S1 (*Carex elata*) swamp and S2 (*Cladium mariscus*) swamp

17.1 Context

Examples of the S2 community have been included within the 'calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*' SAC feature. S1 is an uncommon 'tufted sedge' or 'tall sedge' fen community that does not correspond to any specific European designated (SAC or cSAC) feature.

17.1.1 Floristic composition

S1 is typically dominated by tussocks of *Carex elata*, whilst S2 is a tall sedge community of wet fens and swamps characterised by the dominance of *Cladium mariscus*. Both communities are typically species-poor supporting few uncommon species, though some stands of S1 are important in supporting populations of the rare grass *Calamagrostis stricta* as this often grows on the tops of *C. elata* tussocks. The absence of species found in drier fens and the occasional occurrence of some tall herbs and species of shallow water/swamp help to provide positive characterisation.

Rodwell (1995) recognises no sub-communities within S1 but two sub-communities of S2: *Cladium mariscus* sub-community (S2a); *Menyanthes trifoliata* sub-community (S2b).

17.1.2 Distribution

The two main centres of both S1 and S2 are East Anglia and (to a lesser extent) Ynys Môn, Anglesey (Figures 17.1 and 17.2). Both are characteristic of many wet ground hollows in central and western Norfolk. Elsewhere they grow around the margins of lakes and pools, in overgrown ditches and reflooded peat pits. S2 in particular is an important recolonist community of some reflooded turf ponds in Broadland. S2 is the more widely distributed of the two communities (recorded from 48 sites), occurring also around pools in the West Midlands, NW England, Yorkshire and parts of Scotland (particularly in the west), whilst S1 is more localised and recorded from only 21 sites. Both communities are considerably less well distributed that their nominative species.

Figure 17.1 Distribution of S1 in England and Wales (from FENBASE database)

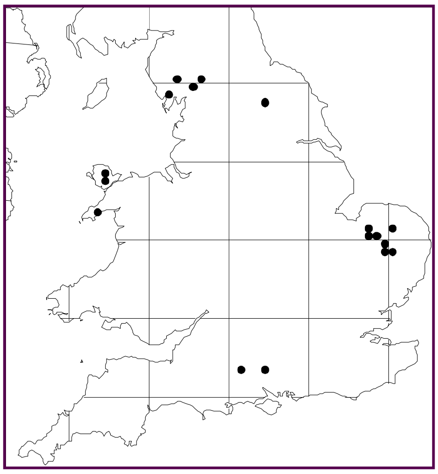
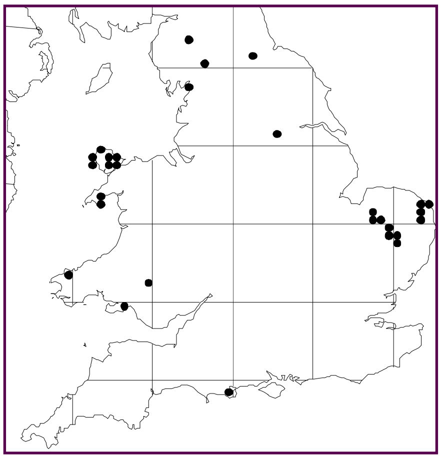


Figure 17.2 Distribution of S2 in England and Wales (from FENBASE database)



17.1.3 Landscape situation and topography

The communities are associated with shallow depressions and small basins or around the margins of lakes and pools. They occur in valleyhead situations, particularly where there are shallow ground hollows, some of which may be pingos or other ground ice depressions, or occluded ditches. Examples recorded from floodplains are all in reflooded peat workings and occluded ditches.

17.1.4 Substratum

The communities occasionally form semi-floating root-mats but most examples are rooted in fen peat or in muddy basin and dyke sediments. Thickness of peat infill ranges from skeletal in examples around the margins of shallow ground hollows, to deep (more than 4 m) in some examples in turf ponds and ditches on floodplains. Some examples around lakes have developed hydroserally over lake muds and marls.

17.1.5 Zonation and succession

Examples of both communities occur peripheral to open water and can form part of terrestrialisation sequences. Clear zonations occur around some of the shallow ground hollows in West Norfolk. Both S1 and S2 can directly adjoin open water, or they may occur in the sequence: open water › S2 › S1. However, frequently such neat sequences do not occur and the distribution of S2 in particular can be idiosyncratic, neither forming clear zones nor occupying discrete ranges of water table. *Carex elata* and *Cladium* quite frequently form mixed swamps, which are not referable clearly to either community. In some cases, entire basins can be occupied by one or both of the communities. Both communities can be truncated on the landward margin and are adjoined by dry ground, but frequently they grade outward into another community, most often M22. In some sites (such as Cors Goch (Anglesey), Cors y Farl (Anglesey), Sunbiggin Tarn (Cumbria)), S2 may grade outwards into M9-2 and at Newton Reigny (Cumbria), a patch of *Cladium* (which might perhaps be considered to be S2) is embedded within M9-2 in a turf pond. In Broadland, S2 sometimes occupies the wettest locations in turf ponds, and can grade out into various other communities, including M9-3 and various, mostly *Cladium*-dominated, forms of S24.

Whilst S1 and S2 sometimes occur in close proximity, or intermingled, in some locations they occupy separate ground hollows for reasons that are not entirely apparent. In certain ground depressions in West Norfolk, S1 can be particularly associated with hollows surrounded by a more acidic drift, and with a lower water pH than S2, suggesting an association with slightly less base-rich conditions than S2 (and also raising questions about the precise groundwater source to the hollows). Another difference between them is that *Carex elata* is much more shade-tolerant than *Cladium*, raising the possibility that the differential distribution of the communities may sometimes relate to past habitat conditions (shaded *versus* unshaded).

The occurrence of clear community zonations around pools is not necessarily indicative of terrestrialisation sequences, but stratigraphical studies suggest that both S1 and S2 can form pioneer swamp communities which become replaced by a less wet form of fen. S1 is also particularly prone to direct colonisation by woody plants, which sometimes gain a foothold on tussock tops, and entire basins of swamp carr based on *Carex elata* tussocks sometimes occur. By contrast, scrub invasion of S2 is often very slow, first because of the wet conditions and then because of the strong dominance by *Cladium*, expressed in terms of the thick leaf canopy and, particularly, the accumulation of dense mattresses of dead, decay-resistant leaves.

In one site (Pilmoor, Yorks) there is clear stratigraphical and visual evidence of the development of *Sphagnum*-dominated vegetation (M5) over former S1 swamp. Such acidification has no known counterparts, and may be a response to a lowering of the telluric water level within the basin, so that the surface is now largely, if not exclusively, rain-water fed.

17.2 Supply mechanism and conceptual model

S1 and S2 are invariably associated with wet, swampy conditions in fens. Many examples occur in depressions with considerable vertical water level fluctuation that may episodically dry out (WETMEC 12, fluctuating seepage basins such as Foulden Common, East Walton Common (both in Norfolk)). Other examples are associated with more constant inputs of groundwater (WETMEC 13, seepage percolation basins such as Cors Erddreiniog (Anglesey), Cors Goch (Anglesey), Great Cressingham Fen (Norfolk), Newton Reigny (Cumbria)) or surface water (WETMEC 6, surface water percolation floodplains such as Catfield Fen (Norfolk)); these may occur in peat cuttings but may also form the main vegetation of some occluded ditches.

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

Groundwater-fed examples are associated with base-rich bedrocks (Chalk or Limestone) although the majority are not obviously associated with strong springs. Their wetness seems to be determined by the intersection of the topography with the water table. The source of groundwater supply to the depressions in the valleyhead fens (that is, chalk water *versus* drift) is not well understood and may vary within individual sites.

The main water supply mechanisms are illustrated schematically in Figure 17.3.

17.3 Regimes

17.3.1 Water

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 17.1, together with mean recorded values for summer water table associated with stands of S1 and S2. Water levels associated with S1 and 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. S2 can extend into deeper water than S1, but generally the two occupy a similar depth range.

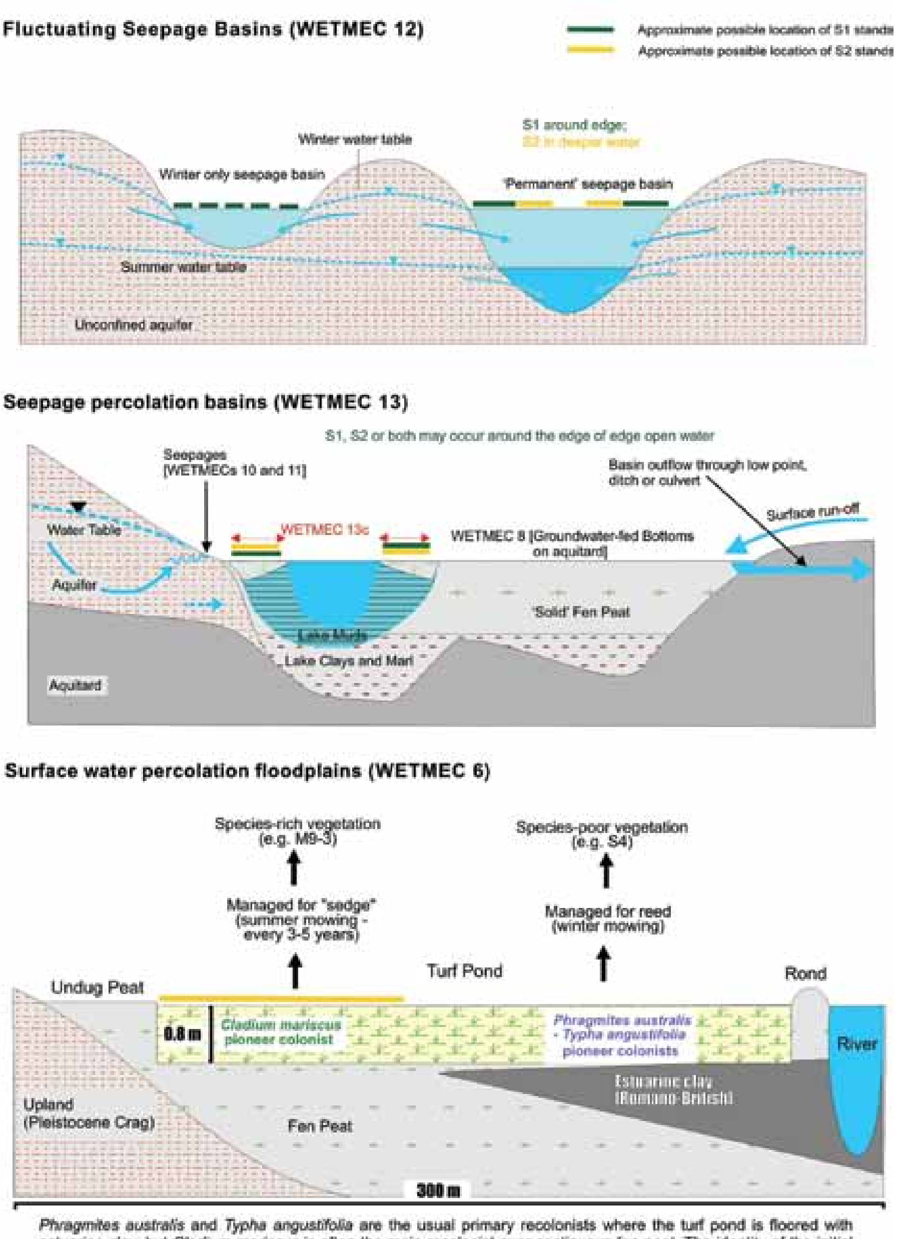
In some East Anglian valleyhead fens, gauge board readings point to water level fluctuations in some ponds of up to about 2 m, indicating periodic deep flooding or subsurface water tables (or both). Although good comparative data do not exist, there is strong reason to suspect that the development of aquatic macrophytes (for example, *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 (for example, 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 S1 and S2 communities 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 S1 and S2 are not available. It is therefore not possible to specify precise water regimes, or tolerance to change, but the following comments can be made:

Table 17.1 Rainfall, potential evaporation and water table data for S1 and S2

	Community	Mean	Min	Max
Rainfall (mm a^{-1})	S1	710	622	994
	S2	827	604	1,348
Potential Evaporation (mm a^{-1})	S1	608	601	613
	S2	596	467	646
Mean Summer Water Table (cm agl or bgl)	S1	6.8	-5	20
	S2	12.9	-20	50

Figure 17.3 Schematic representation of the major water supply mechanisms to S1 and S2 (after Wheeler, Shaw and Tanner, 2009)



Phragmites australis and *Typha angustifolia* are the usual primary recolonists where the turf pond is floored with estuarine clay, but *Cladium mariscus* is often the main recolonist over continuous fen peat. The identity of the initial colonist species appears to determine the subsequent management and species richness of these different parts of turf ponds, although, *Cladium* sometimes invades the reedbeds at a later phase of the successional process.

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). S1 vegetation does not grow in as deep water as S2, but otherwise it has a similar habitat range.

- S1 and 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.

- The tussocky nature of S1 swamp means that it can be prone to scrub colonisation, even when water tables are high. It is presumed that grazing management would be instrumental in preventing this process. The tussock tops also provide a niche for the rare grass *Calamagrostis stricta*.

Sub-optimal and damaging conditions

- *Cladium* seems to be limited by water depth. Protracted subsurface water tables or inundation ›c. 40–50 cm may lead to a loss of *Cladium* vigour, but not necessarily loss of this species.

- Where the vegetation is semi-floating, ongoing hydroseral processes may lead to development of communities such as M9-2 and M9-3, with an 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.

- The tussock-top niche for Calamagrostis stricta provided by *Carex elata* is relatively dry and the reason for the association is not certain.

17.3.2 Nutrients/hydrochemistry

S2 is typically found in base-rich and oligotrophic to mesotrophic conditions. Table 17.2 presents figures for pH, conductivity and substratum fertility measured in stands of S2.

Whilst *Phragmites* can be a swamp dominant in low-fertility conditions, it is also widely found in eutrophic and hypertrophic circumstances, whereas *Cladium* and *Carex elata* swamp appear consistently to be a feature of low-fertility locations. S2 occurs over a wide range of electrical conductivity. Particularly high conductivities were recorded in association with *Cladium* in the Thurne valley of Broadland, especially at Brayden Marshes.

Table 17.2 pH, conductivity and substratum fertility measured in stands of S2

Variable	Mean	±SE	Min	Max
Water pH	6.5	0.06	5.7	7.6
Soil pH	6.3	0.10	5.0	7.2
Water conductivity (Kcorr µS cm^{-1})	1,616	14.4	157	7,530
Substratum fertility[25] (mg phytometer)	7.9	0.48	3	12

[25] Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently the technique of phytometry (measuring the biomass of test species (phytometers) grown on soil samples) was developed. Typical phytometer yields (dry wt.); low fertility ‹ 8 mg, high fertility › 18 mg.

Wheeler and Shaw (1991) report that *Cladium* dominated stands of S2 have a high April standing crop (>250 g m^{-2}) compared with other tall herbaceous fen types but a surprisingly modest April to September standing crop increment (at around 600 g m^{-2}). This reflects the winter-green, long-lived character of *Cladium* foliage, and the relatively low fertility conditions.

Too few hydrochemical data are available from S1 to permit generalisations to be made. The community can occupy conditions as base-rich as those in which S2 occurs (for example, a water pH of 7.5 was measured in S1 at Llyn wyth yr Eidion, Cors Erddreiniog Anglesey). However in other circumstances *Carex elata* swamp has been recorded from relatively base-poor conditions, without *Cladium* (for example, a water pH of 5.3 was measured in S1 at Pilmoor, North Yorkshire).

17.3.3 Management

S2 tends not to receive any specific management except where it occurs alongside or within S24 and M9-3 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, (for example, S24, S25, M24).

Some stands of S1 (& S2) are sometimes grazed by cattle or horses.

17.4 Implications for decision making

17.4.1 Vulnerability

Figures 17.4 and 17.5 respectively outline some of the possible impacts of changes to the S1 and S2 stand environments. 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 for example, aquatic macrophytes (where they occur), followed by development of rank fen, rapidly becoming wooded without management. This process can be slow because of high water tables and constraints on scrub establishment caused by dense vegetation and persistent litter.

17.4.2 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 (for example, numbers of species lost, damage to substratum, degree of enrichment etc). The potential for restoring stands of S1 or S2 to dehydrated or derelict sites is largely untested (most pertinent fen restoration trials are at a relatively early phase), though the propensity for *Cladium* swamp to spontaneously colonise re-flooded turf ponds in the past is encouraging.

17.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here related to S1 and S2 include the following:

- There are currently virtually no data to better inform the temporal water table characteristics of S1 and 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 S1 and S2 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at ‘representative’ sites.
- The potential for restoring stands of S1 and S2 to dehydrated or derelict sites is largely untested.
- Data on the spatial extent of S1 and S2 are lacking.
- Possible differences in environmental conditions influencing the sub-communities have not been explored here.
- More information is needed on tolerance to nutrient enrichment and nutrient budgets.
- More information is needed on appropriate restoration techniques.

Figure 17.4 The possible effects of environmental change on stands of S1

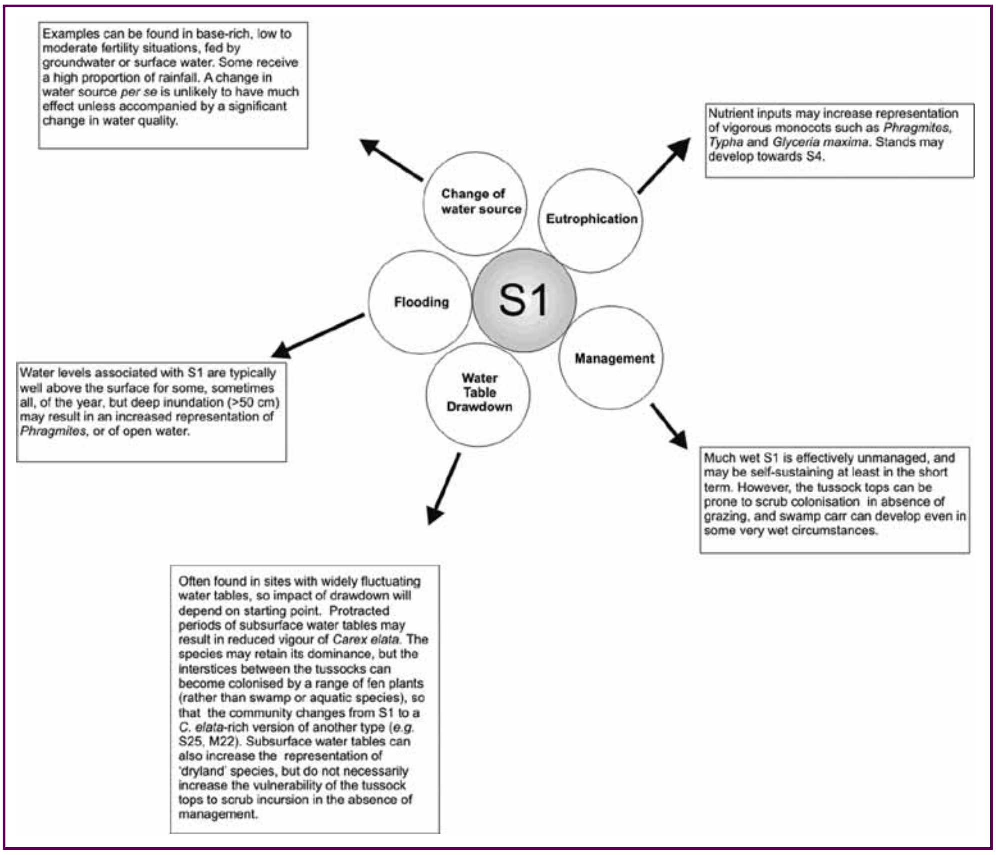
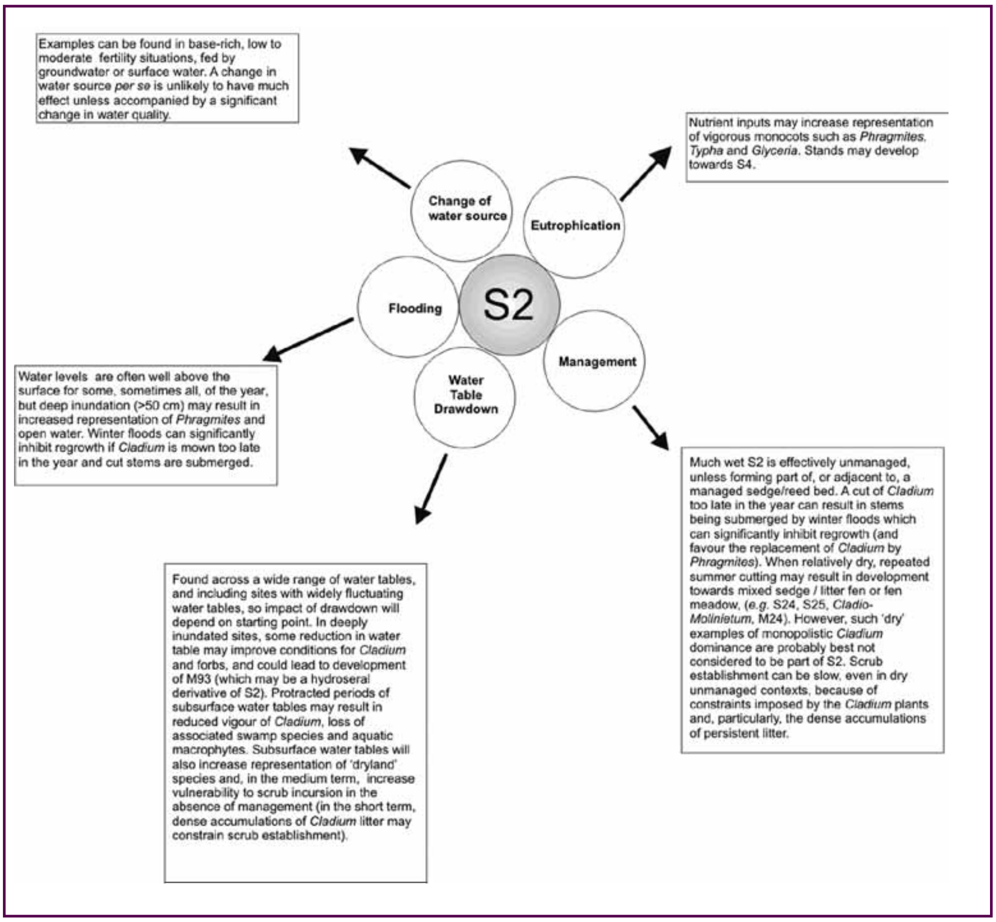


