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Options for remediation

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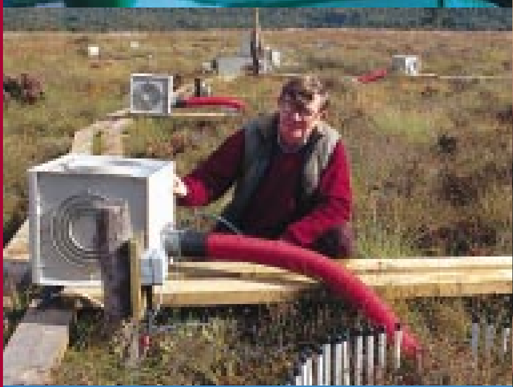
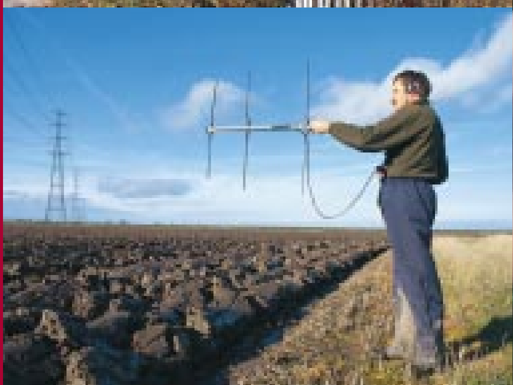


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Nutrient enrichment of basin fens
Options for remediation

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Executive summary

In July 2003, Penny Anderson Associates Limited (PAA) was commissioned by English Nature to undertake a review of the options for remediation of nutrient enrichment of basin fens. The objectives of the project were to provide an overview of the basin fen resource in England, provide a means of assessing the vulnerability of areas and sites to diffuse pollution from agriculture, and present cost-effective options for the remediation of such nutrient enrichment.

The study undertook a comprehensive review of research and other literature on the issues surrounding diffuse nutrient enrichment in general, and in relation to basin fens in particular. A large body of literature on the processes of enrichment through nitrogen and phosphorus inputs was assessed and summarised, and the role of hydrology in contributing to nutrient inputs was also reviewed. The particular vulnerability of basin fens is identified, in relation to their isolated position within an agricultural landscape, their typical low nutrient status and their dependence on groundwater and surface water inputs.

Currently available approaches to mitigating nutrient enrichment in basins fens were assessed in some detail. The assessment led to the development of two general approaches to mitigation; the ‘Protection Model’ and the ‘Prevention Model’. In summary, the protection model aims to install protection measures at the margins of, or near to, the fen area to reduce or prevent excessive nutrients entering the fen. Such action could be undertaken in the short to medium term and include measures such as vegetated buffer zones and constructed wetlands. The prevention model is a more long term strategic approach aimed at reducing the nutrient inputs within the wider catchment. Measures within this model include changes to farming practices and adopting particular farm management regimes.

The basin fen resource in England was also assessed using the databases FenBASE and ENSIS. Interrogation of these databases identified 61 basin fen sites (excluding sites that were dominated by either ombrotrophic vegetation or open water). The majority of sites were in the North West or West Midlands, the remainder in the North East and East Anglia. Only one site was identified in Southern England. These sites were assessed in terms of their general character, potential nutrient enrichment issues and other issues affecting them. The sites were also assessed at a broad level in order to identify possible options for remediation of nutrient enrichment, and some attempt to prioritise sites was made.

The report presents three case studies in order to consider which options for remediation of nutrient enrichment might be applicable for specific basin fen sites. The case studies examine the potential cost implications of applying these measures in terms of losses and gains to the farm business. The sites assessed are Wybunbury Moss (Cheshire), Silver Tarn (Cumbria) and Great Cressingham Fen (Norfolk). All three sites have nutrient enrichment issues.

Finally, an approach to assessing the applicability of different mitigation measures to basin fen sites is presented in the form of a flow chart outlining the decision process required.

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1. Introduction

1.1 Aims and objectives of the Project

In July 2003, Penny Anderson Associates Limited (PAA) was commissioned by English Nature to undertake a project to assess the options for remediation of nutrient enrichment of basin fens (English Nature Contract EIT34-01-009).

The objectives of the project were to provide an overview of the basin fen resource in England, provide a means of assessing the vulnerability of areas and sites to diffuse pollution from agriculture, and present cost-effective options for the remediation of such nutrient enrichment.

This overall objective will be achieved through several specific aims, which are as follows:

- to evaluate the basin fen resource in England through the combined use of ENSIS and FenBASE databases;
- to identify and evaluate the available measures for eliminating the nutrient enrichment of basin fens;
- to identify the factors determining which remediation measures are appropriate in a given set of circumstances;
- to provide a process for evaluating the relevance of each of the remediation options for an individual site;
- to facilitate the national process of tackling diffuse water pollution from agriculture by providing a method for assessing the importance of and nature of such issues within selected priority catchments;
- to inform the AMP4 process where water company abstractions or discharges are adversely affecting basin fens with statutory designations.

1.2 Definition of basin fen

In the context of this report, the term 'basin fen' refers to both discrete basins where fen vegetation has developed and also basin features within other types of fen such as valley mire and floodplain mire. The study does not include basins with primarily ombrotrophic vegetation (ie basin bogs or true raised bogs within basins). Further discussion on the classification of wetland types and the ecohydrological character of basin fens is provided in Appendix I, prepared by the Wetland Research Group (University of Sheffield) as part of this project.

1.3 Structure of the report

This report consists of five further sections. Section 2 is a literature review of research and issues related to basin fens. It examines the susceptibility of basin fens to nutrient enrichment from diffuse sources.

Section 3 discusses the efficacy of nutrient mitigation strategies. It suggests a bilateral approach to the problem of enrichment. The first is referred to the 'Protection' model - a range of methods that can be used to intercept nutrients before they enter the fens eg the construction of buffer zones along wetland margins. The second 'Prevention' model is a catchment-wide strategic approach that attempts to reduce inputs by changing land use practices eg by reducing levels of fertiliser and manure applied by farmers.

Section 4 concerns the revision of FenBASE, a fen inventory of England and wetland database, developed at the University of Sheffield. This is updated using additional information obtained from the English Nature database ENSIS. A summary of the main revisions and an evaluation of the basin fen resource in England are presented. In addition, this section examines the implications of adopting mitigation methods at a regional level and makes recommendations for further research. This section was prepared jointly by the Wetland Research Group (University of Sheffield) and PAA.

Section 5 consists of three detailed case studies of basin fens that are in an unfavourable condition (*sensu* Joint Nature Conservation Committee 2004) largely because of diffuse nutrient enrichment. The problem facing each is described and a management prescription devised, following the process described in Section 5. The financial implications to farmers are evaluated through a cost-benefit analysis undertaken by Asken Ltd and PAA.

