I and IV, augmented with unpublished data for drainage channels collected by the authors of these guidelines.

A summary of these results is given in Table 12.5 and they appear representative of Water-soldier stands generally in East Anglia.

The decline of water-soldier in the UK has been attributed to nutrient depletion, especially phosphorus. Results from the Netherlands provide conflicting evidence, with instances of the community in sites poor in nitrogen and phosphorus, whilst others appear typical of eutrophic waters, especially influenced by fertiliser inputs.

12.8.3 Management

The A4 community is found in unshaded ditches (more rarely ponds, or the sheltered bays of Broads). The prevailing management resembles that of A3, with occasional ditch cleaning operations and marginal grazing to suppress the spread of tall emergent species.

12.9 Implications for Decision Making

12.9.1 Vulnerability

A4 is part of the aquatic element in open-water successions i.e. from duckweed and water-lily dominated vegetation to emergent swamp, and management is necessary to maintain its extent and prevent increased shade of the watercourse. Rationalisation of the drainage network (elimination of field ditches, regrading of main drains and installation of pumps) can destroy the habitat. The vulnerability of the community to changes in water-chemistry is more contentious, but the behaviour of the community in its Broadland stronghold seems consistent. Figure 12.6 shows the main trajectories of potential community change:

Succession passes through a stage of deeper water swamp (S5, S12, S13) to reed-swamp (S4).

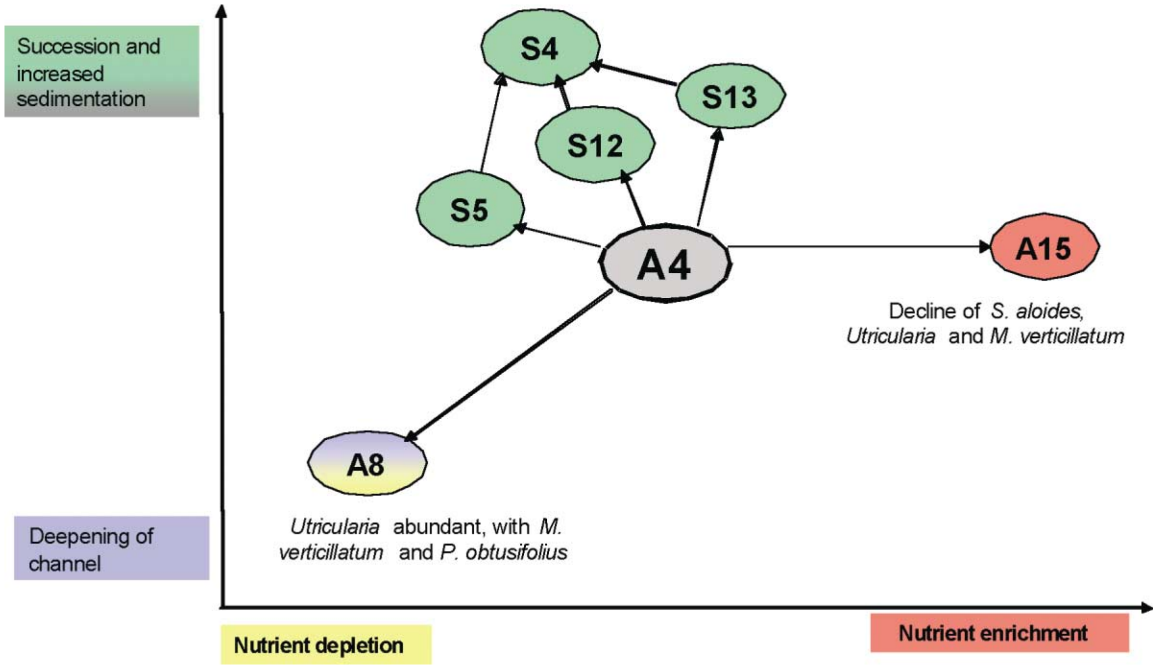

Figure 12.6 Trajectories of Community Change in Response to Altered Water Depth (through succession or over-deepening) and Changes in Water Chemistry

Re-engineering of the channel can produce deep water more favourable to water-lilies (A8), though a variant of this community with prominent bladderwort develops in waters impoverished of nutrients. Eutrophication leads to decline of water-soldier, bladderwort and water-milfoil, and increased dominance of waterweeds (A15).

The following factors appear to be those that most threaten the survival of A4:

- Eutrophication and increased turbidity;
- Altered salinity;
- Elimination following redundancy;

Table 12.5 pH, Nutrient Levels and Redox Values for Drainage Channel Water and Sediments Associated With the A4 Community - Measurements Made in 1980 (after Wheeler and Giller 1982)

a) Water

Water Chemistry Variable	January	July
Soluble reactive phosphorus (mg l^{-1})	0.05	0.03
NH4-N (mg l^{-1})	(no data)	0.15
NO3-N (mg l^{-1})	2.41	1.32
pH (annual range 6.4–7.6)	6.4	7.5

b) Sediment

Sediment Chemistry Variable	January	July
Soluble reactive phosphorus (mg l^{-1})	1.44	1.08
NH4-N (mg l^{-1})	16.2	11.52
NO3-N (mg l^{-1})	7.68	15.52
Mean pH 10 cm below surface (range)	6.5(6.2 - 6.6)	6.8(6.6 - 7.0)
Mean Redox value (mV) 10 cm below surface corrected to pH 7(range of uncorrected values)	61(-30 to +100)	50(-80 to +81)
Cations (mg l sediment^{-1})		
Calcium	300	395
Magnesium	704	94
Sodium	180.4	293.2
Potassium	39.3	45.2

- Excessive shade from overgrown hedges and marginal vegetation;
- Uncontrolled succession to emergent reed etc;
- Fencing of ditches and prevention of access for stock;
- Unsympathetic management e.g.:
  - over-deepening *e.g.* through severe use of *JCB* back-bucket;
  - re-grading to produce very steep banks;
  - aquatic herbicides.

12.9.2 Restorability
The main limiting factors to successful restoration appear to be suitable water-chemistry and the presence of propagules of the more local species. Given a source of propagules, restoration of A4 appears entirely practical within its native range, and indeed in climatically suitable areas elsewhere in lowland England.

12.9.3 Gaps in Knowledge
There is some uncertainty with the proposed trajectories of change, and it is likely that a wider range of degraded communities might be derived from A4 under the range of perturbations listed in Section 12.9.1. More data are required on the preferred nutrient and depth regimes of the component species, and as with all drainage channel types there are problems in enforcing a strictly phytosociological approach.

A9 *Potamogeton natans*

12.10 Context

12.10.1 Floristic Composition
A9 is a distinctive, species-poor community that is dominated by the floating pondweed *(Potamogeton natans)* which, although rooted in the substrate, forms a floating mat of often overlapping leaves. There are three sub-communities, two of which occur in the Anglian Region: A9a species-poor sub-community *(P. natans* monoculture) and A9b *Elodea canadensis* subcommunity, where the pondweed mat may be slightly less dense, with frequent submerged Waterweed, and occasional plants of Water-plantain. The major species found in the A9 community are listed in Table 12.6.

In the following guidelines, the comments and data refer to the overall composite community, rather than to any of the sub-communities specifically - unless otherwise clearly stated.

Table 12.6 Major Species of Floating Pondweed Communities in Eastern England Within A9a and A9b

Characteristic Species	
Alisma plantago-aquatica	*Elodea canadensis*
Potamogeton natans	

12.10.2 Distribution
A9 is not confined to grazing marsh ditches and ponds (Figure 12.7), being found throughout lowland Britain, and also in lakes, tarns and slowing-flowing rivers in the uplands. A9a is widespread, whereas A9b is concentrated in the lowlands e.g. eastern England. Since A9 is in most instances a virtual monoculture of floating pondweed, this map largely reflects the UK distribution of the dominant pondweed. There is some evidence of a trend toward the lowlands.

3. Landscape Situation and Topography
In the Anglian Region, such vegetation is fairly frequent in the coastal and floodplain grazing marshes, but also well-distributed in farm ponds in the higher-lying parts. A9 is found in a greater diversity of landscapes from the Levels to more elevated districts.

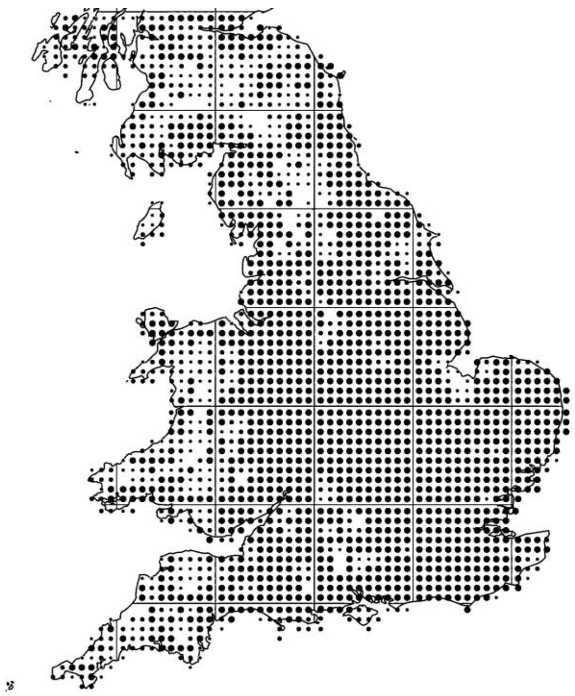

Figure 12.7 Map of A9 Potamogeton natans Community (botanically this illustrates co-occurrence of the main constants)

4. Substratum
A9 has no marked preference for a particular particle size and organic content, and stands are known from peat and gravel, as well as clays, silts and sands. In grazing marsh ditches, floating pondweed sometimes forms dense patches over quite deep organic ooze, but in larger waterbodies (drains and lakes), it is typical of sites that are less silted than those occupied by the yellow water-lily (NVC community A8).

12.11 Supply Mechanism and Conceptual Model

Where A9 occurs in grazing marshes, water supply comes from both rainfall and runoff from the higher-lying land. The water is then regulated by sluices and pumps to achieve the desired level (Figure 12.3). The runoff may supply the ditch network directly through diversions from the main rivers, seepage and overland flow from the surrounding land, or through pumping. Adopted penning levels depend upon those water-management needs that apply locally. Lower winter levels will be maintained to enhance flood storage capacity, whereas higher levels might be adopted to encourage waterfowl and waders. In many grazing marshes, summer penning levels are high, either to maintain the stock-proof barrier or to provide water-supply to the adjacent wet grassland habitat. The community also occurs in ponds and rivers.