Figure 17.5 The possible effects of environmental change on stands of S2



S24 (*Phragmites australis – Peucedanum palustre*) tall-herb fen

18.1 Context

Examples of the S24 community have been included within the 'calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae'* SAC feature (although note that not all stands of S24 necessarily support *Cladium mariscus*).

18.1.1 Floristic composition

Tall herbaceous fen community with monocotyledons, notably *Phragmites australis* and *Cladium mariscus*, as the major structural component. Extremely variable in composition (mean = 17; range = 2–46 spp per sample (Rodwell, 1995)), ranging from species-rich to species poor with a wide range of associated tall forbs (for example, *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 many rare or infrequent mire species, including *Calamagrostis canescens, Calliergon giganteum, Campylium elodes, Campylium polygamum, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Cicuta virosa, Cinclidium stygium, Cladium mariscus, Dactylorhiza praetermissa, Dryopteris cristata, Eleocharis uniglumis, Epipactis palustris, Lathyrus palustris, Oenanthe lachenalii, Osmunda regalis, Peucedanum palustre, Plagiomnium elatum, Plagiomnium ellipticum, Potamogeton coloratus, Pyrola rotundifolia, Ranunculus lingua, Rhizomnium pseudopunctatum, Sium latifolium, Sonchus palustris, Stellaria palustris, Thalictrum flavum* and *Thelypteris palustris*. It is the main community supporting *Peucedanum palustre*, the food plant of the rare swallow-tail butterfly (*Papilio machaon*).

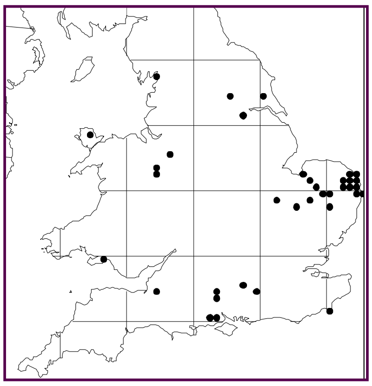
Rodwell (1995) recognises six sub-communities of S24: *Carex paniculata* sub-community (S24a); *Glyceria maxima* sub-community (S24b); *Symphytum officinalis* (S24c); typical sub-community (S24d); *Cicuta virosa* sub-community (S24e), *Schoenus nigricans* sub-community (S24f).

18.1.2 Distribution

In England and Wales, S24 has been recorded from 115 wetland sites. It is very localised and primarily based in Broadland (where it is widespread and extensive), with outliers in a few other East Anglian sites (such as Cranberry Rough and Swangey Fen). It also occurs at Wicken Fen, 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 (such as Crymlyn Bog (Glamorgan), Test Valley (Hampshire), and in small patches associated with some of the West Midlands meres) although the taxonomic relationship of these stands to S24 remains to be clarified.

The distribution of the community is shown in Figure 18.1.

Figure 18.1 Distribution of S24 in England and Wales (from FenBASE database)



18.1.3 Landscape situation and topography

The majority of examples occur in floodplain situations – they form the main herbaceous vegetation over much of the Broadland fens and occupy some of the residual undrained surfaces in Fenland and the Somerset Levels. Some variants occur in basins and troughs.

18.1.4 Substratum

S24 usually occurs on solid fen peat or as a quaking or semi-floating turf pond infill over fen peat. In many cases the peat is deep (> 4m) and continuous and often has a lower layer of rather dense brushwood peat, but in Broadland the alluvial infill often contains a layer of estuarine clay some 50 to 100 cm bgl. Hydroseral examples, both natural and around deep peat workings, may occur over a considerable accumulation of lake muds and, occasionally, marl.

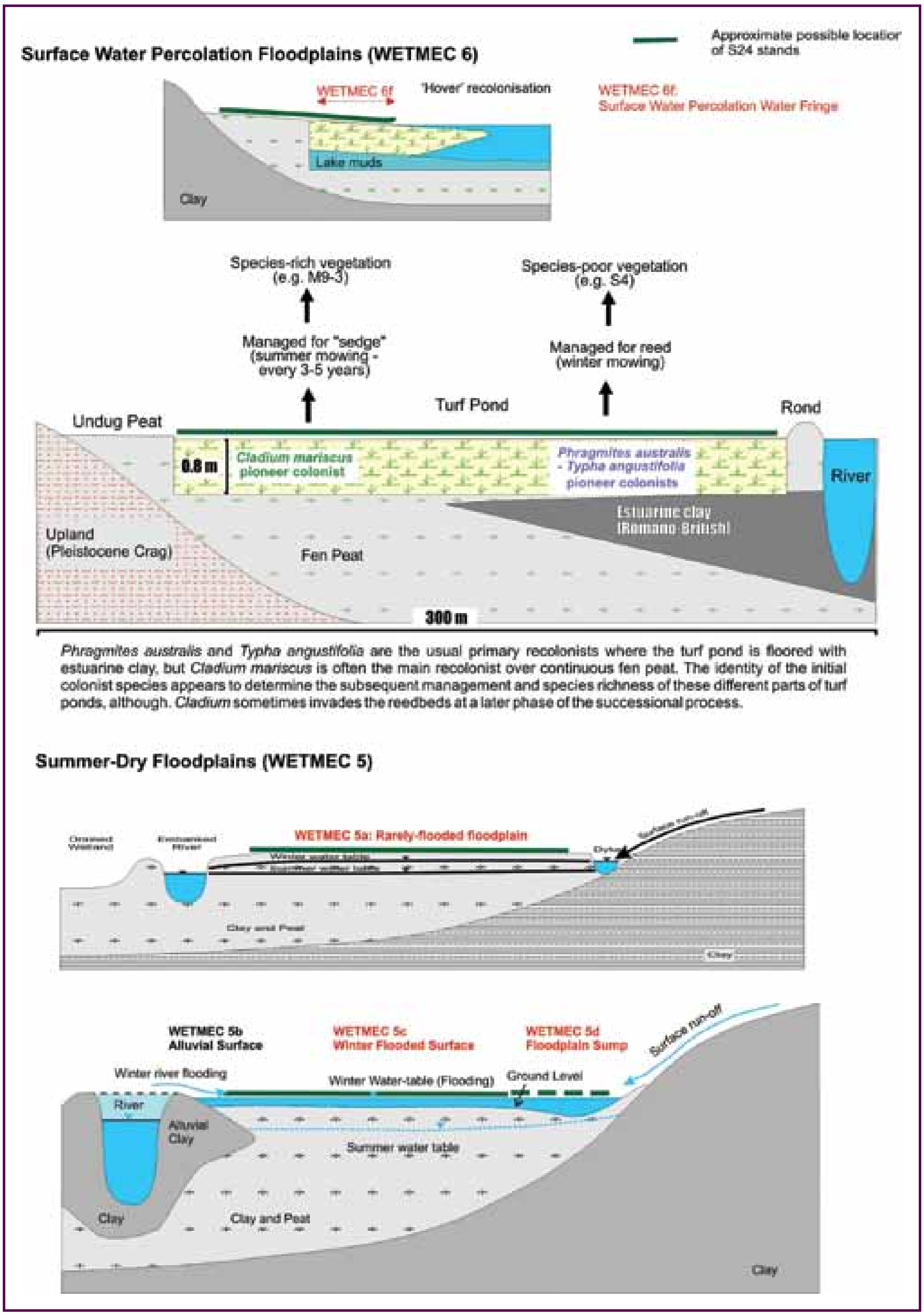
18.1.5 Zonation and succession

Some examples of S24 effectively occur as isolated blocks in residual wetland areas adjoined by, and sometimes elevated above, agricultural land on drained, former wetland surfaces, and are essentially unconformable with their surroundings. In some of these sites, such as Wicken Fen, the S24 vegetation is rather dry and impoverished. Elsewhere, and particularly in Broadland, S24 occurs widely over relatively intact floodplains. Even here, however, natural zonations are often difficult to detect, because the precise character of the vegetation has been much influenced by management past and present, and in places by past peat removal, producing a patchwork of stands of varying character.

Nonetheless, there are some underlying environmental gradients, relating particularly to the proximity of rivers and presence or absence of estuarine clay, and it is possible to detect some broad vegetation patterns derived from either the development of different sub-communities of S24, or the juxtaposition of S24 with others. *Glyceria maxima* is prominent in parts of these fens, and some of the vegetation is referable to S24b. However, much of the vegetation is dominated by reed, to form stands variably referable to S24b, S24d, S25 and even S4. Reed is particularly prominent close to watercourses and at Wheatfen, there is a tendency for a gradual decline in reed dominance and productivity (and an inverse increase in species richness) with distance from the River Yare.