Section 6 provides guidelines on a process to identify signs of diffuse nutrient enrichment on a basin fen and help develop a suitable prescription to combat it.

Tables, figures and references are presented at the end of the report.

2. A review of nutrient enrichment and basin fens

2.1 The effects of eutrophication on wetlands and aquatic systems

The UK hosts a large proportion of the fen surviving in Europe. Fens support a rich diversity of plants, mammals, invertebrates and birds and make a major contribution to the biodiversity of the nation. Their importance has been recognised in the UK Biodiversity Action Plan (Biodiversity Steering Group, 1995), with a Habitat Action Plan (HAP) for fens with the following objectives:

- identify priority sites in critical need of rehabilitation and initiate by the year 2005. All rich fens and other sites with rare communities should be considered;
- ensure appropriate water quality and quantity for the continued existence of all SSSI fens for 2005.

Basin fens, as with other water bodies and watercourses, are increasingly being affected by nutrient enrichment. This is the result of increased inflows of particulate and dissolved materials, including nitrogen (N) and phosphorus (P) species, which promote the growth of algae and macrophyte biomass. Excessive loadings of nutrients, ammonia (NH_3) and sediment inputs can result in siltation, elevated biological oxygen demand (BOD), toxicity and eutrophication.

Generally, two main sources of nutrient supply can be identified:

- internal loading, ie nutrient cycling within the waterbody, sediments or vegetation; and,
- external loading, ie inputs from outside the aquatic or wetland system.

The processes controlling nutrient inputs to aquatic and wetland systems are complex, and both anthropogenic and natural processes can influence the degree and nature of nutrient enrichment (Fischer and others 1995).

A distinction can be made between 'natural eutrophication' and 'cultural eutrophication'. The former refers to the ageing process waterbodies experience over many years. According to this model, lakes are considered to be oligotrophic initially, ie poor in nutrients and plant life but rich in oxygen. With leaching and wind erosion, nutrients are added and plant and animal life encouraged. The trophic status changes to mesotrophic and eventually eutrophic, where primary production exceeds the capacity of the lake to mineralise organic matter (Cartwright and others, 1993). Internal loading is related to the seasonal or annual return to the water column of nutrients that have sunk and accumulated as sediments. This recycling is especially important in shallow lakes and fens where dead plant material accumulates at the surface.

In contrast, cultural eutrophication occurs when there is an increase in the external nutrient input, which artificially increases the trophic status over a relatively short period of time. This increase can be attributed to discharges of domestic waste, soil erosion, phosphates (PO_4) in detergents and also to diffuse inputs from agricultural land where artificial fertilisers and/or farmyard manure (FYM) have been applied in excess of those levels that can be readily taken up by the crop. Atmospheric deposition of both P and N may also be enhanced by anthropogenic emissions.

Throughout this report only cultural eutrophication is assessed, and this is often termed 'nutrient enrichment'. Nutrient enrichment can bring about a range of deleterious, temporary and long-term, effects on aquatic ecosystems, as summarised in Table 2.1. Eutrophication ultimately reduces biodiversity, through the proliferation and dominance of nutrient-tolerant or nutrient-demanding plants and algal species. These tend to displace species of higher conservation value, changing the structure of ecological communities.

Nutrient sources leading to enrichment can be broadly categorised into two: point sources and diffuse sources. Pollution from point sources is from a single discharge such as the effluent releases from a sewage treatment works (STW) or possibly as the result of a pollution incident. Generally, the control of point source pollution is more readily achievable because the cause is understood and mitigation works can be identified and introduced to ameliorate the problem. Eutrophic Sensitive Areas have been designated under the Urban Wastewater Treatment Directive (91/271/EEC) to include 86 rivers and canals, 16 lakes and reservoirs and 10 estuaries in the UK. Designation is considered necessary if there has been an 'undesirable' disturbance to living organisms because of direct nutrient-rich discharges. For designated areas sewage must be treated to an extremely high standard to remove the limiting nutrient, which is P in the case of running water and N in estuarine and coastal waters (Environment Agency, 2004).

The Asset Management Planning Round 4 (AMP4) is the most recent in a programme overseen by the Office of Water Services (Ofwat), to fund water infrastructure and environmental improvements. AMP4 covers the period 2005-2010. The AMP process has been important in controlling and reducing the impact of water company activities, including STWs, and there is considered to have been a marked decrease in point source releases since its introduction.

Diffuse nutrient enrichment presents more of a mitigation problem. D'Arcy and others. (2000) define diffuse pollution as:

> "Pollution arising from land-based activities (urban and rural) that are dispersed across a catchment, or sub-catchment, and do not arise as a process effluent, municipal sewage effluent, or an effluent discharged from farm buildings"

Over recent decades, as point-source pollution has been progressively reduced, there has been a concomitant increase in the levels of diffuse nutrient enrichment, largely because of changing agricultural practices. Diffuse agricultural pollution consists largely of nitrates (NO_3) and phosphates (Morse and others 1993). Following the Second World War, there was a drive towards greater self-sufficiency, which saw the introduction of more intensive farming systems. Average farm sizes have doubled, the area given to arable crops and grassland has increased by 36%, cereal cultivation increased by 60%, cattle numbers by 70% and poultry by 104%. The unguarded application of chemical fertilisers and use of animal manures has acted to elevate diffuse nutrient loads significantly (Mainstone and others 2000; Defra, 2000, in English Nature, 2003).

It is estimated that 70% of the total input of NO_3 to inland surface waters is principally from diffuse sources, particularly agriculture. The remaining 30% comes from point sources, notably sewage effluent and industrial discharges. It is estimate that 41% of PO_4 inputs to surface waters in England and Wales are from point sources while 59% comes from diffuse sources, the majority of which from agriculture (Defra, 2000, in English Nature, 2003).

Farming intensification, which has encouraged hedge removal, increases in stocking and grazing levels and an increase in tillage operations, has accelerated soil erosion and led to aquatic systems receiving higher loads of soil particles. This is particularly significant in terms of PO_4 enrichment, as P can be adsorbed to the surface of fine particles, which then act as a vehicle and distribution mechanism. Siltation is, in itself, a physical threat to aquatic and wetland environments. Increased turbidity and reduced light levels affect submerged plants and aquatic animals, and lake and river sediments may experience reduced aeration because finer particles clog the interstices of coarser material.

In conclusion, it is generally accepted that the main causes of nutrient enrichment are anthropogenic additions of N and P, predominantly from diffuse sources, resulting in cultural eutrophication.