12.12 Regime

12.12.1 Water

The exclusive dominance of a single species in a very species-poor vegetation means that for most purposes, the ecology of A9 may be inferred from the autecology of floating pondweed itself. This species will occur over a wide range of water-depths, surviving in as little as 0.05 m, and being able to grow in up to 5m of water, provided light penetration is good. Having all of its leaves at the surface, floating pondweed is less restricted by deep turbid water, and of all the NVC floating-leaved associations, A9 spreads into the deepest water. Nonetheless, most eastern English stands occur in (0.5–) 1–2 m depth of still water in ponds, lakes and ditches, though there are also populations in moderately fast-flowing rivers. floating pondweed persists in rivers that are prone to spates. The very flexible stems and petioles allow the community to tolerate very marked fluctuations in depth and turbulence, though fairly short periods of drying out are damaging (see Table 12.7).

12.12.2 Nutrients

A9 occurs over a wide trophic range from oligo-/mesotrophic to fairly eutrophic, though poorly represented in the most nutrient-rich waters. The species-poor sub-community (A9a) will grow throughout this entire range, but the waterweed sub-community (A9b) is confined to mesotrophic situations. Most eastern examples of the community are water of pH range 5.57.0, though pH *per se* is probably not a limiting factor to the occurrence of the pondweed in the Anglian Region.

12.12.3 Vegetation Management

There is insufficient data on its occurrence in managed systems (such as ditch networks) to provide a detailed outline the response of A9 to management. However, it is clear that A9 grows under an array of regimes, from typical grazing-marsh situations (with ditch cleaning and marginal grazing/cutting) to natural rivers where a combination of flow and weed-cutting (by EA etc) prevent encroachment from other communities. It is tolerant both of marginal grazing, and of moderate urban pollution.

12.13 Implications for Decision Making

12.13.1 Vulnerability

A9 may be considered a deep-water stage in the hydrosere, and some management may thus be required to conserve it where there are trends to siltation, spread of tall emergents and eventual terrestrialisation. However, its wide tolerance to depth, turbidity and nutrient levels makes A9 a relatively robust community to perturbation (Figure 12.8).

Succession passes through deep-water swamp (S12, S14) to a mosaic of marginal communities. Siltation may also lead to replacement of pondweed by water-lily (A8), which may be reversed through nutrient depletion. Over-deepening of channel is unlikely to lead to any change in community, though extreme eutrophication of deep water will eventually produce vegetation where algae replace vascular plants.

Most conservation problems arise from either lack of management (and hence succession) or a too intensive channel management regime e.g.:

- Extreme eutrophication;
- Altered salinity;
- Spread of tall emergent vegetation through succession (lack of management);

Table 12.7 Water Regime Variables for A9 Vegetation

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)			
Mean water depth (maximum)/m	3.5	4.5	5.5
Mean water depth (minimum)/m	1.5	0.25	0
Maximum duration - single exposure event i.e. drying out of channel	10	10	10
Cumulative duration of exposure (drying out of channel)	30	30	30
Spring (Mar - May)			
Mean water depth (maximum)/m	3.0	4.5	5.5
Mean water depth (minimum)/m	1.0	0.25	0
Maximum duration - single exposure event i.e. drying out of channel	<5	10	10
Cumulative duration of exposure (drying out of channel)	<10	30	30
Summer (Jun - Aug)			
Mean water depth (maximum)/m	2.5	4.5	5.5
Mean water depth (minimum)/m	0.75	0.25	0
Maximum duration - single exposure event i.e. drying out of channel	5	10	10
Cumulative duration of exposure (drying out of channel)	10	30	30
Autumn (Sep - Nov)			
Mean water depth (maximum)/m	3.0	4.5	5.5
Mean water depth (minimum)/m	1.0	0.25	0
Maximum duration - single exposure event i.e. drying out of channel	<5	10	10
Cumulative duration of exposure (drying out of channel)	<10	30	30

Note: 1) Water depth values given relative to soil/sediment surface; and 2) these values are based on published sources cited in references I and IV, augmented with unpublished data for drainage channels collected by the authors of these guidelines.

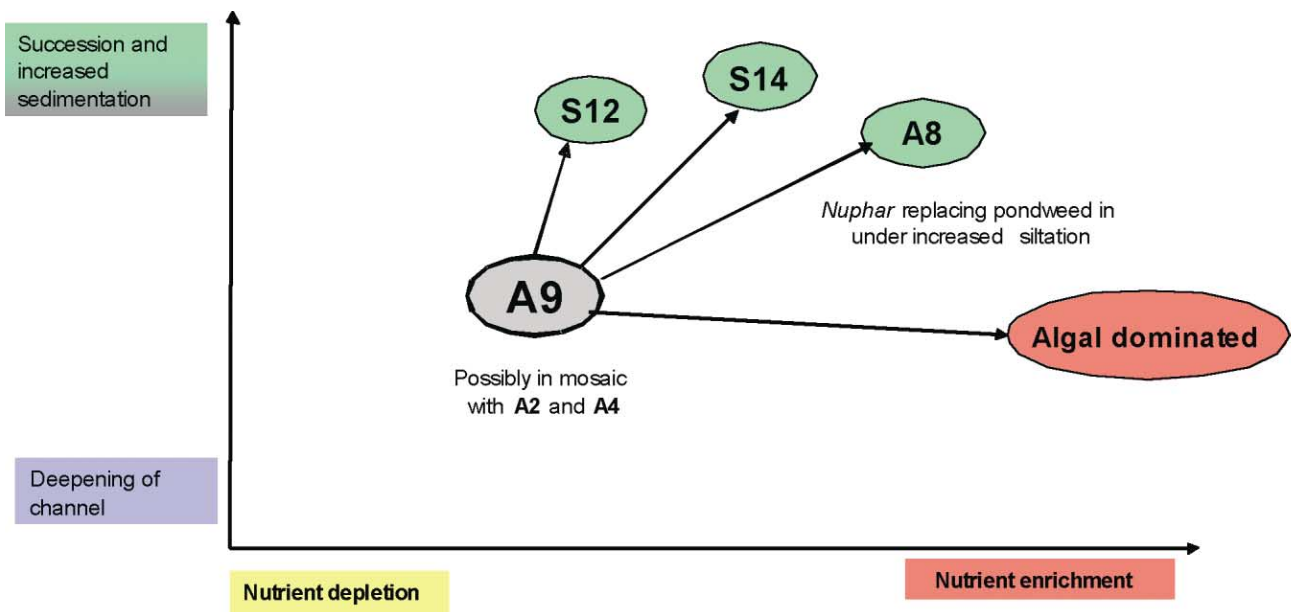

Figure 12.8 Trajectories of Community Change in Response to Succession and Changes in Water Chemistry

- Excessive shade from overgrown hedges and uncontrolled emergent reed etc;
- Unsympathetic management e.g.:
  - aquatic herbicides;
  - very frequent and intensive weed-cutting.

12.13.2 Restorability

A9 is relatively straightforward to restore provided that there is, preferably mesotrophic, open water of sufficient depth to deter the spread of tall emergent swamps. The main species are all widespread, through floating pondweed has declined locally in the more intensive arable ditch systems of the Fenland and restoration in such areas may demand introduction of propagules.

12.13.3 Limitations on the Use of these Guidelines and Gaps in Knowledge

Much of the most detailed information relating to floating pondweed-dominated vegetation is derived from studies of lakes and rivers. Hence many Anglian stands of A9 occur in situations where the precise management and environmental data have not been thoroughly documented. Further effort is required to elucidate the influence of nutrient, sediment and depth regimes on trajectories of community development.

13.S4 *(Phragmites australis)* Reedbed

13.1 Context

Reedbeds are an example of how “species-richness” is not the only, or even the overriding, consideration in assessing the biodiversity value of a habitat. Though generally species-poor, these habitats support some of the most threatened birds and invertebrates in English wetlands, and are also important as a necessary transitional stage between open water (both saline and fresh) and more diverse wetlands such as salt-meadows and fens.

13.1.1 Floristic Composition

There are four types (sub-communities) of the NVC reedbed community S4:

- 4a *Phragmites australis* sub-community - only reed itself abundant;
- S4b *Galium palustre* sub-community - forb-rich and transitional to fen communities;
- S4c *Menyanthes trifoliata* sub-community (absent from eastern England);
- S4d *Atriplex prostrata* sub-community - frequently with many halophytes in saline stands.

Although all three sub-communities that occur in the Anglian Region are dominated by common reed *(Phragmites australis)*, their compositions show marked differences. Combined with the polymorphic nature of reed itself (from 1–3 m in height), S4 can have a highly variable appearance. In the following guidelines, the comments and data refer to the overall composite community, rather than to any of the sub-communities specifically - unless otherwise clearly stated. The major species in reedbeds in the Anglian region are indicated in Table 13.1.

Table 13.1 Major Species in Reedbeds in the Anglian Region

Characteristic Species	
Agrostis stolonifera	*Glaux maritima*
Aster tripolium	*Iris pseudacorus*
Atriplex portulacoides	*Juncus gerardii*
Atriplex prostrata	*Lythrum salicaria*
Bolboschoenus maritimus	*Mentha aquatica*
Calliergon cuspidatum	*Plantago maritima*
Elytrigia atherica	*Puccinellia maritima*
Epilobium hirsutum	*Phragmites australis*
Festuca rubra	*Salicornia dolichostachya*
Galium palustre	*Triglochin maritima*

Note:

1) Apart from the ubiquitous reed, all other species are associated with one particular sub-community:

2) Species marked in green are only common in the “fenny” sub-community S4b, whilst

3) Species marked in blue are typical of the “saline” sub-community S4d.

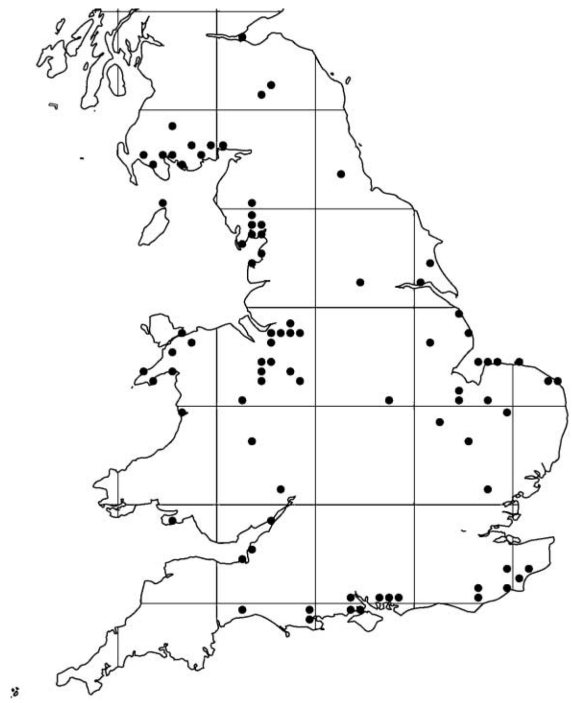

Figure 13.1 Distribution of Examples of S4 *Phragmites australis* Swamp and Reedbeds (After Rodwell 1995) Note that the map does not necessarily indicate the complete distribution of this community, but rather indicates those samples of the NVC survey etc referred to S4.