The preceding observations relate to zonations associated with solid peat and shallow turf ponds, but some of the best known zonations involving S24 occur in hydroseral contexts around some of the broads (Lambert 1946, 1951 and Rodwell 1995). In essence, S24 can form a hydroseral zone on the landward side of various swamp communities, including S2, S3, S4 and S5, with a different sub-community of S24 often being tied into a particular type of precursor swamp: S2 > S24e or S24d; S3 > S24a; S4 > S24d; S5 > S24b. However, the occurrence of *any* significant extent of S24 in these hydroseral zonations is dependent on mowing management, which both prolongs the herbaceous fen phase of the seral sequence and modifies its species composition. In the absence of management, S24 is likely to be fragmentarily developed, and more comparable with small fragments of fen found in the compressed zonations around some of the West Midland meres.

Figure 18.2 **Schematic representation of the major water supply mechanisms to S24 (after Wheeler, Shaw and Tanner, 2009)**



18.2 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 (for example, East Ruston Common and Upton Fen). In some other cases (for example, Sutton Broad) some groundwater contribution is suspected but not demonstrated. In some sites on dysfunctional floodplains (for example, Wicken Fen, Cambridgeshire) the surface of the peat appears now to be fed just by precipitation, creating the paradox of an 'ombrotrophic fen' in which the base-rich peat can be prone to surface acidification.

Examples of S24 on reflooded peat workings tend to have higher mean summer water tables (c. -9.1 cm) compared to examples on solid un-dug peat (c. -23.3 cm), because of their lower surface level, higher rates of water recharge through the more transmissive sub-surface peat infill or, in some instances, buoyant mats of vegetation; leading to the presence of different sub-communities between these two circumstances.

Forty-six per cent of S24 samples recorded occur within WETMEC 5 (summer-dry floodplains such as Wheatfen, Strumpshaw and Catfield Fen, Norfolk), whilst 41% were identified as WETMEC 6 (surface water percolation floodplains such as Sutton Broad (6a), Catfield Fen (6b) and Cranberry Rough (6d), Norfolk). A few examples occurred within WETMEC 7, 8, 13, 15, 16 and 20. The main water supply mechanisms are illustrated schematically in Figure 18.2.

18.3 Regimes

18.3.1 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 annual rainfall and potential evaporation for the sites examined are given in Table 18.1, together with mean recorded values for summer water table associated with stands of S24.

The mean summer water table varies between sub-communities and with the character of peat (solid versus turf pond infill), there can also be considerable between year variation (for example, where summer water tables of 50 cm bgl were recorded in dry summers, these can remain permanently saturated in wet summers). Some river connected sites can experience summer flooding, although flooding is more characteristic of winter conditions when persistent water depths of >50 cm agl are not uncommon.

Optimal water levels

- The summer water level is typically around 15 cm bgl. However, relatively low summer water tables may be a natural feature of some sites. It can be difficult to determine the extent of whether '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 mire species (see table below). These tend to occur on quaking or buoyant rafts on infilled turf ponds. However, stands of the 'drier' sub-communities may still support a good number of rare species where soil fertility is relatively low and the vegetation is well managed.

Table 18.1 Rainfall, potential evaporation and water table data for S24

	Mean	Min	Max
Rainfall (mm a^{-1})	611	539	1,140
Potential Evaporation (mm a^{-1})	622	562	627
Mean Summer Water Table (cm agl or bgl)	-16.7	-78.4	+3.8

- Winter inundation is a natural feature of many S24 stands. The normal range of winter water tables is probably of little importance to the nature of the vegetation.

Suboptimal or damaging water levels

- Strongly subsurface winter and summer water tables are outside of the normal range of this community. This could be likely to lead to a loss of wetland species and increased representation of 'dryland' species. Peat drying and degradation would lead to development of rank fen, rapidly becoming wooded without management, especially when it is associated with substantial nutrient release from mineralisation.
- 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.

18.3.2 Nutrients/hydrochemistry

Typically base rich and, particularly where subject to periodic river flooding, conditions generally range between mesotrophic and eutrophic. Figures for pH, conductivity and substratum fertility measured in stands of S24 in are presented in Table 18.2.

Some examples of S24 have soil and, particularly, water with low pH values. These are mostly recorded from the fen margins of the Ant and Thurne valleys in Broadland, where low pH may be the product of characteristics of the adjoining mineral substrates, or a consequence of drying-induced acidification. Very high EC values have also been recorded in the Thurne valley fens, it is unknown if this is the result of brackish river surges or a legacy of estuarine clays underlying the peat (although saline intrusion into the mineral aquifer underlying the fens is considered unlikely).

Eutrophic examples can occur anywhere where there is a supply of enriched water or soil, or where drying-induced mineralisation has taken place. In Broadland, the Yare valley fens tend to support the most fertile examples, whilst the highest measured fertility (92 mg) has been recorded from Woodbastick Fen at a location that once received mud pumped from the dykes onto the adjoining fen. Peat drying and burning at East Ruston Common caused exceptionally high fertilities (155 mg) that prevented direct restoration of S24 in this damaged site.

Examples of S24 dominated by *Cladium* tend to occur in locations of low fertility; those dominated by *Phragmites* can occupy a wide fertlity range; and examples with much *Glyceria maxima* are consistently associated with eutrophic soils.

Table 18.2 pH, conductivity and substratum fertility measured in stands of S24

Variable	Mean	±SE	Min	Max
Soil pH	6.45	0.03	5.3	7.9
Water pH	6.45	0.01	3.7	7.9
Water Conductivity ($\mu S\ cm^{-1}$)	1,418	2.7	87	7,200
Soil Fertility (mg phytometer)	12.0	0.17	5.0	92.0

18.3.3 Management

S24 appears to be a completely 'artificial' community, derived either by the clearance of carr, the management of drained swamp, or the recolonisation of reflooded, abandoned turbary. Where stratigraphical data are available, it is clear that present day S24 locations were once occupied by fen woodland for much of the post-glacial period. Management is essential to maintain species richness, and is principally by harvesting reed and sedge for thatching. The timing and frequency of management can profoundly influence vegetation composition; 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. Abandoned sedge beds are generally more resistant to scrub encroachment than abandoned reedbeds with a similar water table, but when in an herbaceous unmanaged state, they are very rank and species-poor.

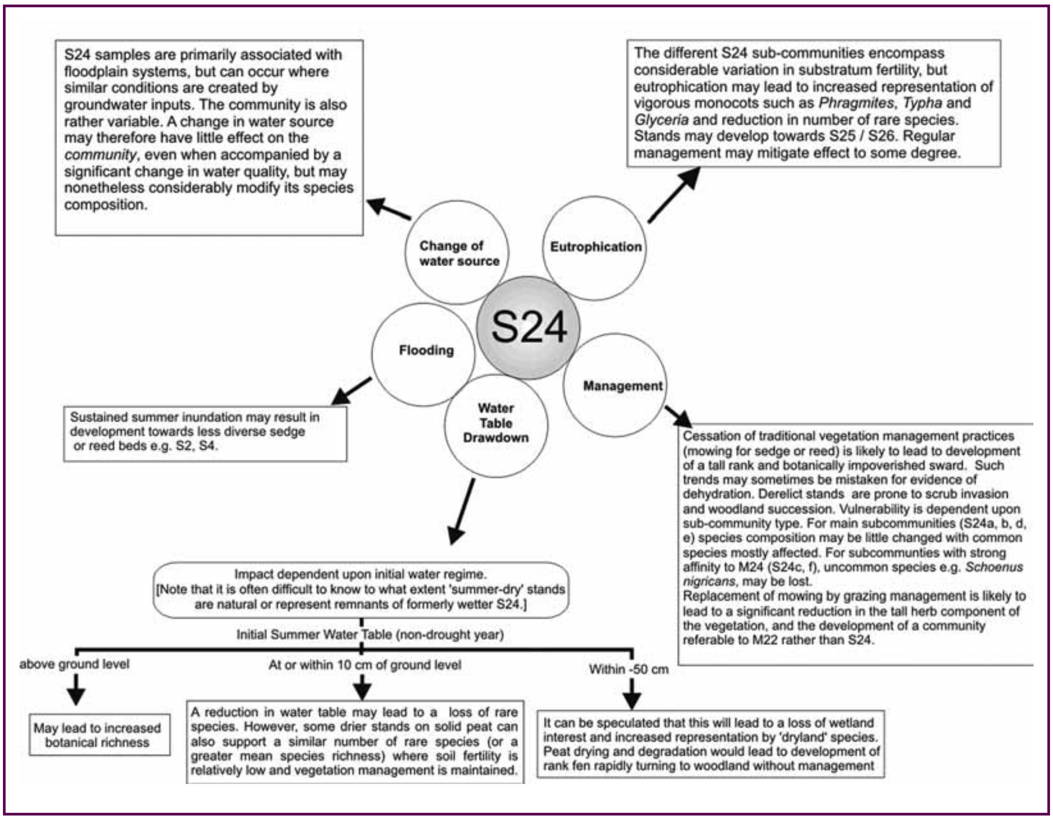
18.4 Implications for decision making

18.4.1 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. Most of the plant species that are characteristic of S24 grow in shaded conditions as well as herbaceous fen (reflecting in some cases the origin of this community from former fen carr). Hence, the rationale for management of S24 is often primarily for a general enhancement of biodiversity and for uncommon species that are not especially characteristic of the community (such as *Schoenus nigricans*).

The wide range of habitat conditions associated with S24 makes it difficult to assess vulnerability to drying and eutrophication, although locations adjacent to eutrophic watercourses, deposition of enriched mud slubbed from adjoining dykes and drying-induced

Figure 18.3 **The possible effects of environmental change on stands of S24**



mineralisation can result in a rank, impoverished stands of S24 or conversion to another community (S25 or S26). Some sites (for example, Lakenheath Poor's Fen, Wicken Fen) have almost certainly been influenced by lowering water tables induced by drainage of adjacent land, but this has not necessarily exceeded the lower water table threshold of the community.

Figure 18.3 outlines some of the possible impacts of changes to the stand environment.

18.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (for example, numbers of species lost, damage to substratum, degree of enrichment). 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 when the scrub is fairly recent; the effectiveness and desirability of clearance of mature fen woodland is much less clear.
- The potential for restoring high grade stands to dehydrated sites through re-wetting is largely untested (most pertinent fen restoration trials are at a relatively early phase).
- Sites that have become nutrient rich as a consequence of drying may benefit from removal of surface layers of peat before S24 restoration is possible.