2.2 The potential for nutrient enrichment of basin fens

Fens are found throughout the UK and are known to be declining in both quantity and quality due to increasingly intensive land use practices (Fojt 1995). The development of more intensive agricultural practices, especially after the First World War, encouraged the destruction and degradation of many habitats including fens. Increased use of inorganic fertilisers and lime to enhance agricultural production has resulted in the seepage of PO_4 and NO_3 into natural water sources (Burt and Haycock, 1993; Heathwaite 1995 and 1995a). This has led to nutrient enrichment and hence eutrophication through the processes and pathways discussed above. Land use changes in the catchment can also alter fen nutrient status through, for example, afforestation of primary unforested catchments (Schot and Van der Wal, 1992). These catchment scale changes can increase the inputs of major nutrient ions either through inorganic/organic fertiliser application or via increased mineralisation or organic matter due to drainage and oxidation of soils (Hill, 1976; Klotzli, 1987; Burt and others 1990; Howard-Williams and Downes, 1993).

A fen hydrological catchment can be defined as consisting of two main features, the surface water catchment (adjacent hill slopes and to a lesser or greater extent the more distance slopes within the catchment) and the groundwater catchment (shallow and deep aquifers) (Fojt, 1991). Hydrological disturbances in the catchment can also have a deleterious effect on the fen habitat. For example, drainage or abstraction can have dramatic effects such as modifying the fen from a groundwater discharge to a groundwater recharge system (Boeye and Verheyen, 1992). Such changes can affect the fen system in various ways through alterations in plant species composition, increases in primary production, increases in organic export and changes in nutrient cycling (Hughes, 1992).

Fens appear to be particularly at risk from nutrient enrichment and eutrophication as they are often found as isolated semi-natural or natural systems within a highly modified agricultural landscape. Their formation within areas where water naturally collects predisposes them to come into contact with many forms of water sources from the catchment, some of which might be heavily enriched with nutrients. In addition, the majority of fens are generally considered to be nutrient-poor systems as most of the nutrients are retained within the developing peat layers and available nutrients are typically tightly cycled within the system (Wassen, 1990; Koerselman and Verhoeven, 1992). Nutrient-enriched water entering a fen can, therefore, increase the nutrient status and has the potential to alter the character of the fen vegetation and, possibly, the associated fauna (Koerselman and Verhoeven, 1995). Such effects on the fen can take many years before changes are discernible in the vegetation. These changes have, however, been detected in the UK over many years in areas such as the Norfolk Broads (Wheeler, 1978), the Somerset Levels (Willis, 1967), and the fens of Anglesey (Gilman, 1994).

Plate 1. Campfield Kettlehole is typical of many basin fens in having agricultural land immediately adjacent to all boundaries of the fen.

Along with catchment changes in terms of hydrological functioning and land use change, fens can also be affected by more distant impacts through precipitation (Koerselman, 1989; Proctor, 1994). The potential influence of such impacts can be significant as peatlands are reported to retain up to 60% of the nutrients entering them via precipitation inputs, surface and sub-surface flows (Verry and Timmons, 1992). Collectively these catchment and precipitation inputs can be described as external factors in the nutrient enrichment of a fen (Koerselman and others 1993), as introduced in Section 2.1.

Nutrient enrichment can also occur as the result of impacts within the fen itself rather than in the catchment. This process has been termed internal nutrient enrichment (Koerselman and others 1993). Fens at later stages of development may be more susceptible to internal nutrient enrichment due to a net accumulation of nutrients within the system, particularly within the peat. The plant unavailable nutrients can be released if changes in the fen environment allow increased nutrient cycling, and these changes are summarised by Verhoeven and others (1993). Increased nutrient release occurs within the fen if anaerobic conditions are not maintained and the peat begins to mineralise. This may happen if water levels fall or fluctuate due to drainage or abstraction (Heathwaite, 1992; Ross, 1995; Freeman and others 1996).

The plant and vegetation community responses to nutrient change within a fen are not necessarily immediate, and there is often some time between changes in the chemistry of a site and these changes being reflected in the vegetation (Fojt, 1991). There appears to be remarkably little published quantitative information on the length of this time lag. Similarly there is little published data on the tolerance of fens to increased nutrients before irreversible changes occur. On this basis it is perhaps pertinent to note that the monitoring of water and soil chemistry along with vegetation might be a better indicator of the potential vulnerability of a fen to enrichment than the monitoring of vegetation alone. This would allow for ameliorative measures to be put in place before species are lost or the site irreparably altered.

However, the relationship between wetland vegetation development and chemistry is by no means clear and well defined. Proctor (1992) suggests the distribution of mire plant species and vegetation communities has little to do with the direct influence of the major ions in solution on ombrotrophic peatlands, but may relate to other factors such as topography and climate. A similar situation might apply to fen plant species distribution and base ions and water level may be more important for the species development rather than nutrient ions (Walbridge, 1994; Boeye and Verheyen, 1994). Similarly, Shaw and Wheeler (1990) found a positive linear correlation between species density and base ion concentration, and to a lesser degree between water level and reduction – oxidation (redox) potential in a sample of base-poor fens across Britain.

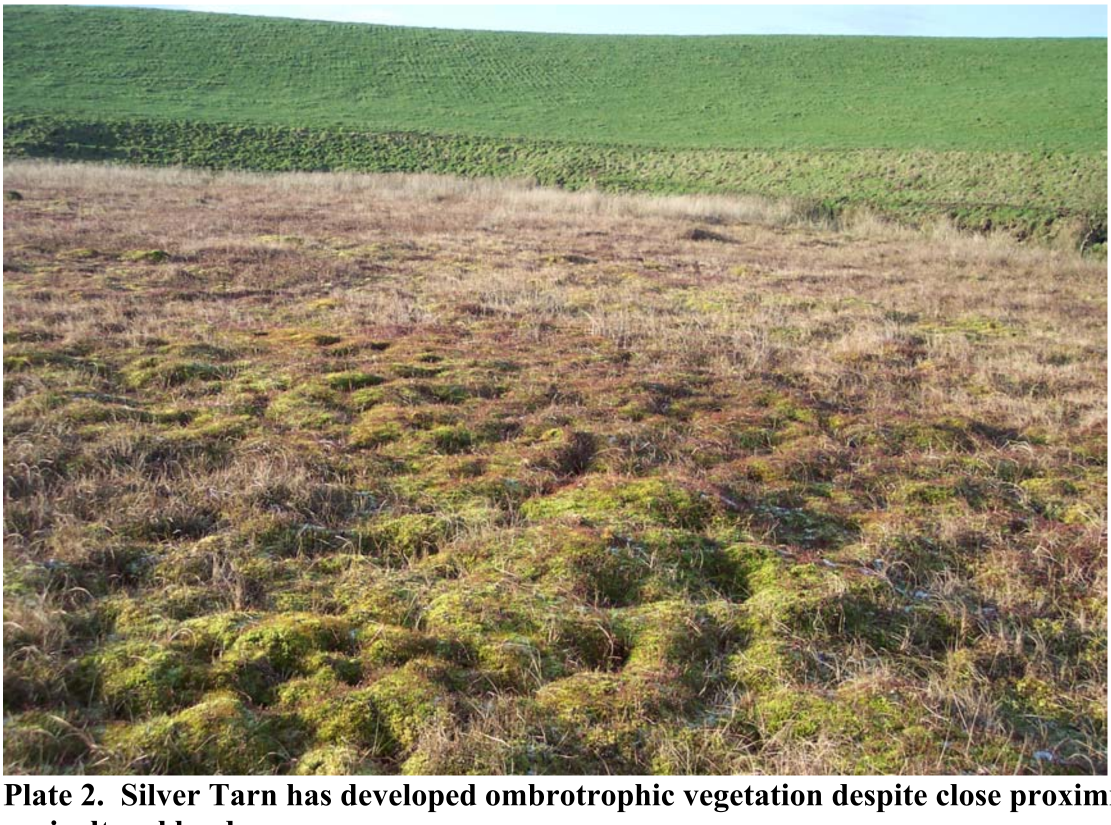

Plate 2. Silver Tarn has developed ombrotrophic vegetation despite close proximity to agricultural land use.