13.1.2 Distribution

The basic sub-community (S4a) occurs throughout the British lowlands, including East Anglia (Figure 13.1). The *Galium palustre* sub-community (S4b) is more scattered, though it is occasional in eastern England, whilst the *Atriplex prostrata* sub-community (S4d) is almost entirely restricted to the coast in eastern Britain, though some related stands do occur around freshwater bodies inland.

13.1.3 Landscape Situation and Topography

Common reed is found throughout Britain (to 500 m AOD) but true reedbeds occur mainly below 150 m

AOD, and are most extensive below 25 m AOD. Dense stands of reed require a growing season from April to September, and the sensitivity of the young shoots to frost limits both the northern and altitudinal spread of the species. S4 reedbed is one of the most widespread communities of open-water transitions around lakes and ponds, but also occurs in floodplain and basin mires, peat-cuttings, estuaries and along watercourses, where in eastern England it can form extensive stands in drainage channels and along sluggish rivers.

Reedbeds are most extensive on flood-plains and levels with minimal topographic variation (flat or slopes ‹20°) e.g. in the Broads and Suffolk River Valleys Environmentally Sensitive Areas (ESAs) and the Fen basin. Some reedbeds may be very extensive (e.g. Walberswick - 300 ha), but the community also occurs in drainage channels where it is most typical in arable ditches only 1–2.5 m wide.

13.1.4 Substratum

S4 reedbeds show few substrate preferences being recorded on substrata ranging from 1–97% organic content i.e. from almost purely mineral to deep peats.

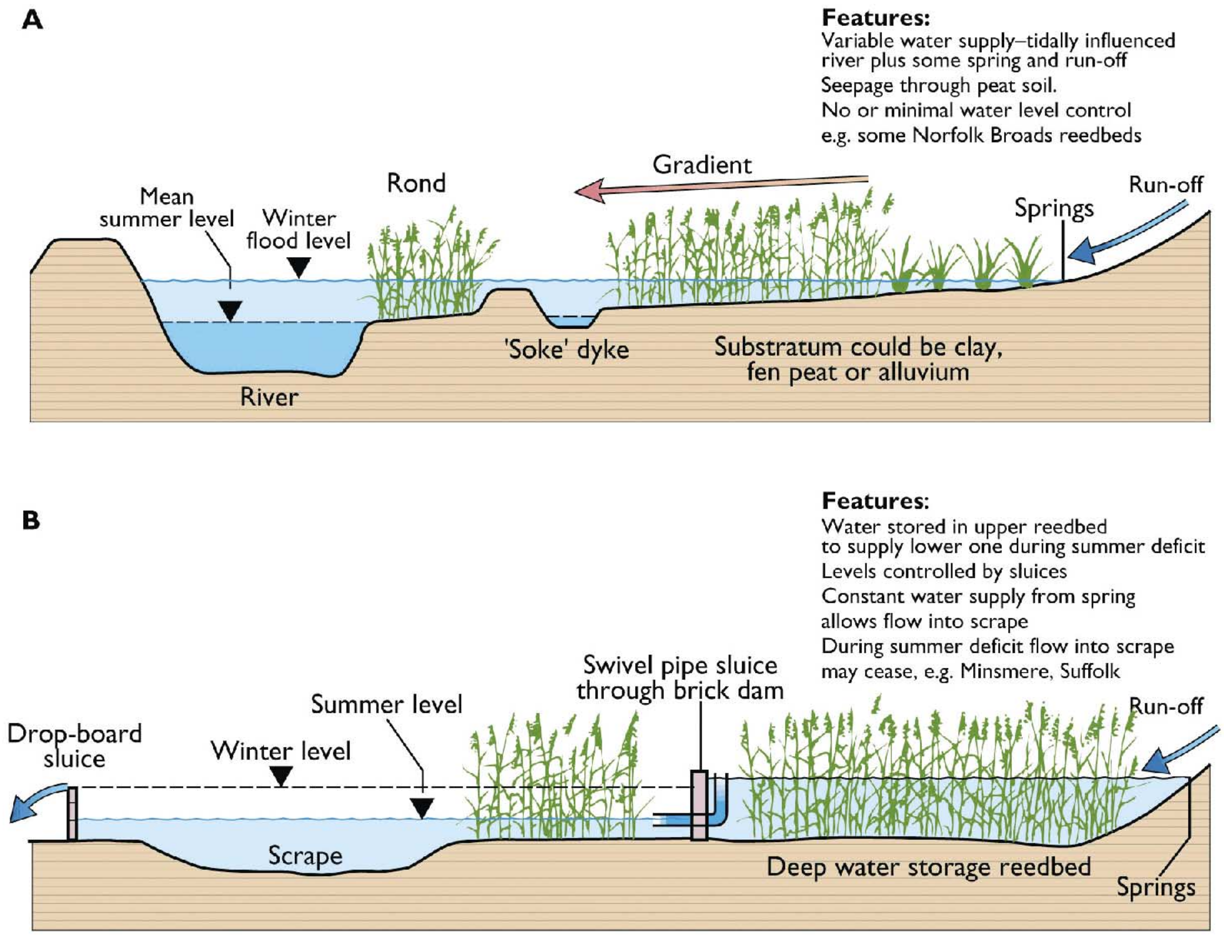

Figure 13.2 Examples of Hydrological Regimes in British Reedbeds (after Hawke & José 1996)

A Continual supply and flow, relying on natural flooding from a river
The water-supply comprises a number of elements, with some water coming from a tidally-influenced river, and some due to springs and runoff from the surrounding upland. There is seepage through a peat soil on a gentle gradient from the upland to the river, and no (or minimal) water-level control. A common scenario within Broadland.

B Continual spring-fed supply, with part of the reedbed used for winter storage (NO continual flow)
The micro-topography includes different levels within the reedbed. In the upper reedbed of more managed systems, water may be stored so as to supply the lower levels during periods of deficit. In such situations, the levels are controlled by a series of sluices, which allow flow when there is constant water-supply stop or control flow during summer deficit periods. This scenario is seen in the large reedbeds at Minsmere.

In grazing marsh ditches, there is an apparent association with groundwater gleys (alluvial and humic-alluvial).

13.2 Supply Mechanism and Conceptual Model

Reedbeds occur under a very wide range of water-supply situations, including both relatively natural and highly artificial examples. Figure 13.2 illustrates five rather different examples of water-supply systems in British reedbeds, drawing particularly on East Anglian examples (see annotated legend to the figure for a description of the varying regimes and mechanisms). Each of these scenarios identifies the water-supply, together with any need for supplementary pumping or water-level control to achieve particular conservation objectives. In addition to the nature of the supply (spring-fed, riverine flooding etc), there is variation in the way that the water may be distributed through reedbed, and many East Anglian examples include an artificial infrastructure (possibly complex) of ditches and grips to ensure effective dispersal of water through the bed. Others may rely on a more natural system of springs and sokeways. Increasingly, reedbeds maintained for both nature conservation and management have control structures installed to control water-levels at different times of the year or when different management objectives are being pursued. Instances of these are included in the outline to Figure 13.2.

13.3 Regime

13.3.1 Water

Reedbeds are found in permanently wet or waterlogged sites, where healthy growth appears to depend on regularity of water-regime (i.e. always deep, always shallow, or regular seasonal fluctuations). Reed grows poorly where there is inconsistent variation in water level. Reedbeds are also often found beside water in topogenous mires, and in sites liable to winter flooding but which can be summer dry.

Reed will grow in water-tables from 2 m above ground level to ›1 m below, though there is variation between the sub-communities and the habitat:

- In open water transition situations, which includes the most important Anglian reedbeds, the usual water depth for the S4a (typical sub-community) ranges from +0.5 m above to -0.13 m below (mean value +0.13 m) ground level, whilst S4b *(Galium palustre* sub-community) occurs from about +0.02 m above to -0.40 m below (mean value -0.1 m) ground level;
- In drainage channels, reed stands (all related to NVC S4a) usually occur in 0.20.8 m of water, though in some variants as much as 30% of samples may be summer-dry;
- In tidal situations, reed has been recorded in the Netherlands growing from -1.5 m below to +0.25 m above mean high water (with greatest vigour between -1.0 m and 0 m). The “saline” sub-community (S4d) may also depend on surface seepage of fresh water from inland;
- Where reedbeds occur in summer-dry situations, with the water-table well below the surface, the S4 stand may be in direct contact with open water situations via its rhizome e.g. where reed becomes a weed in arable land adjacent to drainage channels.

The depth to which reed can grow is limited primarily by a lack of nutrient availability i.e. for reed to produce an effective photosynthesising canopy, then ›35% of each stem must be emergent. The maximum water depth attained increases not only with nutrient availability but also with temperature.

There is also a relationship between water-depth and the maximum productivity achieved by reed. Results from East Anglian fens suggest that maximum productivity is attained when water levels are at, or around, +0.5 m above substrate in winter and -0.2 m below substrate in late summer. Annual water consumption of a hectare of reedbed is about 1.0–1.5 m of water (varying with site and weather). In East Anglia, where the annual rainfall is about 0.6 m, reedbeds thus require at least an additional 0.4–0.6 m to satisfy their evapotranspirative demand. Consequently reedbeds occur most extensively only where water can accumulate.

Attempts have been made to derive an ideal water level programme for maintaining reedbeds where nature conservation is the primary consideration, but where reed production might be a secondary objective. The following five-point schedule meets the needs of such site- and catchment-managers:

1. Raise water-levels as soon as any winter cutting has been completed (late March to early April) to a maximum surface depth of 0.3 m.
2. Maintain surface water in the range 0.05–0.3 m through the spring and summer.
3. Draw down the water-level gradually to just below the reedbed surface from October through to late March.
4. Within a cut reedbed, maintain some wet areas to provide winter feeding for reedbed birds.

5 During the winter period, and when reed-cutting is NOT taking place, set sluices so that the maximum depth though the reedbed does not exceed 1.0 m.