18.4.3 Limitations of these guidelines and gaps in knowledge

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

- There are currently no data to better inform the temporal water table characteristics of S24 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions 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.
- More information on tolerance to nutrient enrichment/nutrient budgets and restoration techniques is required.
- A re-analysis, re-consideration and possible revision of the status and compass of S24 in relation to related syntaxa is required, and may be a pre-requisite for the identification of meaningful environmental thresholds for examples of this vegetation type.

S27 (*Carex rostrata – Potentilla palustris*) tall-herb fen

19.1 Context

Examples of the S27 community have been included within the 'transition mire and quaking bog' SAC interest feature.

19.1.1 Floristic composition

In totality, S27 supports a large number of species (278), however most stands are relatively species poor (NVC: mean = 18, range = 6–37 species per sample (Rodwell *et al.* 1995)) supporting relatively few uncommon species (total = 30, mean = 1, range = 0–8) although those that are found include *Calamagrostis canescens, Calamagrostis stricta, Calliergon giganteum, Carex acuta, Carex appropinquata, Carex diandra, Carex elata, Carex lasiocarpa, Carex limosa, Cicuta virosa, Cladium mariscus, Dactylorhiza praetermissa, Eleocharis uniglumis, Eriophorum gracile, Eriophorum latifolium, Hypericum undulatum, Lysimachia thyrsiflora, Osmunda regalis, Peucedanum palustre, Potamogeton coloratus, Ranunculus lingua, Rhizomnium pseudopunctatum, Sium latifolium, Sparganium natans, Sphagnum contortum, Sphagnum platyphyllum, Sphagnum teres, Stellaria palustris, Thelypteris palustris, Utricularia minor*.

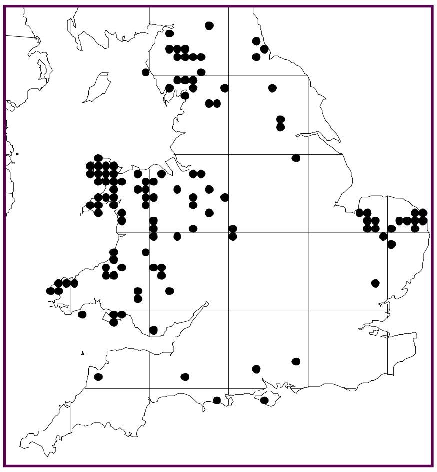
The community is heterogeneous with a variety of dominant species of which *Carex rostrata* is most frequent. Other dominants include *Carex elata* (stands transitional to S1), *Carex nigra* (stands transitional to fen meadow), *Juncus subnodulosus* (stands transitional to M22) and *Phragmites australis* (stands transitional to reed dominated communities). *Potentilla palustris* and to a lesser extent *Menyanthes trifoliata* are often abundant. Herbaceous associates are variable, and bryophytes range from near-absent to prominent patches.

Rodwell (1995) recognised two sub-communities of S27: *Carex rostrata – Equisetum fluviatile* sub-community (S27a); and *Lysimachia vulgaris* sub-community (S27b).

19.1.2 Distribution

In England and Wales, S27 has been recorded from 188 wetland sites (FenBASE database). It is widespread but most characteristic of Northern and Western Britain. S27 tends to be localised and fragmentarily developed in the South and East. The distribution of the community is shown in Figure 19.1.

Figure 19.1 Distribution of S27 in England and Wales (from FenBASE database)



19.1.3 Landscape situation and topography

S27 is a community of topogenous situations, frequently developing as a buoyant loose mat of vegetation. It forms part of a zonation or successional sequence in basin wetlands or around open water margins, or as part of a mosaic in floodplain wetlands or soligenous situations. It occasionally occurs in the lagg of raised bogs.

19.1.4 Substratum

Mainly occurs as a buoyant or quaking infill within basins or turf ponds, or as a hydroseral vegetation raft along the margins of lakes and pools. Sometimes found on more solid, but soft and spongy peat, which can either be deep (>3 m) or shallow (<0.5 m). S27 can also be found on deep alluvial infill in basins (Esthwaite North Fen, Cumbria) or on the margins of floodplains (for example, Catfield Fen, Norfolk). Rodwell (1995) observed that S27 can also occur on humic gleys.

19.1.5 Zonation and succession

In some sites where the community adjoins open water (such as Esthwaite North Fen and Sunbiggin Tarn in Cumbria) and various loch-side locations in Scotland, S27 can form part of a distinctive, and apparently natural, centripetal zonation, often as a fairly narrow band sandwiched between deeper water swamp communities and drier peripheral fen or fen carr. However, the majority of examples of S27 do not occur in this situation, nor do they show a particularly clear zonation. More usually they form a mosaic with a variety of wetter or drier communities, with inconsistent relationships, created sometimes by local variations in topography. In a few sites, the community occupies the lagg of an ombrogenous bog system (such as Abbots Moss (Cheshire), Malham Tarn Moss (Yorkshire)), but in many such contexts it is developed only fragmentarily, if at all, and the lagg is largely occupied by wooded vegetation (such as Cors y Llyn, Radnor).

A particularly large and wet example of S27 occurs in a complex mosaic with various swamp types, at the South-Western end of Rhôs Gôch Common (Radnor), in places showing fairly clear zonations eastwards through bands of M5 and M4 into a gently rising dome of ombrogenous peat. It seems likely that at this site the S27 complex, which occurs on very shallow peat over lake clays, is the result of recolonisation of a largely skinned, cut-over surface. Many of the other hollows which are occupied by S27 also seem to represent excavations of some type, whether for peat (such as Newton Reigny Moss, Cumbria), fish ponds (such as Malham Tarn Fen), duck decoys (such as Catfield Fen), clay workings (such as Dowrog Common) or marl pits (such as Nether Whitlaw Moss, Selkirkshire).

Some of the basin mires in which the community occurs may possess relatively undisturbed post-glacial hydroseral sequences, but the occurrence of past peat digging is often poorly known and may well have been more pervasive than is currently recognised. In lowland England and Wales, S27 seems often to be indicative of some past disturbance, sometimes coupled with nutrient enrichment, and these features may well account for the species poverty of some examples of the community.

The natural role of S27 in the terrestrialisation of topogenous hollows is uncertain, not least because the community does not have a sufficiently clear macrofossil signature to permit its confident identification from stratigraphical data (and, in particular, to enable its distinction from M9-2). On the limited evidence examined, it appears that M9-2 may have made a more important contribution to the infilling of many basins than S27, and that the latter may sometimes be found more as a fairly recent, perhaps enrichment-induced development (perhaps from former M9-2), or as relatively species-poor vegetation that has recolonised disturbed topogenous surfaces.

Small acidic, sometimes ombrotrophic, patches are evident within some stands of S27 and in some sites (such as Parc Newydd, Anglesey) quite extensive *Sphagnum*-dominated surfaces may have developed, at least in part, from former S27. Such acidification is particularly prevalent on buoyant surfaces which are rarely, if ever, flooded by base-rich water.

Occasional flooding, particularly with base-rich water, may be important in preventing the development of ombrotrophic nuclei and succession to community types associated with more acidic conditions (such as *Carex rostrata – Sphagnum squarrosum* mire (M5), *Carex rostrata – Sphagnum recurvum* mire (M4)). For example, telluric conditions in the lagg zone of basins such as Abbots Moss (Cheshire) probably constrain the spread of the ombrotrophic surface and maintain conditions favourable for S27. Nonetheless, floating surfaces of S27 which do not receive minerotrophic flood are prone to ombrotrophication.

19.2 Supply mechanism and conceptual model

S27 occurs within ombrogenous, topogenous, rheo-topogenous and rheophilous conditions, but never soligenous. Some basins supporting the community are believed to be mostly rainwater fed with seasonally varying water tables and minerotrophic conditions provided either by the shallowness of peat allowing contact with underlying mineral layers or by local rain-generated run off.

Twenty-one per cent of S27 stands have been found to occur within WETMEC 13 (seepage percolation basins such as Parc Newydd (Anglesey), Silver Tarn (Cumbria)); 21% in WETMEC 20 (percolation basins such as Dowrog Common (Pembrokeshire), Emer Bog (Hampshire); 15% in WETMEC 6 (surface water percolation floodplains such as Biglands Bog (Cumbria), Sutton Broad (Norfolk)); and 10% in WETMEC 18 (percolation troughs such as Cliburn Moss (Cumbria), Cors Gyfelog (Caernarfon)). A few examples also occur within WETMECs 3, 4, 5, 12, 14 and 16. The main water supply mechanisms are illustrated schematically in Figure 19.2.

19.3 Regimes

19.3.1 Water

S27 is often found as a buoyant raft in topogenous situations with the water level of the mat close to the surface throughout the year. Other examples in shallow basins are more anchored to the substratum, experiencing greater degrees of drying and flooding. Summer water tables lower than 20 cm bgl have been recorded from 5 sites supporting S27 and in at least some of these sites, it occurs in locations subject to lowered water tables and is likely to be a relict of once wetter conditions. Relatively low summer water tables (deeper than 10 cm bgl) may be a natural feature of examples of the community in small ground hollows (such as Swannington Upgate Common) (Wheeler, Shaw and Tanner, 2009) or floodplain margins (such as Catfield Fen) especially in dry summers. Such basins also experience deep winter flooding.

Mean values for annual rainfall and potential evaporation for the sites examined are given in Table 19.1, together with mean recorded values for summer water table associated with stands of S27.

Specific time-series data for stands of S27 are not available and so it is not possible to specify precise water regimes or tolerance to change, but the following comments can be made:

Optimal water levels

- Summer water levels typically at or above surface, particularly where forming a semi-floating raft, but may experience a wide range of conditions and episodically low summer water tables that are not necessarily detrimental to the community (though potentially determining floristic composition).
- Association with a buoyant raft or loose turf pond infill may provide some vertical mobility, water storage and hydrological stability by facilitating lateral recharge.
- Occasional flooding, particularly with base-rich water may be important in preventing the development of rain-fed nuclei and succession to community types associated with more acidic conditions (for example, M5, M4). Floating surfaces of S27 that do not receive minerotrophic flood can be prone to 'ombrotrophication'.

Suboptimal or damaging water levels

- Strongly subsurface winter and summer water tables are outside of the normal range of this community. This could be likely to lead to a loss of wetland species and increased representation of 'dryland' species. Partial drainage accompanied by vegetation management may lead to increased species richness as a form of fen meadow establishes. Further peat drying/degradation would lead to development of rank fen becoming wooded without management. Persistence of patches of S27 in dry, eutrophic sites (for example, Cornard Mere) indicates it can be extremely tolerant of periods of low water, albeit in impoverished form.