A study of basin fens within Scotland (Ross, 1999) further highlights the difficulty of linking water chemistry and vegetation. The hydrochemical data from water samples taken from 18 basin fens across Scotland indicated that nutrient concentrations were generally low with little indication of enrichment, despite often having an agricultural land use type adjacent to the fen. Only four sites showed elevated nutrient concentrations (compared to data published for other fen sites) and these measurements often related to specific sampling points on the fen rather than reflecting an increase across the whole fen site. In addition, fen sites appeared to have either elevated NO_3 or PO_4, rather than both nutrients. This might suggest some site-specific nutrient limitation, with sites either being PO_4 or NO_3 limited.

Nitrate and potassium concentration within these Scottish basin fens also often increased toward the edges of the fen, while PO_4 concentrations increased toward the centre. The edges of the fens might be more susceptible to nutrient enrichment from the catchment where both diffuse and point source pollution will enter the fen environment (Wheeler, 1993; Tratt, 1997), linked to external nutrient enrichment. In contrast the centre of the fen can be dominated more by precipitation inputs and *Sphagnum*-rich vegetation (Tratt, 1997). Increased phosphate concentrations have been linked to pH and mineralisation rates within fens (Verhoeven and Aerts, 1987; Veroeven and others 1988b), and can be considered as an internal nutrient enrichment process.

Plate 3. Tall herb fen vegetation at the edge of Wybunbury Moss.

In an attempt to define the relative levels of plant available nutrients within fen systems (rather than those measured by chemical analysis), peat 'fertility' has been measured by comparing the growth of a phytometric indicator plant species (Wheeler, 1988; Wheeler and Shaw, 1987; Shaw and Wheeler, 1990, 1991). These studies include a range of base-rich and base-poor fens and offer one of the most comprehensive comparative studies of fen habitats within the UK. However, such an approach required intensive study and specialist equipment, and is perhaps a less realistic option for assessment and monitoring of the nutrient status of large numbers of fen sites.

2.3 The role of nitrogen and phosphorus in nutrient enrichment

2.3.1 Nitrogen

Nitrogen undergoes gaseous transformations, and its major reservoir is the atmosphere. The majority of flows and exchanges within the nitrogen cycle are mediated by organisms, ie biological rather than physical-chemical processes. It is an essential macronutrient for plants and, more than any other nutrient, controls the rate of plant growth (Grobbelaar and House, 1995).

Nitrogen is added to the soil by processes such as fixation of atmospheric nitrogen (N_2) by bacteria operating symbiotically with leguminous plants. Other types of bacteria add small amounts, as does rain, and some forms of industrial pollution. Most of a soil's N is found in the fresh and humified organic material of the topsoil. Organic N can be made plant-available as inorganic NO_3 by the action of soil bacteria and other micro-organisms. Organic N is converted to ammonia (NH_3), which is then changed to NO_3 by nitrifying bacteria. Ammonia and NO_3 are, therefore, found naturally in the soil but these are frequently supplemented with the addition of chemical fertilisers, the commonest being ammonium nitrate.

Unfortunately, it is difficult to gauge the correct quantity of N that should be applied as fertiliser to obtain maximum crop yields. Nitrate moves freely in solution and is not adsorbed to soil particles, unless they carry a positive charge. Consequently, it can be leached out of the soil in solution. This rarely happens in the growing season but NO_3 left in the soil in autumn will be lost during the winter except on highly moisture-retentive soils (Davies and others 2001).

Inflowing surface and diffuse water contains various forms of N, which can be taken up by phytoplankton entering the dissolved pool or sediments. It occurs in aquatic environments as dissolved molecular nitrogen (N_2) and fixed and incorporated in algal biomass. Various forms of N can leave the system and N_2 can leave anaerobic sediments through denitrification. Depending on the levels of oxygenation of the water, nitrification and transformations can take place. This can convert the organic N into several states of oxidation: nitrite (NO_2), N_2 and NH_4. Nitrate and NH_4 then become available for uptake by aquatic plants and incorporated into organic fractions, either dissolved or particulate (Melak, 1995).

2.3.2 Phosphorus

The reservoir for P is in soils and sediments, and physical-chemical processes are responsible for major flows. Phosphorus naturally occurs as ortho-, poly- or meta-phosphates, all of which constitute dissolved inorganic phosphorus (DIP) and are plant-available. Colloidal forms of P are not available for plant uptake. Orthophosphate is released by weathering of catchment soils and rocks with phosphate material, whilst other forms are the products of biological metabolism. In aquatic environments, nearly all P is present as organic P in living and dead material. Yet, in many wetlands, lakes and watercourses, the majority of P is, ultimately, attributed to cultural eutrophication and it is generally recognised that external sources are the main cause, especially in lakes and fens (Sharpley and others 1995). It is also an important element limiting primary production in aquatic ecosystems and of all the elements required by phytoplankton and aquatic macrophytes, production can be stimulated greatly by additions of P or a combination of P and N.

Phosphorus is present in a number of forms and measured in a number of ways. Bio-assimilable P is soluble orthophosphate in the form of PO_4^{3-}. The soluble reactive phosphorus (SRP), dissolved reactive phosphorus (DRP) and bio-available P are generally considered to be equivalent to soluble orthophosphate. These terms are often applied in the context of enrichment because it is highly available for algal growth. Total soluble phosphorus (TSP) measures soluble P in the form of PO_4^{3-} and any other soluble forms. Total phosphorus (TP) is a measure of all P species present including those associated with solids (Cartwright and others 1993; Melak, 1995).

Only orthophosphate (PO_4^{3-}) appears to be taken up directly by membrane transfer to plant roots and incorporated into the particulate or organically bound P fraction. Algae are especially well adapted to scavenge P and can even excrete compounds to change the pH of their surroundings, which in turn can render adsorbed P available. Eventually, this can be released as orthophosphate by the process of mineralisation of organic material or as excreta.