Water regime variables for S4 are presented in Table 13.2 below.

13.13.2 Nutrients

Reed has been recorded on sites with pH values anything above 4.5, although studies of reed-stands in grazing marsh ditches indicate a preferred water pH value of 6.1–7.0. Reed thrives in anaerobic soils provided that the rhizomes are aerated via dead aerial stems. Reedbeds can be found from oligotrophic to eutrophic (or even hypertrophic) situations, and both nitrogen and phosphorus are limiting for growth.

In very nutrient-rich situations, reed will compete successfully with other tall emergents. However, prolonged growth in eutrophic conditions weakens the structural tissue in the reed canes, leaving them liable to breakage (due to waves, wind or grazing) and eventual decay/death if the broken tips are immersed, thus preventing aeration of the rhizome.

Reed tolerates salinities from 2–12(–22) gm Cl-/l, but salt may limit bud development in spring, meaning that reedbeds in brackish or tidal sites may be stunted or recede with saline incursions.

13.13.3 Management Regime

Reed is very productive, with an annual biomass accumulation of 1(–2) kg m^{-2}, hence its exploitation as a crop. Increasingly, commercial output and biodiversity are both considerations in determining the form of management undertaken - see Table 13.3 below.

Winter cutting of reed allows a commercial crop to be taken with minimal adverse effects on both biodiversity interest (except as a roost for migrant birds) and the growth of the reed itself. Reed cutting not only reduces litter accumulation, but also stimulates production of new buds and slows down the spread of reedswamp into open water (should it be desired to maintain such a feature).

Table 13.2 Water Regime Variables for S4 Reedbed

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)			
Mean water depth (maximum)/m	+0.75	+1.5	+2.0
Mean water depth (minimum)/m	+0.25	0	-0.5
Maximum duration - single exposure event (days)	5	5	5
Cumulative duration of exposure (days)	10	10	10
Spring (Mar - May)			
Mean water depth (maximum)/m	+0.5	+1.25	+1.5
Mean water depth (minimum)/m	+0.1	-0.25	-0.4
Maximum duration - single exposure event (days)	10	10	10
Cumulative duration of exposure (days)	20	20	20
Summer (Jun - Aug)			
Mean water depth (maximum)/m	+0.2	+0.5	+1.0
Mean water depth (minimum)/m	-0.4	-0.8	-1.2
Maximum duration - single exposure event (days)	90	70	50
Cumulative duration of exposure (days)	90	70	50
Autumn (Sep - Nov)			
Mean water depth (maximum)/m	+0.2	+0.75	+1.25
Mean water depth (minimum)/m	0	-1.0	-1.25
Maximum duration – single exposure event (days)	25	25	10

Notes: 1) Composite of all sub-communities; 2) water depth values given relative to bottom of water-body; and 3) these values are based on published sources cited in references I and II, augmented with unpublished data for reed-swamps, tall-herb fens and drainage channels collected by the authors of these guidelines.

Table 13.3 Suggested Water-Level Guidelines for Different Objectives (after Hawke & José 1996)

Main Regime	Regime Variant	Summer Level	Winter Level	Why?	Comments
Winter Cut	A	+5 to 30 cm	Max +100 cm	Optimum for reed wildlife	Summer levels varied for habitat mosaic. If winter levels kept at *ca* +30 cm, Bittern etc may use the reedbed.
Winter Cut	B	Max + 100 cm	0 to ca- –20 cm	Optimum for reed harvest. Draw-down for machinery use and maximum butt length.	High summer levels enhance reed growth & reduce competition. Water >1 m may inhibit growth.
Winter Cut	C	Max + 30 cm	Split-regime: +30 cmca – 20 cm	Integration of two reed uses	Summer levels kept mod high for growth. Winter levels varied to provide some harvest and some wildlife use.
Summer Cut		+2 cm to subsurface	Max +30 cm	For wildlife and harvests (reed **plus** Great Fen Sedge & marsh-hay)	For late Great Fen Sedge harvest - winter levels <+30 cm. Summer draw-down allows cutting and minimises rutting.

Although a combination of winter cutting and spring flooding is the best approach to maintaining the dominance of reed in commercially operated reedbeds, where nature conservation concerns are paramount, then some modification of the regime for the benefit of biodiversity is appropriate i.e.:

- Cut (or graze) in late summer and remove cuttings to reduce accumulation of litter;
- Summer water level at or just below soil/litter surface;
- Winter water level above soil/litter surface;
- However -such a regime will slowly reduce the proportion of reed in the vegetation.

Growth of reed can be suppressed directly by grazing or browsing, or indirectly through trampling, which may damage surface rhizomes. Such suppression of reed is very apparent in drainage channels where stock have access to the water's edge, and reed stands are markedly better developed in arable land, and also by roads or fenced grassland or in channels with a high freeboard.

The occurrence of different sub-communities in drainage channels is related to management. Pure reed stands (S4a) occur primarily in ditches that are not subject to cleaning, or which are cleaned very infrequently (e.g. at intervals of 5 years and more). Forb-rich reedbeds (S4b) occur in drainage channels subject to annual or even more frequent management (e.g. cleaning, cutting), occurring in some IDB or EA drains.

13.4 Implications for Decision Making

13.4.1 Vulnerability

Reedbeds occur primarily as successional communities in the transition from open water to terrestrial conditions. Reed itself is a robust species that is able to tolerate some changes in water level and quality. The successional relationships of S4 with other communities are often complex, and transitions are heavily influenced by nutrient levels, management and chance factors. In addition, in many Anglian examples the successional stages are truncated such that the classic "hydrosere" (see Figure 13.3) may not be apparent.

Deep flooding of reed-swamp can initiate a succession through lesser reedmace (S13) or bulrush (S8) swamp to communities of floating-leaved and/or submerged aquatic macrophytes. Succession via tall-herb fen to carr and woodland may follow several routes. In oligotrophic situations, a *Carex rostrata-Potentilla palustris* fen may develop (S27), whilst in somewhat more nutrient-rich conditions in Broadland and locally in the Fens, an intermediate Great Fen Sedge swamp (S2) gives way to a *Phragmites-Peucedanum* tall-herb fen (S24). In somewhat more

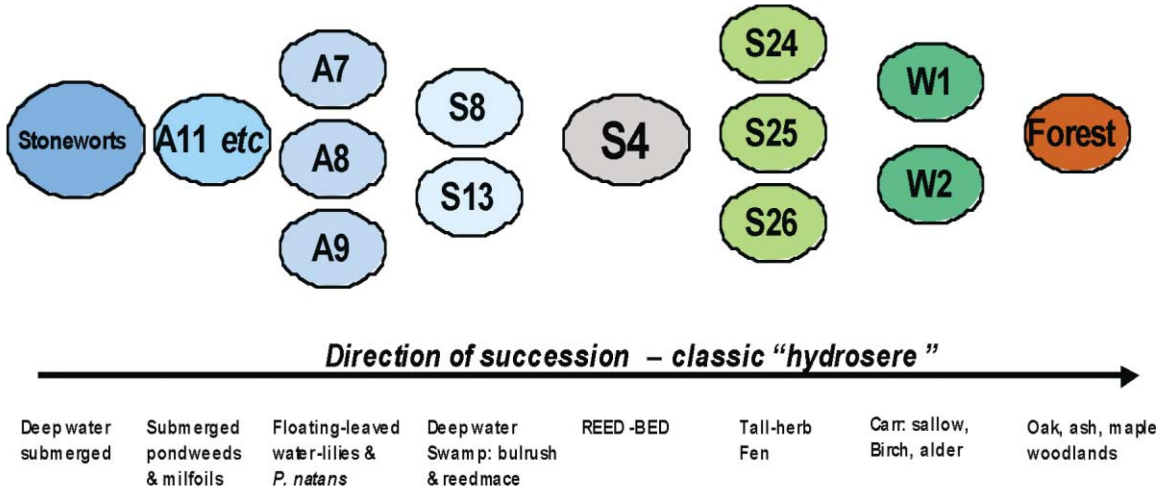

Figure 13.3 Idealised Succession From Open Water Through Reedbed to Climax Forest - Based Upon the Studies of Prof Richard West at Hickling Broad

mesotrophic situations, reedbeds are replaced by *Carex paniculata* swamp (S3). Eutrophic successions may pass through a *Glyceria maxima* phase (S5). Where reedbeds are invaded by saline water, succession is influenced by any defoliation regime - grazed sites can acquire communities dominated by *Puccinellia, Juncus gerardii* and *Festuca rubra* (SM13, SM16), whilst in ungrazed saline sites, a cord-grass community (SM6) can replace reed.

Figure 13.4 indicates the effects on reedbed of changes in water level and nutrient regime. However, there are also other causes of reedbed loss e.g.:

- Succession through to fen and carr woodland;
- Erratic water-regime leading to accelerated succession, decay of litter and consequent release of nutrients - resulting in a eutrophic fen;
- Eutrophication of the water supply can affect the

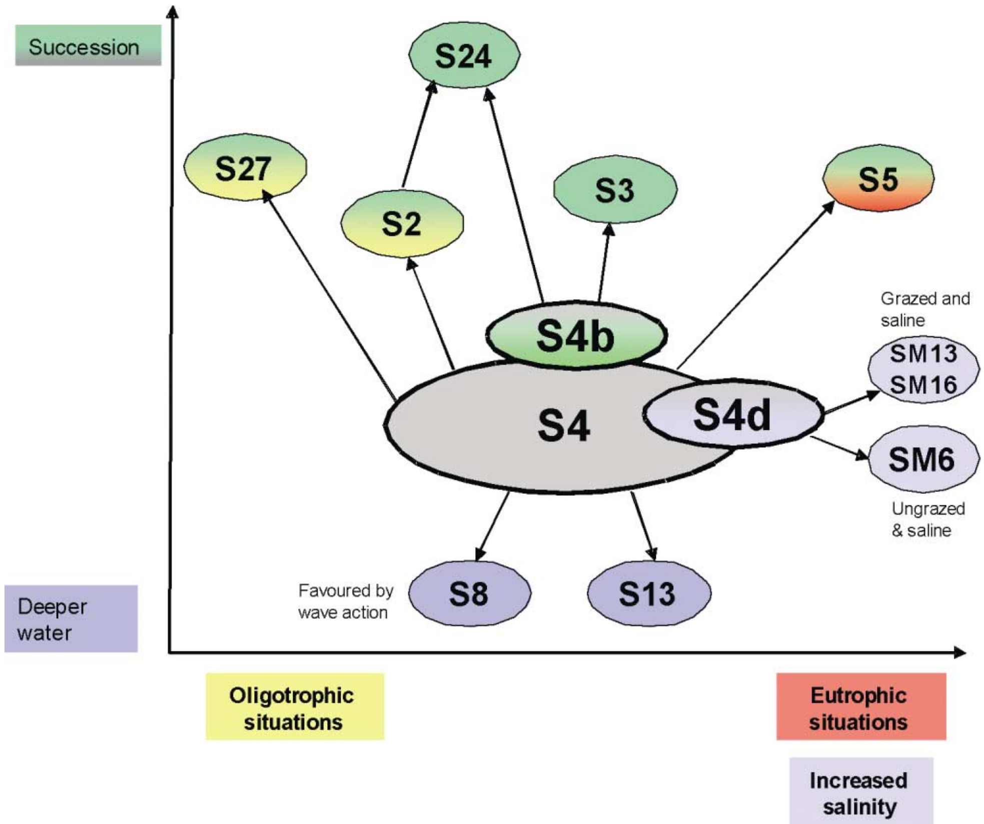

Figure 13.4 Trajectories of Community Change in Response to Succession and Changes in Water Chemistry

structural, photosynthetic and/or aeration tissues of the plant, which can result in weakened stems and regression of the reedbed;