Table 19.1 Rainfall, potential evaporation and water table data for S27

	Mean	Min	Max
Rainfall (mm a^{-1})	889	561	1,826
Potential Evaporation (mm a^{-1})	582	462	646
Mean Summer Water Table (cm agl or bgl)	2.2	-50	30.6

Figure 19.2 Schematic representation of the major water supply mechanisms to S27 (after Wheeler, Shaw and Tanner, 2009)

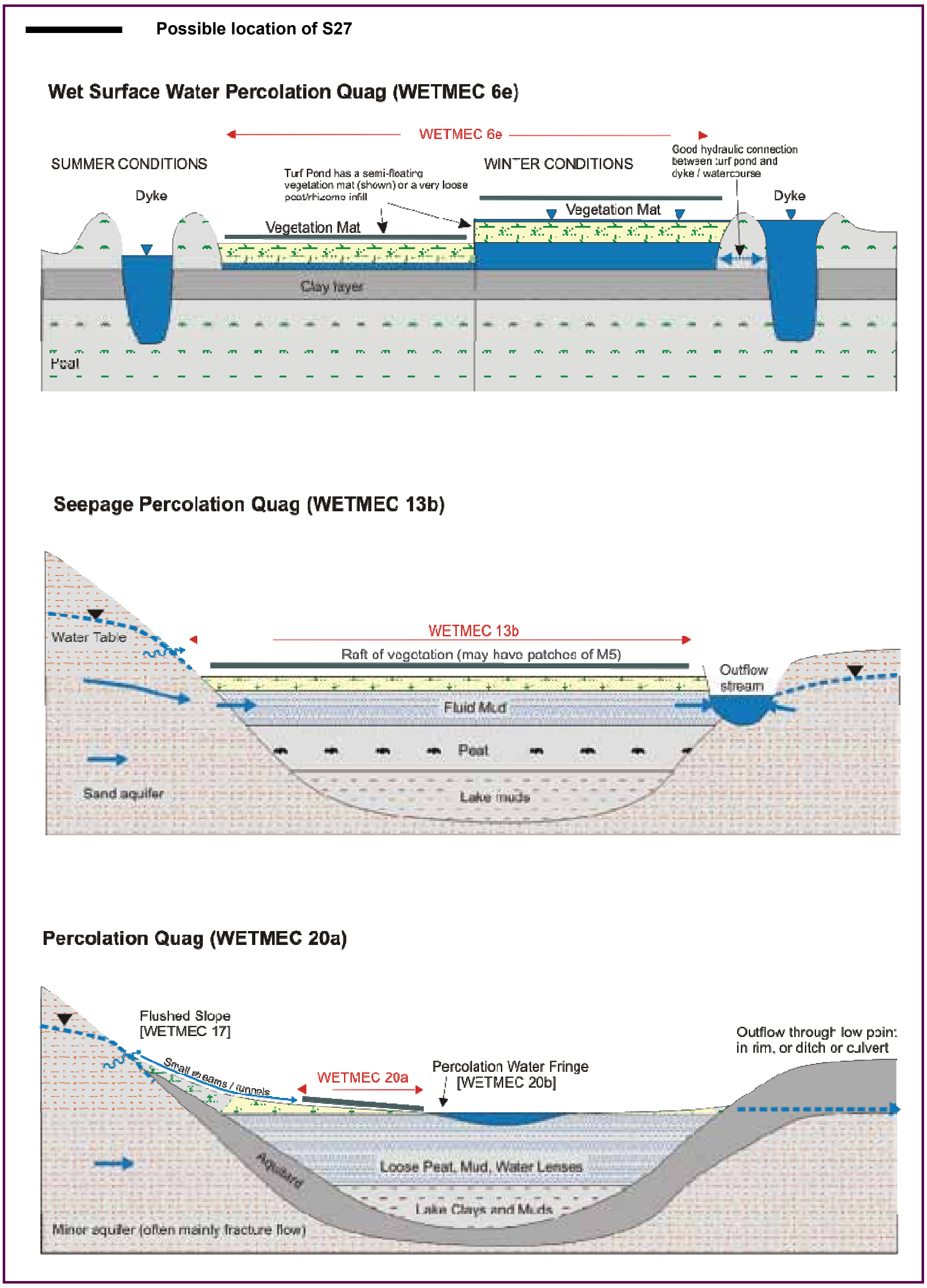
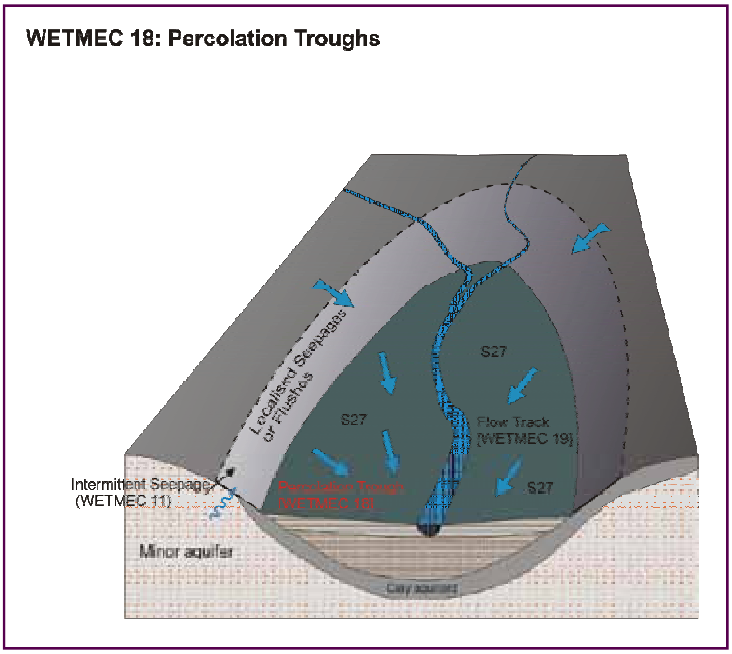


Figure 19.2 (continued)



- Prolonged deep inundation is likely to kill some species leading to a less diverse form of S27 or swamp vegetation types (for example, S9, S10), although these conditions may provide a basis of hydroseral regeneration of semi-floating S27 surfaces.

19.3.2 Nutrients/hydrochemistry

S27 is typically found in conditions of intermediate base status but covers a wide range. Substrata are generally moderate in fertility, and stands of S27 occur in mosaics of either rich or poor fen, mediated by small differences in water and substratum chemistry and water regime. Figures for pH, conductivity and substratum fertility measured in stands of S27 are presented in Table 19.2.

The lowest pH circumstances of this community have been recorded from the laggs of basin bogs (for example, Abbots Moss) and from the edge of some of the Broadland floodplains (for example, Catfield Fen). Examples of sites with high fertility include Cridmore Bog (Isle of Wight), possibly due to flooding by sewage-effluent enriched water from the River Medina; and Cliburn Moss (Cumbria), which may receive nutrient-rich runoff from adjacent agricultural land. The very high EC value of 2,150 µS cm^{-1} was recorded from a rather dry patch of S27 embedded with *Glyceria maxima* dominated vegetation at Cornard Mere (Suffolk), but the reason for the high value is not known.

Table 19.2 pH, conductivity and substratum fertility measured in stands of S27

Variable	Mean	±SE	Min	Max
Soil pH	5.7	0.02	4.6	7.0
Water pH	5.6	0.02	4.5	7.1
Water conductivity (µS cm^{-1})	260	1.4	38	2,150
Soil Fertility (mg phytometer)	13.6	0.24	2	50

19.3.3 Management

Conservation management involves ensuring moderate fertility and intermediate base status, and relatively high water levels. S27 can be fairly stable in the absence of management, and substratum wetness may mean that stands are infrequently grazed even where open to stock. Stands may be subject to light grazing, which generally has a beneficial effect on species density, retarding scrub invasion. Grazing may also favour the dominance of *Juncus* species (Rodwell 1995). Long term lack of management may result in considerable scrub development (W2, W3) and natural succession processes may also mean that where the community is established on a buoyant raft, conservation of this vegetation type may eventually require rejuvenation of the hydroseral conditions (by excavation of the substratum).

19.4 Implications for decision making

19.4.1 Vulnerability

S27 may be resistant to moderate nutrient inputs, but high levels of eutrophication lead to impoverishment with an increase in species like *Agrostis stolonifera*, *Juncus effusues* and *Phragmites australis*. Examples in basins may be particularly vulnerable to inflow of agricultural pollutants from adjacent land. At Sunbiggin Tarn, located within moorland, an apparent former stand has been impoverished as a consequence of being used as a roosting site by black headed gulls.

Vulnerability to changes in water supply depends on their precise water supply mechanism. Where basin water level is predominantly groundwater dependent, vulnerability may be related to the degree of water level reduction that can be accommodated by a buoyant surface before significant grounding and drying occurs. In other sites over low permeability deposits, where rates of outflow and inflow control water level, groundwater levels will have less of an effect. Here vulnerability will be related to increased drainage in the fen, especially if groundwater inputs are not strong. Nonetheless, established S27 appears to be quite persistent in unfavourably low water conditions, although in an impoverished form.

Figure 19.3 outlines some of the possible impacts of changes to the stand environment.

19.4.2 Restorability

As with all restoration measures, their likely success depends on the cause of the 'damage', and how far the starting conditions are from the objective, both in time and conditions (for example, numbers of species lost, damage to substratum, degree of enrichment). Limited information is available on restoration of S27 stands, but the following observations can be made.