Over recent decades there has been a steady increase in environmental stores of P. There are two major repositories: soil and sediments. The behaviour of P in soils is very different to that of N. Whereas NO_3 is soluble in water and readily assimilated by plants and lost from the soil by leaching, PO_4 are insoluble, does not move with soil water and is not leached from the soil. The steady increase in the P status in soils results in P deficiency for arable crops being rare. Soils first adsorb PO_4 strongly as the soil approaches P-saturation, it is held progressively less securely (Foy and Lennox, 2002; Davies and others 2001).

The degree to which it adheres, and thus its availability to crops, is also related to soil type. It adsorbs strongly with clay whereas calcareous and Lias clays adsorb less strongly. Acid soils quickly convert fertiliser PO_4 to unavailable forms so that levels of available PO_4 does not build up in the soil (Davies and others 2001). Where deficient, soils require liberal manuring, which, in turn, has implications to P loss, and diffuse enrichment. A number of studies have shown that increasing soil P is associated with increasing P losses to water. Heckrath and others (1995) using experimental plots in England note that there was negligible drainage loss of P until the soil P exceeded 60mg P kg^{-1}. The same research group reported that the 'critical' value could be substantially lower than this. Another study (Tunney and others 2000) found a strong positive correlation between soil P and the loss of P from grassland.

In fens, as with other water bodies, dissolved P in organic and inorganic forms interacts strongly with sediments and this will determine the fate of much of the P in basin fens. It interacts with substrate surfaces through the formation of specific inorganic surface complexes to become bound strongly with particulate matter. This includes organic detritus and mineral precipitates formed *in situ*, such as calcite and iron-hydroxides. Deposition in lakes usually exceeds the re-suspension of sediments and the release of soluble P. Another mechanism responsible for the effective removal of P in fens is the co-precipitation of calcite and P as calcium phosphate compounds. The amount removed in this way is slightly variable and depends on the presence of other compounds dissolved in the water. But the loss is substantial, with 25-45% of total P removed from the epilimnion. It is thought that in eutrophic, hard-water lakes and fens, a release of P from the sediments does not occur, so that co-precipitated P becomes trapped in the mineral substrate (Grobbelaar and House, 1995).

2.4 The role of hydrology

An understanding of relationships between basin fen and the catchment hydrology is essential to selecting an effective remediation to reduce existing, and guard against future, enrichment. Hydrological inputs are the main 'carriers' of P and N to a fen habitat.

The situation of a basin fen can vary considerably, according to the topography, environmental conditions, catchment land use, vegetation communities and the water supply mechanism. It is often difficult to determine the hydrologic functioning and identify the hydraulic pathways. Different parts of a single fen site may have different supply mechanisms. Wetlands are not uniform, with most displaying some degree of within-site ecological, vegetation and hydrological variation. Basin fens can be supplied wholly by groundwater whereas other fens develop largely because the configuration of the landscape results in impeded drainage. These topogenous water inputs may be related to flooding, precipitation and runoff where water drains to topographical hollows.

The capacity of diffuse pollution to disrupt and damage basin fens will depend on a number of factors. Of primary importance will be the extent to which the water has been loaded with P and/or N. Farming activities will be highly influential. The process of transmission and the nature of the aquifer can also be important. It is known that rocks and substratum can intercept P and N and act as a filter mechanism to reduce the load and effectively clean up the water. Chalk, for example, can have a natural buffer effect and act to protect aquatic systems. Other rock types, like sandstone, are chemically rather inert and are much less successful in moderating diffuse pollutants.

The substratum of the fen may also have a strong influence on the water quality. The water source provides the body of fen water but the physicochemical conditions are also determined by the nature of the substratum. The method of water delivery will be significant in terms of regulating levels and the condition of the water. For example, increased flows in spring may elevate redox potential and play a part in promoting the co-precipitation of P with calcite but inputs of water are not necessarily important in determining the surface conditions. Although planktonic organisms, like algae, draw on dissolved nutrients in the water, those aquatic plants that are rooted in the fen banks and bed are mostly independent of water supply. Properties of the substrata exert more of an influence on the chemical environment experienced by these organisms. For example, a base-poor supply of meteoric water may be offset by a calcareous substratum that supports a base-rich fen. Similarly, a peat or sandy substrate may sustain a nutrient poor wetland despite the water source being naturally or anthropogenically charged with nutrients. In short, there is not necessarily a correspondence between the physiochemical character of the substrate, experienced by the plant roots, and that of the quality of the water source. This could be related to a period when the water supply mechanism that prevailed earlier and determined the chemical state of the substratum has since changed eg the contribution was originally from groundwater but the supply mechanism altered to that of rain-generated inputs.

The supply mechanism has been used, in a large part, as the basis of the Wetland Framework Classification system (Wheeler and Shaw, 2001) where, in order to devise a typology for wetlands, three sets of data are used. These include the 'Situation Type', which describes the general landscape context in which the wetlands occur. The 'Ecological Type' considers permutations of water base richness (measured pH, or implied from the plant communities) and soil fertility categories (obtained through phytometric analyses of soil). Central to this system are nine main hydrological units or Wetland Water Supply Mechanisms (WETMECs). The Ecological Type and the WETMECs effectively identify the main wetland habitats and WETMECs are usually referable to an ecological type that supports one sort of vegetation. This information is summarised in Table 2.2.

Any basin fen can be allocated to one, or more, of the nine hydrological unit types. From the descriptions it is clear that mechanisms exist for the introduction of diffuse pollution in eight of the WETMECs. The only exception is Type 9, which includes drained ombrogenous surfaces. It encompasses peat areas that have grown in vertical extent because of peat accumulation. This isolates the peat from the water table so that it becomes fed directly and exclusively by precipitation. Although rain can have very slightly elevated NO_3 levels it is usually insufficient to cause nutrient enrichment. That basin fens can be in receipt of potentially enriched water from eight of the nine types highlights a number of points. It shows that there are a great variety of potential sources and delivery mechanisms for fen water. Although a fen may be receiving surface water this may have been supplied by groundwater affected by diffuse pollution. Individual fens may have an almost unique set of hydrological and ecological circumstances that need to be understood if the right management prescription can be devised. There is, therefore, a general need to understand the complexities of hydrological functioning of basin fens much better.

2.5 Agricultural practices and nutrient enrichment

A problem found widely in the UK, and one most relevant to basin fens fed by water from agricultural areas, is that farming typically operates under conditions of nutrient surpluses. In arable areas, N, P, and K are used widely as constituents of fertilisers but not all reach their intended destination within the cropping or pasture system. Soil storage and leaching loss to aquatic systems accounts for some losses. Similarly, with livestock rearing, although cattle eat grass, much of the energy requirement is obtained from imported foodstuffs. The result is that more nutrients are imported into the system, in the form of fertilisers and animal foodstuffs, than are exported in the form of agricultural produce (Heaney and others 2001).