- Breakage or submergence of dead stems leads to aeration stress and reduction of reed bud inception;
- Grazing leading to regression of the community edge from landward and/or open water (e.g. by geese) margins. Shallow rhizomes are sensitive to trampling/poaching of livestock;
- Climatic effects (shortened growing season and reduced competitive ability through frosting);
- Unfavourable cutting season e.g. when green;
- Intolerant of marked wave or current action (in tidal rivers reedbed is often protected by a fringe of bulrush (Scirpus) or reedmace *(Typha)).*

13.4.2 Restorability

Widespread observation of wild situations and recent large-scale attempts at the re-creation of reedbed (Hawke and José 1996) both show that the S4 community is relatively straightforward to establish, though post-establishment management often needs to be intense. Reed may be introduced as seedlings or as rhizome fragments, and will usually colonise and spread rapidly. In deep-water situations, reedmace can establish preferentially, and where the restored reedbed is dry for long periods, willows and other woody plants may colonise. Maintenance of a water level and cutting regime appropriate to reed is therefore important.

13.4.3 Limitations of These Guidelines and Gaps in Knowledge

There is a substantial amount of quantitative information on the creation and maintenance of reedbeds for commercial purposes. However, further investigation is required into the mechanisms by which reedbeds might evolve into tall-herb rich-fen (S24 *etc*) in order to achieve more consistent success in fen restoration schemes. More studies are also required of the dynamics of swamp and aquatic vegetation under a range of water- and nutrient-regimes, so as to better inform habitat management. Finally, there is a real need for additional development of predictive modelling of wetland management (including reedbeds) at the catchment scale since, increasingly, potentially conflicting or interacting factors have to be integrated into an effective overall catchment management plan.

14. S5 *(Glyceria maxima)* Swamp

14.1 Context

The importance of S5 reed sweet-grass *(Glyceria maxima)* swamps lie partly in their role as bird habitat, but especially in the perceived problems that result when S5 vegetation invades those valuable washland and wet grassland communities whose biodiversity for animals and plants is higher than S5.

14.1.1 Floristic Composition

S5 swamps comprise vegetation where reed sweet-grass is dominant, often to the exclusion of most other species. Such swamps may grow either firmly rooted or frequently as a floating "hover" on the deeper water fringes of other swamps, whence it may become a detached island. Two sub-communities occur in Britain, including the EA Anglian region:

a) S5a *Glyceria maxima* sub-community: only dense reed sweet-grass normally present;

b) S5b *Alisma plantago-aquatica-Sparganium erectum* sub-community: rather more open cover, narrow fringing stands with occasional water-plantain, watercress and bur-reed.

In the following guidelines, the comments and data refer to the overall composite community, rather than to any of the sub-communities specifically - unless otherwise clearly stated.

14.1.2 Distribution

Reed sweet-grass (and both sub-communities of S5) is more strictly lowland than reed *(Phragmites)* - widespread in England (except Devon and Cornwall), but rare in Wales, the Pennines and in Scotland (other than the Central Valley and the northeast (see Figure 14.1). The centre of its distribution is below 150m in the English Midlands and the East, including the Anglian Region.

14.1.3 Landscape Situation and Topography

S5 often fringes water, sometimes where slow-moving but more commonly where still. As well as pools and lakes, this vegetation is common by canals and especially in drainage channels (mean width 1.8 m), and S5 is equally frequent in arable and pastoral ditches. Within eastern England, reed sweet-grass forms extensive stands on washes, i.e. lowland (often embanked) floodplains that are regularly flooded in winter. The community is best developed on level sites, though occasionally it extends onto very gentle slopes (‹15°).

14.1.4 Substratum

S5 swamps occur mainly on mineral, often alluvial, substrates that are nutrient-rich, and between mildly acidic and basic in reaction. In Fenland and Broadland, S5 extends onto neutral and fen peats, but only very rarely onto acid peats. In such peaty sites, development of reed sweet-grass swamp appears to depend on inputs of mineral-rich water. Variation in growth form and habitat are linked to differing types of substrate i.e. rooted stands are associated with firm sediment, whilst "hover" occurs over soft ooze.

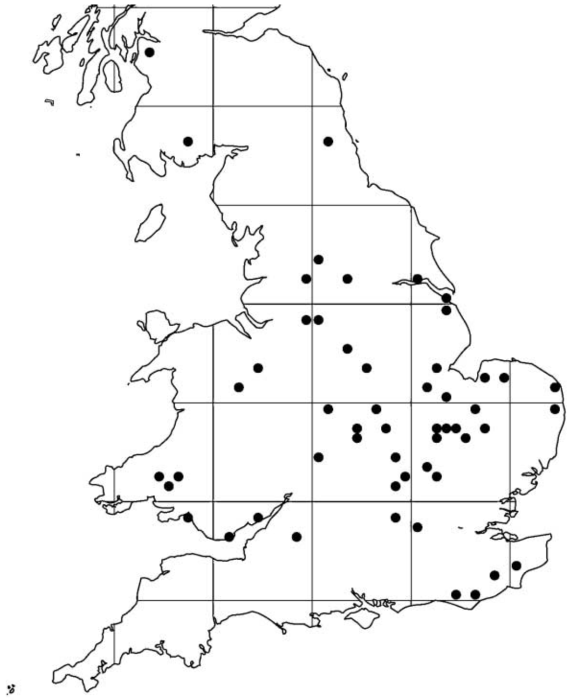

Figure 14.1 Distribution of Examples of S5 Glyceria maxima swamp (After Rodwell 1995)
The map does not indicate the complete distribution of S5, but rather indicates those samples of the NVC survey etc referred to S5.

14.2 Supply Mechanism and Conceptual Model

Reed sweet-grass swamps occur in and by still water, and the most important areas within the Anglian Region occur on the washes of major rivers, with much smaller stands lining slowflowing rivers and drainage channels. The classic washland (e.g. the Ouse and Nene Washes of Fenland) channels winter flood waters from the uplands onto an embanked floodplain through slackers (Figure 14.2). During the summer, lower water-levels in the main drains, and increased evapotranspiration from the highly productive reed sweet-grass stands leads to a lowering of the water-table. The duration and depth of this lowered water-

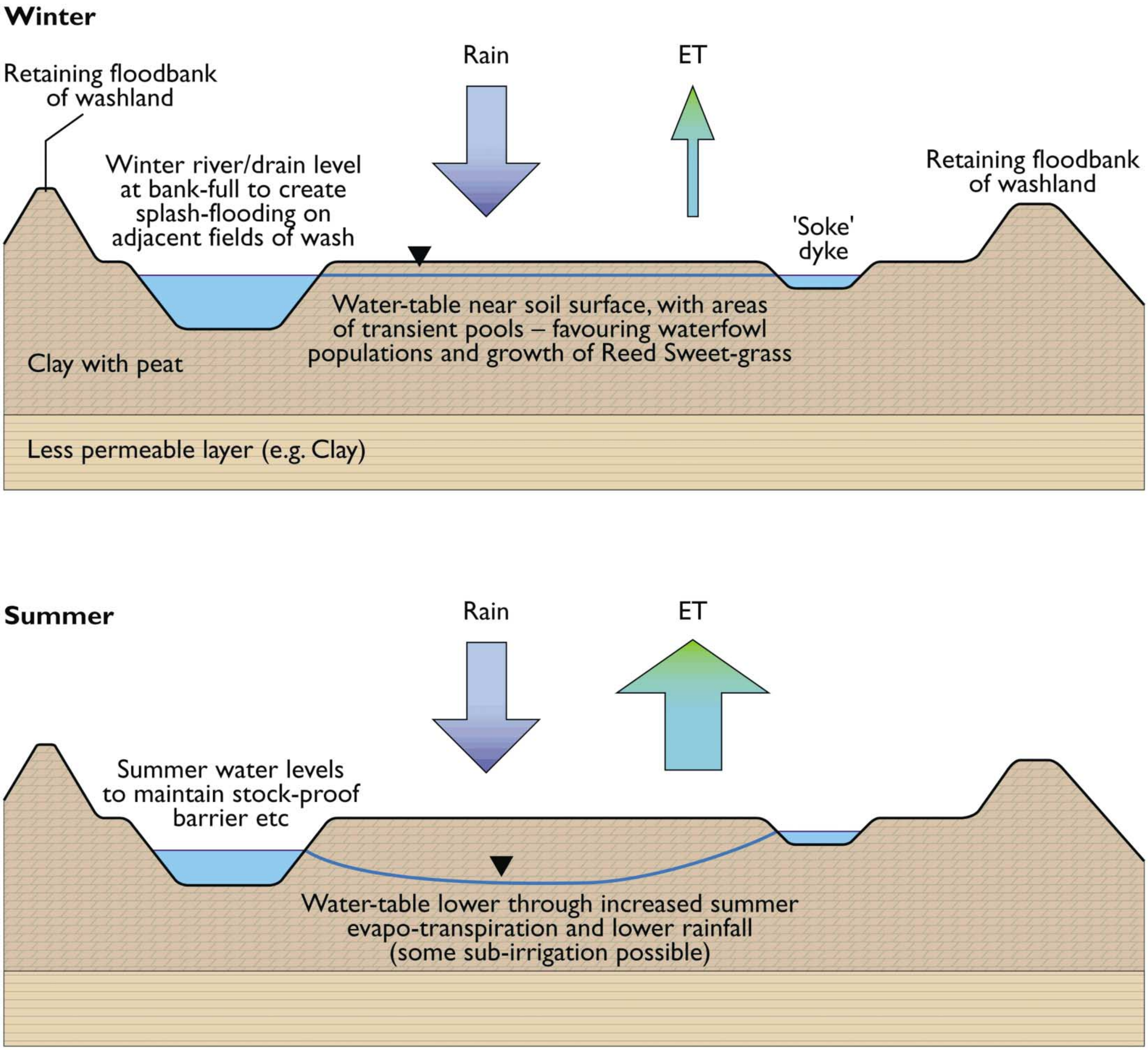

Figure 14.2 Conceptual Diagram of Major Water Fluxes in S5 Swamps, Especially on Washland

table determines the access for mowing machinery and stock, and hence the competitive balance between S5 swamp and lowland wet grasslands such as MG13 inundation grassland etc. Flood storage capacity is also available during the summer period, when severe short duration floods may threaten groundnesting birds. Prolonged flooding (especially in the growing season), coupled to elevated nutrient levels in the floodwater can favour S5 swamp at the expense of inundation grasslands (e.g. MG13) and species-rich meadow communities (e.g. MG8), since S5 thrives in a poorly aerated root-zone.