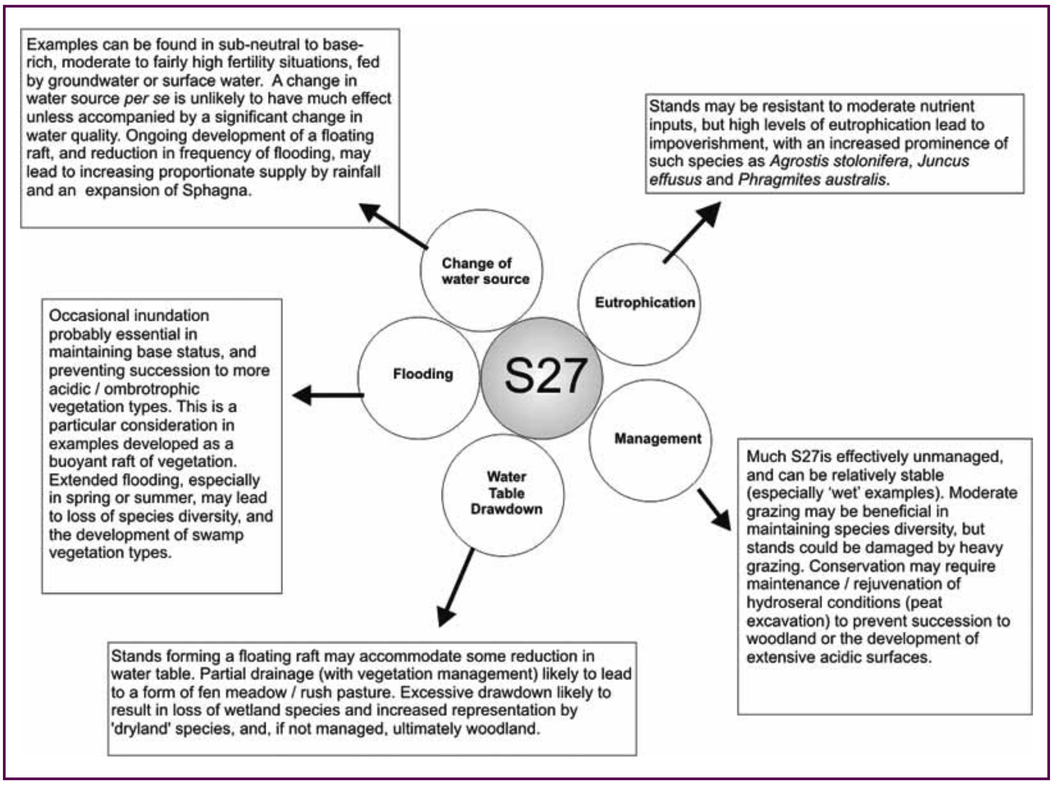
- Where the community has recently been damaged and this has not been intensive, corrective management may be sufficient to rehabilitate S27 in the short to medium term.
- Prolonged water drawdown that has resulted in both grounding of the floating raft, and mineralisation of nutrients from the peat, may require many years and major operations such as peat removal to reverse.
- Reversal of problems caused by nutrient enrichment is likely to be difficult, especially where excess nutrients cannot be removed by management. Physical removal of enriched sediments may provide a solution, but this could risk spreading enriched material into less affected locations. Removal strategies may only be viable where there is control over water levels, where the whole basin is to be stripped, or where the whole surface is so degraded that further deterioration is unlikely.

19.4.3 Limitations of these guidelines and gaps in knowledge

The limitations of the information presented here related to S27 includes the following:

- There are currently no data to better inform the temporal water table characteristics of S27 stands. Time series of dipwell measurements are required to fill this gap.
- In order to make predictions with respect to the vulnerability of S27 stands to water levels, models are required that can connect hydrogeological processes with hydrological conditions at the fen surface. This may require detailed ecohydrological investigations at 'representative' sites.

Figure 19.3 The possible effects of environmental change on stands of S27



- Data on the spatial extent of S27 are lacking.
- Possible differences in environmental conditions influencing the two sub-communities have not been explored in detail here.
- S27 shows considerable floristic overlap with (the generally more uncommon) M9-2 and it would be of interest to identify the salient environmental differences between the two communities. A prerequisite for this is likely to be an improved characterisation of the distinction between S27 and M9-2.
- More information on tolerance to nutrient enrichment/nutrient budgets and restoration techniques is required.

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Glossary

Abstraction
The removal of water from a groundwater source or 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).

Acrotelm
The uppermost, active layer of a peat deposit, most often used with regard to an undamaged raised bog, comprising the living plant cover passing downwards into recently dead plant material and thence to fresh peat. It forms the largely oxygenated surface layer with high hydraulic conductivity, within which the water level fluctuates and the main water movement occurs (cf. Catotelm).

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
Lacking free 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 high concentration of calcium (Ca^{2+}) 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.

Catotelm
The lower, so-called inert layer of a peatland. The catotelm underlies the acrotelm and is permanently saturated, mainly anoxic and usually of lower hydraulic conductivity and storage capacity than the acrotelm.

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 calcium from a soil.

Defoliation
The loss of foliation (leaves).

Diffuse pollution
Pollution from a non-specific location/sources (for example, surrounding farmland) that cannot be readily identified as occurring from a given point or location (for example, 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 (that is, 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 (that is, 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, that is, 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 for example, surface drainage channels. This landscape was created by the early phases of agricultural reclamation of floodplain and coastal wetlands, although a large proportion of the original area was later subject to further drainage and converted to intensive arable land.

Gauge board
A vertically aligned device for measuring surface water levels.

Hectare
One hectare (Ha) is equal to 2.47 acres or 0.1 Km^2.

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 (for example, 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 of the three statutory conservation agencies (namely Natural England, 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 (that is, 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 (for example, 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 (for example, 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 confined aquifer
Condition where groundwater is partly prevented from rising to its true level by an 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 one (very acidic) to 14 (very alkaline or basic). Seven 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.

Rheophilous
Literally 'flow loving', and used often to refer to plants, communities or mire types that are particularly associated with lateral water flow within mires.

Rheo-topogenous
Topogenous surfaces with significant lateral water movement (percolation).

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 a given area.

Stagno-topogenous
Topogenous surfaces which have little water throughflow (percolation).

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, for example, 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 for example, 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 does not have a confining layer between it and the surface.

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.

Species names

Flowering plants (excluding grasses, sedges and rushes)

Alnus glutinosa	Alder
Anagallis tenella	Bog pimpernel
Andromeda polifolia	Bog rosemary
Apium graveolens	Wild celery
Bartsia alpina	Alpine bartsia
Berula erecta	Lesser water parsnip
Betula pubescens	Downy birch
Calluna vulgaris	Heather
Ceratophyllum demersum	Rigid hornwort
Cicuta virosa	Cowbane
Cirsium acaulon	Dwarf thistle
Cirsium arvense	Creeping thistle
Cirsium dissectum	Meadow thistle
Cirsium palustre	Marsh thistle
Corallorhiza trifida	Coralroot orchid
Crepis paludosa	Marsh hawk's-beard
Dactylorhiza incarnata	Early marsh orchid
Dactylorhiza praetermissa	Southern marsh orchid
Dactylorhiza traunsteineri	Pugsley's marsh orchid
Drosera intermedia	Oblong-leaved sundew
Drosera longifolia (= *D. anglica*)	Great sundew
Drosera rotundifolia	Common sundew
Empetrum nigrum	Crowberry
Epilobium hirsutum	Great hairy willow-herb
Epipactis palustris	Marsh helleborine
Erica ciliaris	Dorset heath
Erica tetralix	Crossed-leaved heath
Eupatorium cannabinum	Hemp agrimony
Euphrasia pseudokerneri	Eyebright species
Filipendula ulmaria	Meadowsweet
Galium aparine	Common cleavers
Galium palustre	Common marsh bedstraw
Gymnadenia conopsea	Fragrant orchid
Hammarbya paludosa	Bog orchid
Hippuris vulgaris	Mare's tail
Hottonia palustris	Water violet
Hydrocharis morsus-ranae	Frog-bit
Hydrocotyle vulgaris	Marsh penny-wort
Hypericum elodes	Marsh St. John's wort
Hypericum undulatum	Wavy St. John's wort
Iris pseudacorus	Yellow flag iris
Lathyrus palustris	Marsh pea
Liparis loeselii	Fen orchid
Listera ovata	Common twayblade
Lysimachia thyrsiflora	Tufted loosestrife
Lysimachia vulgaris	Yellow loosestrife
Mentha aquatica	Water mint
Menyanthes trifoliata	Bog bean
Myrica gale	Bog myrtle
Narthecium ossifragum	Bog asphodel
Oenanthe lachenalii	Parsley water dropwort
Ophrys apifera	Bee orchid
Parentucellia viscosa	Yellow bartsia

Parnassia palustris	Grass of Parnassus	*Salix pentandra*	Bay willow
Pedicularis palustris	Marsh lousewort	*Scheuchzeria palustris*	Rannoch rush
Pedicularis sylvatica	Lousewort	*Schoenus nigricans*	Black bog-rush
Peucedanum palustre	Milk parsley	*Selinum carvifolia*	Cambridge milk parsley
Pinguicula lusitanica	Pale butterwort	*Sium latifolium*	Greater water parsnip
Pinguicula vulgaris	Common butterwort	*Sonchus palustris*	Marsh sow-thistle
Pinus	Pine	*Sparganium minimum*	Least bur-reed
Potamogeton coloratus	Fen pondweed	*Stellaria palustris*	Marsh stitchwort
Potamogeton polygonifolius	Bog pondweed	*Stratiotes aloides*	Water soldier
Potentilla erecta	Tormentil	*Succisa pratensis*	Devil's-bit scabious
Potentilla palustris	Marsh cinquefoil	*Symphytum officinalis*	Common comfrey
Primula farinosa	Bird's-eye primrose	*Thalictrum flavum*	Common meadow-rue
Pyrola rotundifolia	Round-leaved wintergreen	*Trifolium spp.*	Clover species
Ranunculus flammula	Lesser spearwort	*Triglochin palustre*	Marsh arrow-grass
Ranunculus lingua	Greater spearwort	*Typha angustifolia*	Lesser bulrush/reedmace
Ranunculus trichophyllus	Thread-leaved water crowfoot	*Typha latifolia*	Greater bulrush/reedmace
Rhododendron ponticum	Rhododendron	*Urtica dioica*	Nettle
Rorippa nasturtium-aquatica	Water cress	*Utricularia minor*	Lesser bladderwort
Rorippa palustris	Marsh yellow cress	*Utricularia intermedia*	Intermediate bladderwort
Rumex hydrolapathum	Water dock	*Utricularia vulgaris*	Greater bladderwort
Sagina nodosa	Knotted pearlwort	*Vaccinium oxycoccos*	Cranberry
Salix cinerea	Grey willow	*Viola palustris*	Marsh violet
Salix fragilis	Crack willow	*Viola persicifolia*	Fen violet