Although nutrient surpluses are common in the UK, there have been relatively few catchment-loading studies. However, research in Northern Ireland has been valuable where, for many years, the problems of eutrophication have been studied. Much has been prompted by the well-documented transition of Lough Neagh from a mildly mesotrophic lake in the 19th century to a hypertrophic lake. Its history is mirrored in many other British catchments. The initial cause is related to urban discharge but these point sources have been largely controlled and now 80% of the total P entering Lough Neagh is estimated to be from diffuse sources (Foy and others 2002; Environment and Heritage Service, 2001).

A study of the River Main, between 1974 and 1995, measured SRP annual loads and related levels to sewage derived P and FYM derived P produced in the catchment. Although there has been a reduction in sewage P there has been an upward trend in general levels of P and a consensus view developed that it is related to increases in diffuse SRP. This was also observed in the six feeder rivers entering Lough Neagh and considered to originate from diffuse or agricultural sources. Foy and Lennox (2000) argue that the increase in SRP inputs is due primarily to an increase in soil P.

Where livestock farming is important, FYM can be a source of diffuse P. Losses as overland flow follows FYM applications and a P signal is detectable many weeks after the original application. Losses are influenced by the degree of saturation of the soil, the discharge of streams and the application rate of manure. Sherwood and Fanning (1981) noted the persistence of P in runoff for six weeks after the application of FYM to grassland whereas N lasted for less than a week. Winter applications of FYM to arable land in England saw losses increase exponentially at application rates over $50m^3\ ha^{-1}$. Loadings appear, therefore, to be higher in the winter months when river discharge is at its greatest. It seems clear, that in situations where the catchment area for basin fens consists of land where FYM is applied, there can be an expectation that diffuse P is being augmented by these farming practices (Smith and others 2001).

2.6 Existing management of nitrogen and phosphorus

2.6.1 Nitrogen

The protection of waterbodies and wetlands, and the efficient use of soil N for agriculture, requires minimum losses of N by leaching. Rainwater naturally has a concentration of about 1.5mg nitrate-N l^{-1}. Soils lose a small amount of nitrate to groundwater and 1-5mg nitrate-N l^{-1} is the normal range of concentration for British aquifers (Addiscott and others 1991). If levels of NO_3 increase as a consequence of mineralisation or the application of fertilisers, the potential for leaching and nutrient enrichment is also increased. This NO_3 burden in water from agricultural land is often a major contributor to diffuse nutrient enrichment in lakes, rivers and associated wetlands (Rowell, 1994).

The problem associated with nitrates in surface waters and groundwater has led to a considerable amount of research. The establishment of the Global Nitrogen Enrichment (GAN_2E) programme by National Environmental Research Council (NERC) and other funding authorities demonstrates one expression of interest in the issue of nutrient enrichment. It aims to investigate some of the key questions concerning the problems arising from nitrogen enrichment of our environment (NERC, 2001).

The control of NO_3 in freshwater systems is important from an environmental and health perspective. NO_3 is known to cause blue baby syndrome (Martin and others 1999) and NO_3 in drinking water can contribute to asphyxiation in livestock (Prasad and Power, 1995). Drinking water regulations in the UK call for a maximum of 50mg nitrate-N l^{-1} but this is exceeded in some areas (Brown, 2003)

The European Community (EC) has been taking measures concerned with N pollution in waters for over twenty years. The Council Directive 91/676/EEC (Nitrates Directive) concerning the protection of waters against pollution caused by NO_3 from agricultural sources, was adopted in 1991. The initial directives concerned themselves mainly with water for human consumption, more recent directives have placed increased emphasis on the environmental effects of excess N, in particular eutrophication. The Directive requires Member States to implement one of the following two options; either apply agricultural Action Programme Measures or designate Nitrate Vulnerable Zones (NVZs).

Article 10 of the Nitrates Directive requires that Member States submit a report to the Commission every four years following its notification. Action Programme measures apply only in NVZs. They promote best practice, following guidelines set out in the Code for Good Agricultural Practice for the Protection of Water. Sixty-six NVZs, covering some 600,000 hectares (8%) of England, were designated in 1996 to protect drinking waters from NO_3

pollution. The Government also encourages farmers outside of the NVZs to follow these voluntary Codes of Good Practice, to prevent NO_3 levels rising to the point where regulation becomes necessary.

Thirty-two areas within NVZs have been designated under the Nitrate Sensitive Areas (NSA) Scheme to help reduce or stabilise NO_3 levels in public water supplies. This voluntary scheme, which closed for further entrants in 1998, compensates farmers for changing their practices in order to protect drinking (Defra, 2003). These measures are likely to benefit basin fens within NVZs but may not be 'strict' enough to remove the need for targeted measures.

Nitrate groundwater concentrations recorded in abstraction boreholes have been rising steadily over the last 20 years (Anning, 2004) where catchments have been in receipt of chemical fertilisers. The control of levels is difficult, not least because the hydrogeological and chemical processes that influence the passage and residence time of nitrates is difficult to model. Contaminated groundwater generally moves slowly through aquifers and elevated nitrate levels measured today can be the result of fertiliser applications made many years earlier.

2.6.2 Phosphorus

The extent basin fens can be screened from excessive P loading will depend, to a large extent, on the hydrological pathways. Fens supplied predominantly by surface flows may achieve reductions by controlling soil erosion and introducing measures to intercept particle-bound P. However, P trapped in sediment sinks may present a longer-term problem where there is a risk of remobilisation at a later date. P release is generally slow and amelioration strategies may require some time before total P reduction is achieved

The reinstatement of fens to pre-enrichment status is possible. P is a particularly effective eutrophic agent, capable of generating 500 times its own weight in biomass, so when P is added to fens there is likely to be a rapid increase in algal productivity but this is not sustained. It decreases rapidly to levels comparable to those prior to enrichment and increased productivity can only be maintained if there is continuous P loading (Foy and O'Conner, 2002).

Measures so far adopted to protect rivers and lakes have concentrated on restricting nitrate and sediment loss. These may not be appropriate for P, particularly where P is in soluble form. Foy and Lennox (2000) point out that buffer strips, for example, may be of limited use in farmland where a large proportion of P is in soluble form (SRP). In addition, maximum permitted application rates for FYM, designed to protect against excessive NO_3 leaching, will still oversupply P because manures are relatively richer in P than N. It may be possible to predict P loss and its relation to application rates, to recommend appropriate application levels that do not trigger the mobilisation and transfer of P. Yet, from work to date, simple and consistent relationships have not become apparent (Smith and others 2001; Tunney and others 2000).

The seasonal release of SRP is important to the nutrient supply of shallow lakes and fens. Research suggests that release rates from sediment vary greatly. One study (Sas, 1989) shows the amount of P in surface waters to be critical to P release. For sediments with greater than 1mg P g^{-1}, P release will still take place over the five years following a cessation of external nutrient loading. In basin fens, the length of time over which P enrichment has taken place is significant. For those that have been in receipt of P for many years, recovery can be very slow because of persistent, slow release from the sediment (Keto, 1982; Mainstone and others 1993).