Smaller stands of S5 depend upon rainfall and runoff from the higher-lying land surrounding the grazing marsh to supply the drainage channels along which reed sweet-grass grows. The water-levels are regulated by sluices and pumps.

14.3 Regime

14.3.1 Water

Reed sweet-grass swamp is essentially a still-water community, which is absent where there is rapid lateral water movement - flows >0.5 km hour^{-1} will not support S5. Where there is slight flow or other disturbance, the reed sweet-grass swamp tends to be represented by the S5b subcommunity.

The ability of the *Glyceria maxima* to occur as “hover” means that S5 can occur over a very wide depth range, provided that the nutrient supply is good:

- Best growth and productivity occurs where the water-table is at substrate level or flooding the soil to a depth of +0.4 m;

Table 14.1 Water Regime Variables for S5 Swamps (excluding "hover")

Seasons and Variable	Green	Amber	Red
Winter (Dec - Feb)			
Mean water depth (maximum)/m	+0.9	+1.2	+1.5
Mean water depth (minimum)/m	-0.3	-0.75	-1.0
Maximum duration - single exposure event (days)			
Cumulative duration of exposure (days)			
Spring (Mar - May)			
Mean water depth (maximum)/m	+0.7	+1.0	+1.25
Mean water depth (minimum)/m	-0.6	-0.9	-1.2
Maximum duration - single exposure event (days)			
Cumulative duration of exposure (days)			
Summer (Jun - Aug)			
Mean water depth (maximum)/m	+0.7	+1.0	+1.25
Mean water depth (minimum)/m	-0.8	-1.0	-1.5
Maximum duration - single exposure event (days)			
Cumulative duration of exposure (days)			
Autumn (Sep - Nov)			
Mean water depth (maximum)/m	+0.8	+1.1	+1.3
Mean water depth (minimum)/m	-0.6	-0.9	-1.0
Maximum duration - single exposure event (days)			
Cumulative duration of exposure (days)			

Notes: 1) Water depth values given relative to soil/sediment surface; and 2) these values are based on published sources cited in references I and III, augmented with unpublished data for reed-swamps, tallherb fens and drainage channels collected by the authors of these guidelines.

- S5 extends to sites with the water-table is -0.8 m below soil surface and into water as much as +1.0 m deep;
- Where reed sweet-grass swamps occur in rich-fen systems, the normal water table is -0.01 to -0.8 m below the soil surface (mean ca -0.19 m);
- In contrast, results from drainage channels show a preferred mean water depth of +0.39 m.

S5 withstands regular marked changes in water depth. For example, within rivers in Broadland where freshwater is ponded back by the tides, the community will tolerate variation of up to 0.3 m, especially in its buoyant "hover" form. When "hover" becomes disconnected from the marginal swamp, the plants soon become chlorotic and die.

14.3.2 Vegetation Management

Although the balance between reed sweet-grass and reed is partly determined by the nutrient level, the management regime is very influential. Whereas reed is excluded by summer cutting and grazing, reed sweet-grass tolerates occasional defoliation during the growing season. Studies of individual catchments reveal that reed sweet-grass swamp is absent from those where there has been no improvement i.e. S5 is favoured by some combination of management, nutrient input and drainage of natural wetlands to ditched systems or washlands.

Within drainage channels, S5 occurs under a wide range of management regimes, but achieves highest cover in ditches that are protected from grazing and only cleaned out every 3–5 years or more. Such channels typically are overhung by bank-rooted woody and herbaceous vegetation, with up to 30% of the water surface shaded by such growth. Such occasionally managed ditches also have a moderate depth (*ca* 0.4m) of accumulated sediment.

Reed sweet-grass was once harvested for fodder early in the season and litter later in the year, and can be cut up to three times during the growing season. It is highly palatable to stock, and also eaten by wildfowl. However, more frequent cutting and intensive grazing will reduce the extent of the S5 swamp. Evidence from rich-fens shows that the community was most extensive (and productive) in sites both where stock had access only rarely and where the water-table is at substrate level.

14.4 Implications for Decision Making

14.4.1 Vulnerability

Given no other perturbation, the reed sweet-grass community will gradually succeed to a tallherb fen. Management may be required to prevent this, though more intensive cutting and grazing regimes reduce the extent of S5. Severe nutrient depletion reduces the vigour of reed sweet-grass, and may lead to community change. Likely transitions are illustrated in the Figure 14.3, but the main causes of S5 loss may be summarised as:

- Succession through to fen and carr;
- Severe nutrient depletion of water can alter competitive balance, allowing reed and other tall emergent swamp dominants to replace Reed Sweet-grass;
- Intensive grazing by livestock, waterfowl etc or mowing more than three times a year during the growing season will limit reed sweet-grass, though it will withstand more intensive winter cutting and grazing;
- Incursion of saline water.

Raising water-levels may lead to development of *Sparganium erectum* (S14) swamp, possibly through an intermediate stage of the S5b sub-community. Succession to tall-herb fen may begin with loss of associated species to form a reed sweet-grass monoculture (S5a). Composition of the fen that develops depends on whether there is associated nutrient depletion: S26d *Phragmites australis-Urtica dioica (Epilobium hirsutum* sub-community) where very eutrophic; S24b *Phragmites australis-Peucedanum palustre (Glyceria maxima* sub-community) where depletion is quite marked; and S28 *Phalaris arundinacea* in intermediate situations. Where terrestrial stands are cut or grazed intensively, S5 gives way to mesotrophic grasslands: MG13

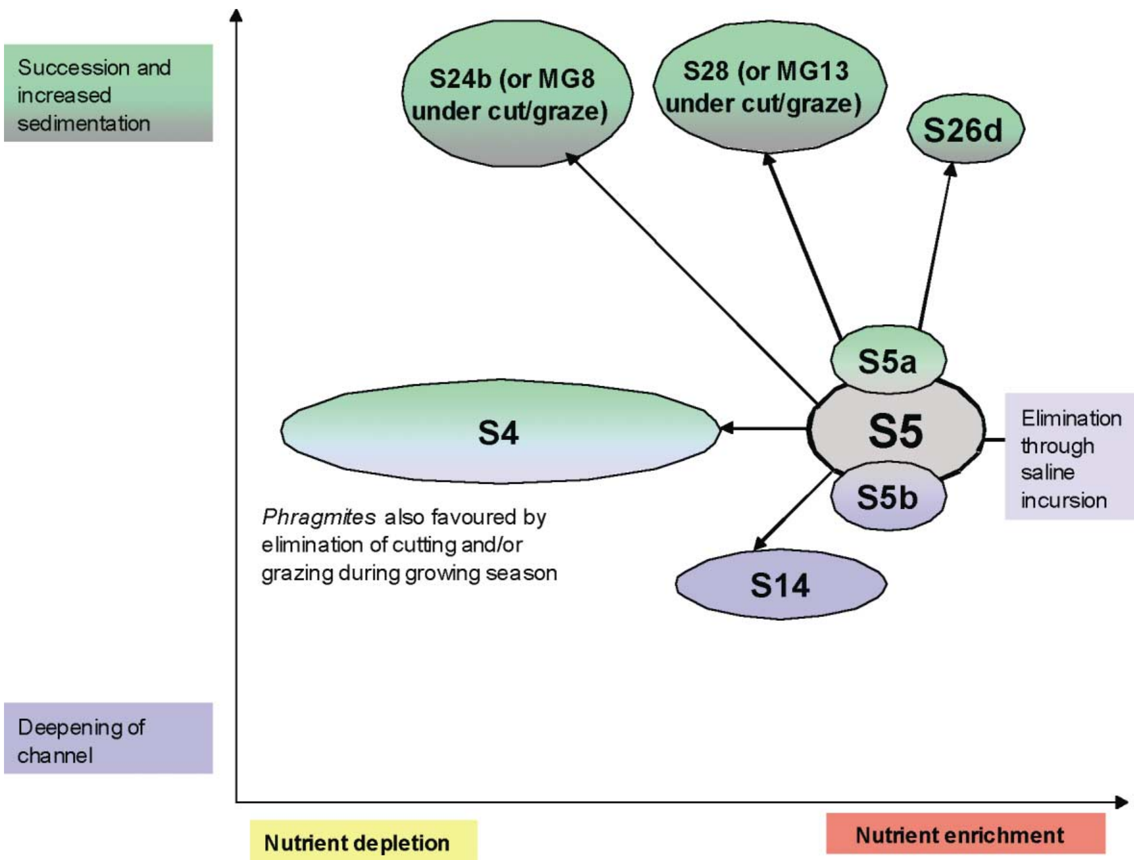

Figure 14.3 Trajectories of Community Change in Response to Succession and Changes in Water Chemistry

Agrostis stolonifera-Alopecurus geniculatus where nutrient levels are relatively high or MG8 *Cynosurus cristatus-Caltha palustris* where they become depleted. Nutrient depletion, without any deepening or sedimentation, is likely to lead to an S4 reedbed. Saline incursions into S5 may simply lead to vegetation death.

14.4.2 Restorability

Reed sweet-grass is readily introduced and maintained, provided site fertility is high and management favourable. The national distribution of such vegetation has increased over the past 50 years, especially in northern Britain, either from deliberate introduction or naturalisation and spread from sites where it was planted originally.