Grasses, sedges and rushes

Agrostis canina	Velvet bent
Agrostis stolonifera	Creeping bent
Arrhenatherum elatius	False oat grass
Blysmus compressus	Flat sedge
Briza media	Quaking grass
Calamagrostis canescens	Purple small reed
Calamagrostis stricta	Narrow small reed
Carex acutiformis	Lesser pond sedge
Carex appropinquata	Fibrous tussock sedge
Carex binervis	Green-ribbed sedge
Carex diandra	Lesser tussock sedge
Carex dioica	Dioecious sedge
Carex disticha	Brown sedge
Carex echinata	Star sedge
Carex elata	Tufted sedge
Carex hostiana	Tawny sedge
Carex lasiocarpa	Slender sedge
Carex limosa	Mud sedge
Carex magellanica	Bog sedge
Carex panicea	Carnation sedge
Carex paniculata	Greater tussock sedge
Carex pauciflora	Few-flowered sedge
Carex pseudocyperus	Hop or cyperus sedge
Carex pulicaris	Flea sedge
Carex rostrata	Bottle sedge
Carex viridula ssp. brachyrrhyncha (= C. lepidocarpa)	Long-stalked yellow sedge
Carex viridula ssp. oedocarpa (= C. demissa)	Common yellow sedge
Cladium mariscus	Saw sedge (great fen sedge)
Deschampsia cespitosa	Tufted hair grass
Eleocharis multicaulis	Many-stalked spike rush
Eleocharis quinqueflora	Few-flowered spike rush
Eleocharis uniglumis	Slender spike rush
Eleogiton fluitans	Floating club rush
Eriophorum angustifolium	Common cottongrass
Eriophorum gracile	Slender cottongrass
Eriophorum latifolium	Broad-leaved cottongrass
Eriophorum vaginatum	Hare's-tail cottongrass
Festuca arundinacea	Tall fescue
Glyceria maxima	Reed sweet-grass
Juncus acutiflorus	Sharp flowered rush
Juncus alpino-articulatus	Alpine rush
Juncus bulbosus	Bulbous rush
Juncus effusus	Soft rush
Juncus inflexus	Hard rush
Juncus subnodulosus	Blunt-flowered rush
Molinia caerulea	Purple moor grass
Phalaris arundinacea	Reed canary-grass
Phragmites australis (= P. communis)	Common reed
Rhynchospora alba	White beak-sedge
Scirpus cespitosus	Deer grass
Scirpus lacustris	Common club-rush
Scirpus maritima	Sea club-rush

Lower plants

Mosses

Bryum pseudotriquetrum
Calliergon cuspidatum
Calliergon giganteum
Campylium elodes
Campylium stellatum
Cinclidium stygium
Cratoneuron commutatum
Dicranum undulatum
Drepanocladus exannulatus
Drepanocladus lycopodioides
Drepanocladus revolvens
Drepanocladus vernicosus
Fissidens adianthoides
Gymnostomum recurvirostrum
Homalothecium nitens
Paludella squarrosa
Philonotis calcarea
Philonotis fontana
Plagiomnium elatum
Plagiomnium ellipticum
Rhizomnium pseudopunctatum
Scorpidium scorpioides
Sphagnum spp (bog mosses)

Liverworts

Aneura pinguis
Cladopodiella fluitans
Leiocolea rutheana
Moerckia hibernica = M. flotoviana
Pellia endiviifolia
Preissia quadrata
Riccardia chamedryfolia
Riccardia multifida

Other

Chara spp. (stoneworts)
Lycopodiella inundatum (marsh clubmoss)
Cladonia spp. (lichen)
Selaginella selaginoides (lesser clubmoss)

Ferns and horsetails

Dryopteris cristata	Crested buckler-fern
Equisetum fluviatile	Water horsetail
Equisetum telmateia	Great horsetail
Equisetum variegatum	Variegated horsetail
Osmunda regalis	Royal fern
Thelypteris palustris	Marsh fern

List of abbreviations

agl
Above ground level

bgl
Below ground level

Kcorr
Conductivity of a solution, corrected for the contribution made by hydrogen ions.

FertilityPhal
Experience has shown that N and P data derived from soil analysis has only limited use in assessing fertility of wetlands. Consequently, the technique of phytometry was developed (Wheeler, Shaw and Cook, 1992). This involves measuring the biomass of test species (phytometers – in this case reed canary grass *Phalaris arundinacea*) grown on soil samples. Typical phytometer yields (dry wt.): low fertility $<$ 8 mg, high fertility $>$ 18 mg.

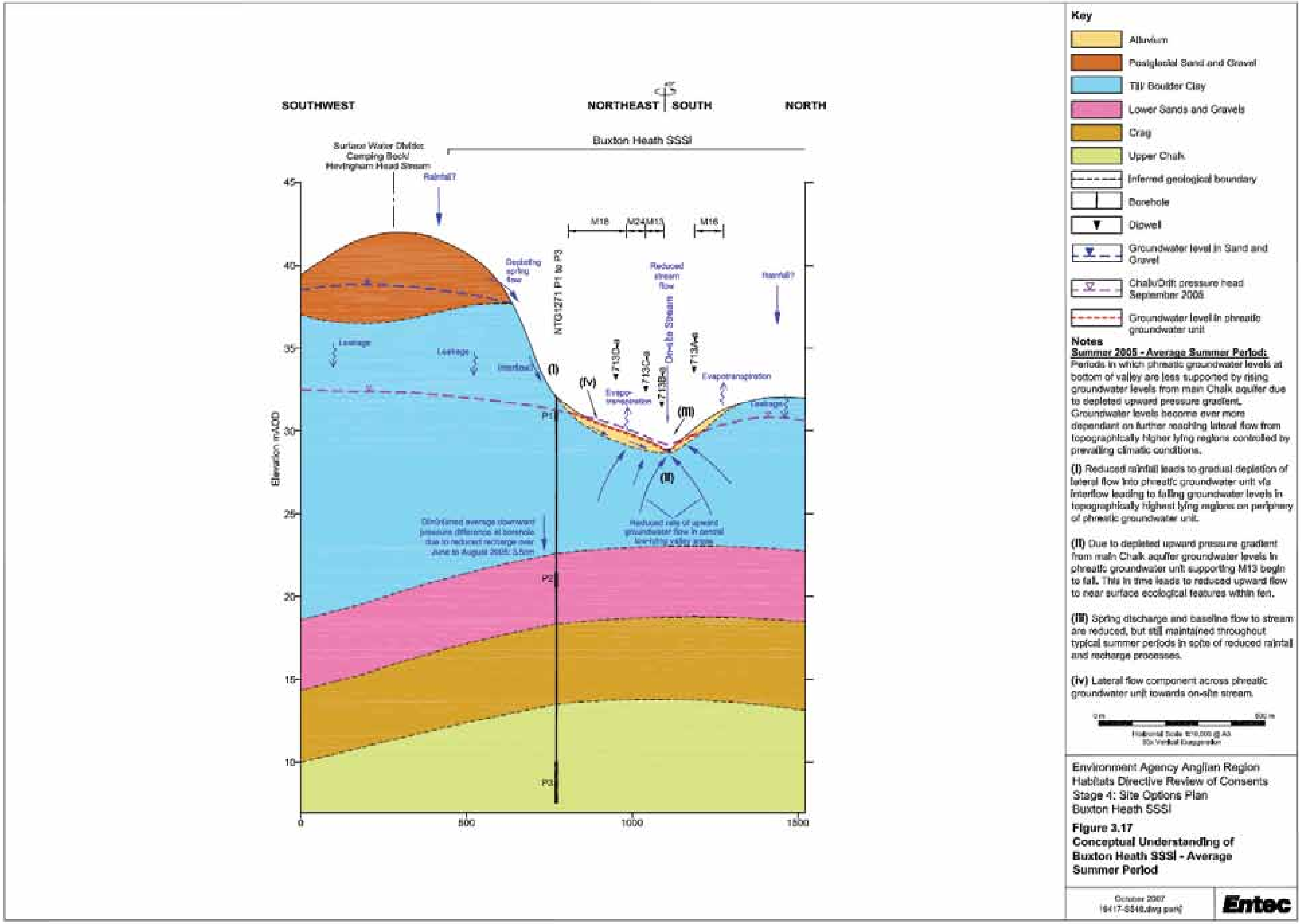
pH
A value on a scale of one to 14 which gives a measure of the acidity or alkalinity of a medium (such as soil or water). Seven is neutral pH.

PE
Potential evapotranspiration. The amount of water that would evaporate or transpire from a surface if water supply were unlimited.

SE
Standard error.

spp.
Species.

Conceptual understanding of Buxton Heath SSSI – average summer period


SOUTHWEST
NORTHEAST
SOUTH
NORTH
Buxton Heath SSSI
Surface Water Divide: Camping Beck/ Hevingham Head Stream
Rainfall?
M18
M24
M13
M16
Depleting spring flow
NTG1271 P1 to P3
Reduced stream flow
On-site Stream
Leakage
Interflow
(I)
(iv)
(II)
(III)
Evapo-transpiration
Evapotranspiration
P1
P2
P3
Diminished average downward pressure difference at borehole due to reduced recharge over June to August 2005: 3.5cm
Reduced rate of upward groundwater flow in central low-lying valley areas
Elevation mAOD
45
40
35
30
25
20
15
10
0
500
1000
1500
Key
Alluvium
Postglacial Sand and Gravel
Till/ Boulder Clay
Lower Sands and Gravels
Crag
Upper Chalk
Inferred geological boundary
Borehole
Dipwell
Groundwater level in Sand and Gravel
Chalk/Drift pressure head September 2005
Groundwater level in phreatic groundwater unit
Notes
Summer 2005 - Average Summer Period:
Periods in which phreatic groundwater levels at bottom of valley are less supported by rising groundwater levels from main Chalk aquifer due to depleted upward pressure gradient. Groundwater levels become ever more dependant on further reaching lateral flow from topographically higher lying regions controlled by prevailing climatic conditions.
(I) Reduced rainfall leads to gradual depletion of lateral flow into phreatic groundwater unit via interflow leading to falling groundwater levels in topographically highest lying regions on periphery of phreatic groundwater unit.
(II) Due to depleted upward pressure gradient from main Chalk aquifer groundwater levels in phreatic groundwater unit supporting M13 begin to fall. This in time leads to reduced upward flow to near surface ecological features within fen.
(III) Spring discharge and baseline flow to stream are reduced, but still maintained throughout typical summer periods in spite of reduced rainfall and recharge processes.
(iv) Lateral flow component across phreatic groundwater unit towards on-site stream.
Environment Agency Anglian Region
Habitats Directive Review of Consents
Stage 4: Site Options Plan
Buxton Heath SSSI
Figure 3.17
Conceptual Understanding of Buxton Heath SSSI - Average Summer Period
October 2007
Entec

Key to patterns used to represent strata in cross-sections

Water table

Vegetation mat/raft

Acidifying surface

Minerotrophic (fen) peat

Lake muds

Water

Littoral colonisation

Ombrotrophic (bog) peat

Peat with sediments or clay

Lake clays and marl

Aquifer (unspecified)

Sandy drift (permeable)

Chalk or limestone

Aquitard (unspecified)

Clay/aquitard

Tufa or mineral inwash

Clay-rich drift

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