2.7 Future impacts

Although climate change is not a major component of this review, some mention needs to be made of this issue in order to recognise the potential future implications on the sustainability of mitigation measures along with the possibility of further changes in land use, agricultural practices and, therefore, diffuse pollution.

As with all ecosystems, basin fen habitats are likely to adjust to climate changes linked to global warming in the long term. There remains some contention over the issues, but a consensus view has emerged that suggests likely global impacts: sea-level rise, increased storm intensity, changing rainfall patterns and temperature rise (IPCC, 2003). If, as some predict, the frequency and magnitude of intense rainfall events increase, surface run off is also likely to increase. This will tend to mobilise soil and associated adsorbed P as well as unincorporated manure and chemical fertilisers presenting an additional threat to fens and aquatic habitats. There is empirical evidence to support the notion that these macroclimate vacillations are real but the smaller scale implications remain uncertain (US Environmental Protection Agency, 2003).

In the face of such uncertainty it is difficult to foresee outcomes but these factors should be kept in mind when planning long-term mitigation strategies. One management strategy being increasingly used, because of the increased frequency of summer droughts, is the provision of winter storage to augment water levels during dry periods. If this pattern continues it is likely to instigate changes in fen vegetation community composition. If these changes are considered undesirable, alternative summertime water sources will need to be found (RSPB and others 1999; ITE, 1990; Tyndall Centre and Hadley Centre, 2002; IPCC, 2003).

3. An assessment of options available for the mitigation of nutrient enrichment of basin fens

3.1 Introduction

This section is divided into two parts: the ‘protection model’ and the ‘prevention model’. The protection model examines measures that can be applied to reduce the impact of nutrient enrichment near to the basin fen. The prevention model is concerned primarily with farm practices and how they might be managed to reduce the release of nutrients.

Methods of nutrient reduction generally aim to harness natural nutrient transformation processes such as sorption, co-precipitation, active uptake, nitrification and denitrification. These processes remove P and N and transfer them to the atmosphere, substrate and biota for storage.

The removal of N is principally through denitrification. This occurs anaerobically whereby NO_3 is reduced to N_2 by organisms, which oxidize the organic matter and use NO_3 as an electron acceptor. To be a significant factor in removing N from a fen, the N_2 must be allowed to escape to the atmosphere, before it is fixed to NO_3 again to accumulate and cycle in the wetland system.

There is no counterpart to denitrification for P and no process that enables P to escape completely. Permanent removal can only be achieved by physically removing plants that contain P. Loss of P to the system takes place when refractory or insoluble compounds enter the substrate. But sequestration may not be permanent and the substrate may act as a source as well as a sink. The exchange of P between sediments and fen water is related to adsorption-desorption processes and is influenced by pH, reduction - oxidation (redox) potential and calcium (Ca). The redox potential is a relative measure of the concentrations of oxidants eg O_2, NO_3 and reductants including most organic compounds, weighted by their oxidizing power. It depends greatly on the presence or absence of dissolved O_2 and low redox potential, ie low dissolved O_2 promotes solubilisation of P. The chemical and physical character of the substrate particles is also important, as is the pH. At pH 5-7, P is unlikely to go into solution from sediments but the solubility increases above and below these values (Sloey and others 1978).

3.2 The 'Protection Model'

3.2.1 buffer zones and their use in managing nutrient enrichment at the local scale

“A buffer zone (BZ) is a vegetated area lying between agricultural land and a surface water body, and acting to protect the water body from harmful impacts such as high nutrient, pesticide or sediment loadings that might otherwise result from land use practices. It offers protection to a water body through a combination of physical, chemical and biological processes” (Blackwell and others 1999)

As with riparian zones, fen margins may occupy only a small fraction of the landscape but assume a greater importance because they have a critical position linking aquatic and terrestrial ecosystems. They play a significant role in controlling the nutrient movement from the catchment to the fen (Pinay and others 1998).

Research consistently indicates that the planting/preservation of BZs, such as a vegetated strip that extends around the fen, can be an effective means of reducing pollution from agriculture. BZs of grass, trees and shrubs are often recommended among general guidelines for water management, as means of guarding water quality because they act as biomechanical filters for enriched runoff and groundwater (Norris, 1993). They are capable of removing nutrients in solution and as particulate material carrying adsorbed pollution (Jordan and others 1993).

Plate 4. Algal mat at Wybunbury Moss resulting from increased nutrient inputs.

As well as protecting the fen from high nutrient inputs, there are often additional benefits:

- provide feeding, breeding habitat and shelter for fauna;
- contribute to wildlife corridors between adjacent wetlands and countryside;
- aesthetic enhancement;
- aid fen margin stabilisation and prevent livestock poaching;
- minimise invasion by weed species;
- obscure incompatible scenery from the fen eg residential or industrial areas; and,
- provide an area for passive recreational activities such as bird watching.

The degree of protection afforded by a BZ will depend on a number of factors, however, the size of the BZ is significant. So too are the hydrological pathways, the type of vegetation, substrate and the soils found within the catchment (Phillips, 1989). Some concerns over increased water loss through evapotranspiration on wooded buffer zones have been raised, but there is little published research on the implications of nearby tree planting on water inputs to a fen area, although there is research to indicate trees on mires do draw down the water table (Keleman and Ingram, 1999; Bragg, 2002). Broadleaved trees can lose up to 6mm/day of water through evapotranspiration, although losses through coniferous trees are much lower (Baldocchi and others 2000). The benefits of nutrient removal, therefore, need to be assessed against potential negative effects of increased water loss, particularly for sites with more limited surface water resources.

3.2.2 Mechanisms of diffuse nutrient enrichment transport

There are two mechanisms of diffuse pollution transport to fens: surface flow and subsurface flow. These transport processes can influence the effectiveness of BZs. Surface flow is associated with saturated soils when water supply exceeds infiltration capacity. Surface runoff can be a major mechanism for transporting soluble nutrients following applications of fertilisers and FYM. Surface flow can also lead to sediment loss, eg as sheet erosion in the event of spatially uniform overland flow. Surface water can also result in concentrated flow forming small rills and gulleys. The erosion risk is greatest with coarse-textured soils, which lack internal cohesion. Soils are particularly vulnerable when unvegetated and exposed to heavy rain, eg during the autumn when land is being prepared for winter cereals. Organic and mineral sediments can adsorb pollutants including nutrients. It is well documented that P adheres strongly to particulates and sediment P constitutes a high proportion of total P loss, especially in association with the fine fraction.

Subsurface flow also is a major mechanism for the transport of soluble nutrients, especially in the wetter winter months when evapotranspiration is low and water tables high. The subsurface diffuse movement of N loss from soils results in a seasonal pattern of elevated winter concentrations. This is associated with increased N loads because of the flushing effect of N released by mineralisation at a time when vegetation uptake is reduced. This may be exacerbated by rapid movement through micropores in cracking clay soils and lead to significant export before field capacity is reached (Muscutt and others 1993).