14.4.3 Gaps in knowledge

Reed sweet-grass and S5 are relatively well-researched, with information derived from both semi-natural situations and where it has been encouraged as a crop. More attention may be needed on the complexities of the various pathways by which both S4 and S5 swamps evolve into tall-herb fens, with particular reference to the preferred water - and nutrient-regimes. Such research might be of particular value where fen restoration schemes are proposed.

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Appendix A

Glossary

Abstraction	the removal of water from a groundwater source of surface water source.
Acidification	an increase in acidic conditions – essentially an increase in the number of hydrogen (H+) ions, causing a decrease in pH (less than pH7).
Adsorption	the adhesion of a liquid, gaseous or dissolved substance to a solid, resulting in a higher concentration of the substance.
Aerenchymotous	tissue in a plant containing large, intercellular air spaces.
Alluvial	Sediment which is transported by river and deposited at points along the flood plain of a river.
Anaerobic	refers to a process/activity that does not require oxygen to occur.
Anoxic	an environmental conditions which exists in the absence of oxygen.
Aquifer	geological source of groundwater seepage for example chalk aquifer.
Artesian	overflow of groundwater where water rises under pressure above the top of the aquifer without being pumped.
Autecology	the ecology of individual organisms and populations.
Basic	refers to the condition of a solution/habitat that has a decrease in hydrogen ions (pH higher than 7).
Basin mire	peat forming habitat in the 'hollow' of a valley.
Biodiversity	the variety of living organisms considered at genetic, species and higher taxonomic levels, and the variety of habitats and ecosystems as well as the processes occurring there.
Biogenic calcite precipitation	calcite produced by organisms or their activities.
Biomass	total dry weight of a selected species or all organisms in a sample, area or population.
Biota	living organisms.
Brackish	refers to the saline nature of water under marine influence?
Calcareous	the condition of a solution/habitat containing a comparatively higher concentration of calcium (Ca2+) ions.
CAMS	Catchment Abstraction Management Strategy.
Carr	wet woodland habitat in which typical species are willow and alder, typical on old river floodplains, bogs and fens or on the margins of open water bodies.
Cations	a positively charged ion.
CCW	Countryside Council for Wales, the statutory government agency for wildlife in Wales.
Chlorotic	a symptom of disease or disorder in plants, which involves a reduction in or loss of the normal green coloration.
Circumneutral	refers to a habitat/plant community that is at pH 7 (neutral).
Community	populations of different species inhabiting the same area or habitat bound together by their biotic relationships.
Conductivity	the property by virtue of which a substance allows the passage of an electric current.
Culm	stem of grasses and sedges.

Decalcified	the loss of calcite from a soil.
Defoliation	the loss of foliation (leaves).
Diffuse pollution	pollution from a non-specific location/sources number (e.g. surrounding farmland) that cannot be readily identified as occurring form a given point or location (e.g. a pipe).
Dipwell	perforated tube inserted into substrate to allow monitoring of water-table levels.
Ecohydrological	ecological conditions relating to water movement/regimes/ conditions.
Ecosystem	communities of organisms interacting with the abiotic (i.e. chemical and physical) environment as an ecological unit.
Emergent	relating to vegetation, vegetation that is normally partially submerged.
Empirical data	data obtained from observation of events occurring without the influence of scientific method.
Eutrophication	the nutrient enrichment of bodies of water caused by nutrient enrichment. This can either be a natural or artificial process.
FenBASE	an ecological database on fens maintained by the Wetland Research Group, University of Sheffield.
Floristic composition	the number of different plant species.
Ferrous	Iron (II) compounds.
Forb	an herbaceous broad-leaved, non-woody plant (i.e. that is neither a grass, a sedge nor a rush, and normally has obvious petals), often loosely referred to as ‘wild flowers’.
Freeboard	the vertical distance between water-level and bank-full i.e. distance that the water in a river or drainage channel can rise before it spills out over the surrounding land.
Gleyed	a soil that is permanently, or periodically, waterlogged and therefore anaerobic, characterised by blue-grey colours.
Grazing marsh	a landscape (rather than habitat), occurring mainly on low-lying land with little topographic variation, and comprising wet grassland with other features e.g. surface drainage channels. This landscape was created by the early phases of agricultural reclamation of floodplain and coastal wetlands, although but a large proportion of the original area was later subject to further drainage and converted to intensive arable land.
Gauge boards	A vertically aligned device for measuring surface water levels.
Hectare	1 hectare (Ha) is equal to 2.47 acres or 0.1 Km2.
Herbs	herbaceous non-woody plants with a relatively short lived aerial portion.
Hollows	lower elevations of the ground profile (see microtopography).
Humic	from decomposing organic matter (e.g. humic water from peat).
Humic-alluvial	an accumulation of organic matter in sediment deposited from running fresh water in a channel.
Hummocks	‘hump’ like structures of the ground profile (see microtopography).
Hydraulic connectivity	also referred to as hydraulic conductivity, K, the rate at which water moves through a material.
Hydraulic gradient	the change in hydraulic head or water surface elevation over a given distance.
Hydrological regime	the set of conditions relating to water depth, flow and water chemistry etc that occurs over a period of time.
Hydrosere	the succession of vegetation types whereby open water develops via fen to forest or bog.

Hypertrophic	extreme eutrophication.
Inundation	the periodic flooding of water into a region/habitat.
Ion	an atom or molecule that has lost or gained one or more electrons and is thus positively or negatively charged.
JNCC	the Joint Nature Conservation Committee, the UK governments wildlife adviser working on behalf o the three statutory conservation agencies (namely English Nature, Countryside Council for Wales and Scottish Natural Heritage).
Legumes	members of the pea/bean family of plants (Fabaceae) plants that from a symbiotic relationship with rhizobial bacteria that enables the plant to fix nitrogen from the soil.
Litter	dead plant material.
Loam	the relative composition of gravels, sand and clay that gives rise to a soil that contain essentially a balance of these components so that no one is more dominant. Ideal agricultural soils.
Macrophyte	bigger (i.e. not microscopic) aquatic plants and algae, including emergent, floating and submerged types. The term extends to larger filamentous algae, as well as flowering plants, but excludes planktonic algae.
Manganous	rich in the element Manganese (Mn).
Microtopography	the fine scale topographical profile of the ground/habitat (e.g. runnels, hummocks, hollows).
Mineralisation	the introduction of minerals into pre-existing rocks.
Mesotrophic	a habitat/community moderately rich in nutrients.
Monocotyledons	plants whose embryo has one cotyledon (seed leaf) upon emergence from the soil after germination; one of the two great classes of angiosperms (plants whose seeds are borne in fruit), the other being dicotyledons.
Monoculture	refers to the existence of a block or ‘stand’ of vegetation containing only one species.
N	nitrogen.
Naturalised alien	species that although originally not native to this country has established, spread and essentially widespread and ‘naturalised’.
NGO	non-government organisation (e.g. the wildlife trusts a charity based organisation.
Nutrient loading budget	the balance between nutrients (for example Nitrates and Phosphates) entering and leaving a system or catchment.
NVC	National Vegetation Classification – a classification for British plant communities.
Oligotrophic	a habitat/plant community that is low in nutrients.
Ombrotrophic	a habitat/plant community that is independent of groundwater influence relying upon rainwater for water and chemical input.
Oxidation	a reaction where an electron is lost by an atom or molecule.
P	phosphate.
Partially aquifer	condition where groundwater is partly prevented from rising to its true level by an confined overlying low permeability layer such as clay.
Piezometric head	the pressure of groundwater in the aquifer.
pH	a logarithmic scale of the number of hydrogen ions in a solution on a scale of 1 (very acidic) to 14 (very alkaline or basic). 7 is neutral pH.
Photosynthesis	the conversion (in plants) of light energy to chemical energy; the production of carbohydrates from carbon dioxide and water in the presence of chlorophyll using light energy.

Phytometer	device for measuring fertility/nutrients.
Phytosociology	the study of plant species in terms of their existence in communities.
Poaching	the trampling of the ground/soil by cattle.
Polymorphic	showing a great variety in shape and size.
Porosity	the 'porous' (sieve-like) nature of soils facilitating water movement.
Propagules	seeds or vegetative plant parts that are able to provide new growth of individual plants.
Quadrat	a standardised unit of area for ecological survey.
Rank fen	fen habitat containing and dominated by tall herbaceous plants.
Redox	a chemical process known as a reduction or reduction-oxidation reaction in which a metal is 'brought back' from its oxide – essentially one atom loses an electron and another gains it.
Rhizome	underground plant stem.
Runnels	shallow troughs.
SAC	Special Area of Conservation – a statutory European designated site (designated under the European Habitats Directive 1994), as a component of a protected area network called Natura 2000.
Saline intrusion	intrusion of marine saltwater.
Secondary vegetation	vegetation type formed as a consequence of anthropogenic (human influenced) activities.
Slackers	local term used in Eastern England for pipes used to transfer water by gravity from a river to an artificial drainage ditch system at a lower elevation.
Soligenous	wetness induced by water supply (seepage slopes etc).
SPA	Special Protection Area – a statutory European designated site (designated under the European Birds Directive 1992), as a component of a protected area network called NATURA 2000.
Species composition	the number of species present.
Species richness	the number of species present in an area.
Stand	a 'block' of homogeneous vegetation.
Succession	process or sequence whereby one ecological community replaces another eventually leading to a climax community which remains relatively stable in terms of transition.
Telluric	water derived from the earth, e.g. river water.
Terrestrialisation	a process induced either by lowering of the water table or vegetative succession whereby a habitat/plant community becomes independent of aquatic influence, usually leading to the persistence of terrestrial species.
Topogenous	indicates situations where a mire (fen, bog etc), develops due to concentration of the water in a region by drainage from a catchment e.g. around an open water body, in a basin or along floodplains.
Transmissivity	the product of hydraulic conductivity and the saturated thickness of the aquifer, and represents the ability of the aquifer to transmit water through its entire thickness.
Tufaceous concretion	a hard, compact mass or aggregate of mineral matter formed by the deposition or precipitation of calcium carbonate.
Turions	the resting buds of plants.

Tussock	a raised and compact above ground vegetative structure consisting of dead stems.
Unconfined aquifer	Aquifer that outcrops at the surface where the water table occurs within the aquifer.
Water budget	the identification and estimation of the inflow and outflow components of the total catchment.
Waders	birds reliant upon mudflats in the intertidal regions of shorelines and estuaries for feeding/breeding.
Waterfowl	birds reliant upon aquatic habitat and associated fringe habitats for feeding/breeding.
Wetland	An area of low-lying land where the water table is at or near the surface most of the time, leading to characteristic habitats.
WFD	Water Framework Directive.
WLMP	water level management plan.

Appendix B

Species Names

Scientific	English
Agrostis stolonifera	Creeping bent
Alisma plantago-aquatica	Water-plantain
Alnus glutinosa	Alder
Alopecurus geniculatus	Marsh foxtail
Anagallis tenella	Bog pimpernel
Aneura pinguis	a Liverwort
Arrhenatherum elatius	False oat-grass
Aster tripolium	Sea aster
Atriplex portulacoides	Sea-purslane
Atriplex prostrata	Spear-leaved orache
Berula erecta	Lesser water-parsnip
Bolboschoenus maritimus	Sea club-rush
Briza media	Quaking-grass
Bryum pseudotriquetrum	a moss
Calamagrostis canescens	Purple small-reed
Calliergon cuspidatum	a moss
Callitriche platycarpa	Various-leaved water-starwort
Caltha palustris	Marsh-marigold
Campylium elodes	A moss
Campylium stellatum	A moss
Carex dioica	Dioecious sedge
Carex elata	Tufted-sedge
Carex hirta	Hairy sedge
Carex hostiana	Tawny sedge
Carex paniculata	Greater tussock-sedge
Carex pulicaris	Flea sedge
Carex rostrata	Bottle sedge
Carex viridula ssp brachyrrhyncha	Yellow-sedge
Centaurea nigra	Common knapweed
Ceratophyllum demersum	Rigid hornwort
Ceratophyllum submersum	Soft hornwort
Cicuta virosa	Cowbane
Cirsium dissectum	Meadow thistle
Cirsium palustre	Marsh thistle

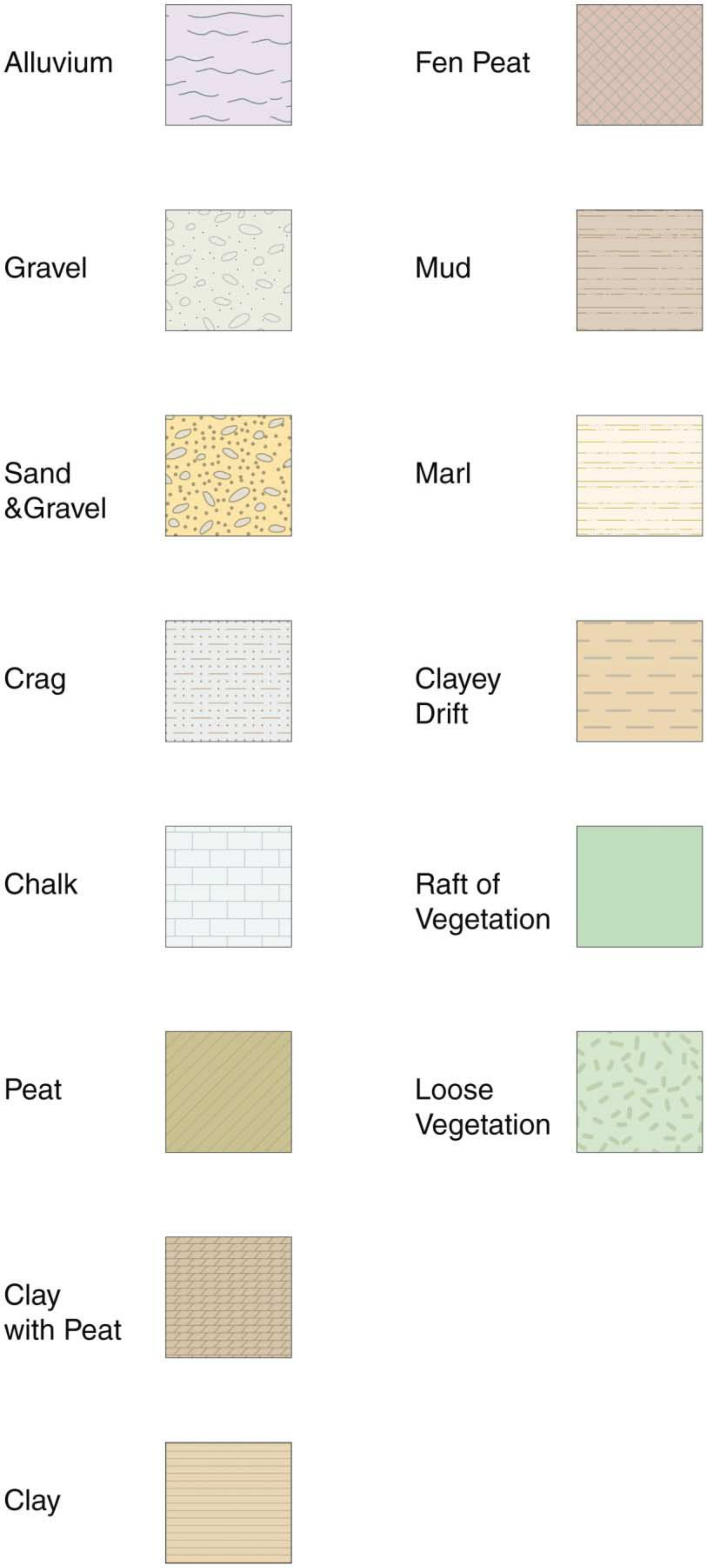
Scientific	English
Cladium mariscus	Great fen-sedge
Cratoneuron commutatum	a moss
Cynosurus cristatus	Crested dog's-tail
Dactylis glomerata	Cock's-foot
Dactylorhiza incarnata	Early marsh-orchid
Dactylorhiza praetermissa	Southern marsh-orchid
Dactylorhiza traunsteineri	Narrow-leaved marsh-orchid
Deschampsia cespitosa	Tufted hair-grass
Drepanocladus lycopodioides	a moss
Drepanocladus revolvens	a moss
Drepanocladus vernicosus	a moss
Drosera longifolia (Drosera anglica)	Great sundew
Eleocharis palustris	Common spike-rush
Eleocharis quinqueflora	Few-flowered spike-rush
Elodea canadensis	Canadian waterweed
Elodea nuttallii	Nuttall's waterweed
Elytrigia atherica	Sea couch
Epilobium hirsutum	Great willowherb
Epipactis palustris	Marsh helleborine
Erica tetralix	Cross-leaved heath
Eriophorum latifolium	Broad-leaved cottongrass
Eupatorium cannabinum	Hemp-agrimony
Euphrasia pseudokerneri	an eyebright
Festuca pratensis	Meadow fescue
Festuca rubra	Red fescue
Filipendula ulmaria	Meadowsweet
Fissidens adianthoides	a moss
Fraxinus excelsior	Ash
Galium palustre	Common marsh-bedstraw
Galium uliginosum	Fen bedstraw
Geum rivale	Water avens
Glaux maritima	Sea-milkwort
Glyceria fluitans	Floating sweet-grass
Glyceria maxima	Reed sweet-grass
Gymnadenia conopsea	Fragrant orchid
Heracleum sphondylium	Hogweed
Holcus lanatus	Yorkshire-fog
Hottonia palustris	Water-violet

Scientific	English
Hydrocharis morsus-ranae	Frogbit
Iris pseudacorus	Yellow iris
Juncus acutiflorus	Sharp-flowered rush
Juncus gerardii	Saltmarsh rush
Juncus subnodulosus	Blunt-flowered rush
Lathyrus pratensis	Meadow vetchling
Lemna gibba	Fat duckweed
Lemna minor	Common duckweed
Lemna trisulca	Ivy-leaved duckweed
Leucanthemum vulgare	Oxeye daisy
Liparis loeselii	Fen orchid
Listera ovata	Common twayblade
Lolium perenne	Perennial rye-grass
Lotus corniculatus	Common birds-foot-trefoil
Lychnis flos-cuculi	Ragged-robin
Lysimachia vulgaris	Yellow loosestrife
Lythrum salicaria	Purple-loosestrife
Mentha aquatica	Water mint
Menyanthes trifoliata	Bogbean
Moerckia hibernica	A liverwort
Molina caerulea	Purple moor-grass
Myriophyllum verticillatum	Whorled water-Milfoil
Nuphar lutea	Yellow water-lily
Oenanthe aquatica	Fine-leaved water-dropwort
Oenanthe fistulosa	Tubular water-dropwort
Parnassia palustris	Grass-of-Parnassus
Pedicularis palustris	Marsh lousewort
Pellia endiviifolia	a liverwort
Persicaria amphibia	Amphibious bistort
Peucedanum palustre	Milk-parsley
Phalaris arundinacea	Reed canary-grass
Philonotis calcarea	a moss
Philonotis fontana	a moss
Phragmites australis	Common reed
Pinguicula vulgaris	Common butterwort
Plagiomnium elatum	a moss
Plagiomnium ellipticum	a moss
Plantago lanceolata	Ribwort plantain

Scientific	English
Plantago maritima	Sea plantain
Poa trivialis	Rough meadow-grass
Potamogeton coloratus	Fen pondweed
Potamogeton natans	Broad-leaved pondweed
Potamogeton obtusifolius	Blunt-leaved pondweed
Potentilla palustris	Marsh cinquefoil
Preissia quadrata	a liverwort
Prunella vulgaris	Selfheal
Puccinellia maritima	Common saltmarsh-grass
Pulicaria dysenterica	Common fleabane
Ranunculus flammula	Lesser spearwort
Rhinanthus minor	Yellow-rattle
Riccardia chamedryfolia	a liverwort
Riccardia multifida	a liverwort
Rorippa nasturtium-aquaticum	Water-cress
Rumex crispus	Curled dock
Sagina nodosa	Knotted pearlwort
Salicornia dolichostachya	Long-spiked glasswort
Sanguisorba officinalis	Greater burnet
Schoenus nigricans	Black bog-rush
Scorpidium scorpioides	a moss
Selinum carvifolia	Cambridge milk-parsley
Silaum silaus	Pepper-saxifrage
Sium latifolium	Greater water-parsnip
Sparganium erectum	Branched bur-reed
Sparganium minimum (Sparganium natans)	Least bur reed
Sphagnum spp.	a moss
Spirodela polyrhiza	Greater duckweed
Stratiotes aloides	Water-soldier
Symphytum officinale	Common comfrey
Thelypteris palustris	Marsh fern
Trifolium pratense	Red clover
Triglochin maritimum	Sea arrowgrass
Typha angustifolia	Lesser bulrush
Urtica dioica	Common nettle
Utricularia vulgaris	Greater bladderwort

Appendix C

Key to Patterns Used to Represent Strata in Cross-sections



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