In agricultural areas artificial drainage plays an important role in subsurface water movement. Mole drains are common in clay soils where drainage is impeded and, in conjunction with natural soil macropores, they provide routes for the rapid transport of water and nutrients. High NO_3 concentrations in the order of 30-50mg 1^{-1} can be expected in winter in artificial subsurface drains (Muscutt and others 1993).

Sediment movement below ground is much more limited because flow velocities are low and the carrying capacity of the water reduced. Nevertheless, subsurface sediment movement may occur in association with land drains and soil macropores.

Box 3.1 Summary: mechanisms of diffuse nutrient enrichment transport

- There are two mechanisms: surface and subsurface flow including percolation.
- Surface flow occurs when soil is saturated and precipitation exceeds infiltration capacity.
- Organic and mineral sediments strongly adsorb P and particles.
- Subsurface flow is important in transporting soluble pollutants.
- There is a greater loss of N in solution in the winter.
- Subsurface movement is increased by drainage and soil macropores.

3.2.3 Mechanisms of nutrient removal

The most important pollutants in terms of diffuse nutrient enrichment are N and P. The manner with which they are removed in vegetated BZs is different. They can be examined in terms of removal of nutrients in solution and removal of sediment, although the two processes are closely linked.

Three mechanisms are cited for the removal of N in BZs:

- plant uptake;
- microbial immobilization;
- bacterial denitrification.

The relative importance of each of these mechanisms is not understood well and it may vary in different situations. Plant uptake has been shown to be significant, but bacterial denitrification is the most frequently cited mechanism for the attenuation of NO_3 in subsurface water. Microbial immobilization is thought to be of minor importance. Bacterial denitrification is the dissimilatory reduction of nitrogen oxides (NO_3 and NO_2) to gaseous oxides (NO and N_2O), which may be further reduced to N_2. If this is the final product it represents complete removal from the system and it is, consequently, considered to be the best mechanism for NO_3 removal. In contrast, NO_3 immobilised by microbes or bioassimilated by vegetation, has the potential to return N to the ecosystem through decomposition and mineralisation. Plant uptake is a temporary store and in constructed wetlands and buffer zones vegetation may require harvesting for the complete removal of nutrients from the system (Yates and Sheridan, 1983; UK-CHM, 2000).

BZs have the effect of increasing the residency time of waters or sediments before entry into fen to allow plant uptake, microbial immobilization and bacterial denitrification to occur. Yet, the important process of denitrification is less dependant on residency time but rather on the conditions that affect the rate of denitrification. These are:

- the supply of carbon;
- an anoxic environment which generally corresponds with waterlogging;
- temperature; and,
- nitrate availability.

The importance of carbon has been shown in a number of studies where 'hotspots' have been discovered. Addy and others (1999) report on a number of investigations where a correlation has been found between N loss by dentrification through microbial activity in the subsoil, where there are carbon-rich patches. This is also noted by Jacinthe and others (1998) and Gold and others (1998). Some studies suggest wooded vegetated BZs are more effective than grassland at NO_3 removal because of the greater amount of soil carbon (C) added by leaf fall, which in turn promotes denitrification (Hubbard and Lowrance, 1997). The importance of carbon prompted Haycock and Pinay (1993) to comment that the carbon dynamics and organic matter status are major factors affecting N removal in vegetated buffer zones. Organic soils and a high water table are preferred where plant decomposition and root exudates can form carbon compounds and contribute to denitrification.

Johnes and Burt (1991) suggest that particulate organic N could form as much as 20% of total N load in streams. It is though, generally considered that removal in solution is the most significant process in N loss. The removal of P in vegetated BZs is more closely associated with the trapping of particulate matter to which it is adsorbed. This is often eroded soil. Much of the research has demonstrated that BZs are highly effective sediment traps halting movement within the first few metres of the vegetated strip where P accumulates (Burt and Haycock, 1993).

Box 3.2. Summary: Mechanisms of diffuse nutrient removal in buffer zones

- There are three mechanisms for N removal:
  - Plant uptake;
  - Microbial immobilisation;
  - Bacterial denitrification.
- Bacterial denitrification is the most significant.
- Denitrification represents a complete loss of N from the system.
- Factors that affect the rate of denitrification are:
  - Carbon supply;
  - Anoxic conditions;
  - Temperature;
  - N availability.
- Carbon-rich patches cause 'hotspots' of denitrification.
- N is more often lost in solution.
- P is more often lost in sedimentation, adsorbed to organic and mineral particles.

3.2.4 Nutrient retention processes in buffer zones

Diffuse nutrient enrichment occurs because of a range of mechanisms and vegetated BZs are likely to vary in their effectiveness according to source and transport mechanism of the pollutant. The effects of vegetated BZs on water quality can be divided into. Each of these is discussed, in turn, below.

- Direct effects by removal of the fen margins from active agricultural use.

- Those resulting from processes of retention in the vegetated buffer zones; which can be either:
  - retention under conditions of surface runoff; or,
  - retention under conditions of subsurface runoff.

3.2.4.1 Direct effects by removal of the fen margins from active agricultural use

Direct effects by removal of fen margins from active agricultural is not strictly a retentive process, but if the fen is fringed by permanently vegetated land that is managed separately from the rest of the catchment it will benefit, for example, from reduced applications of agrochemicals. Fields near the fen can escape the impact of grazing, where nutrients tend to be cycled through the soil-plant-animal system and removed with surface runoff when excreted. If livestock are excluded from the edges of the fen there may also be a small reduction in soil erosion caused by poaching. Vegetated BZs can also reduce off-target contamination of water by pesticide spray drift (Peters and Walling, 1991; Muscutt and others 1993).

Plate 5. Campfield Kettlehole basin fen is entirely surrounded by agricultural land and has only a small length of buffer strip.

3.2.4.2 Effects resulting from processes of retention in the vegetated buffer zones

(A) Retention under conditions of surface runoff

The effectiveness of a vegetated buffer strip to retain surface water flow depends partly on its physical properties. Norris (1993) identifies a number of important factors:

- structure and species of the vegetation;
- length, gradient and shape of the runoff area (ie width and steepness of the BZ);
- length, gradient and shape of the slope upstream of the BZ;
- the rate of flow of surface water;
- the depth of the water in comparison with the height and density of vegetation;
- hydraulic conductivity and holding capacity of the buffer zone soil; and,
- the presence of under-drainage.

The relative importance of these characteristics depends on the type of nutrient pollution. To remove nutrients adsorbed to particulate matter eg P, the BZ must reduce the flow velocity and encourage deposition. This is largely determined by the vegetation, surface texture and gradient of the BZ.

A vegetated buffer strip spreads and divides incoming overland or channelised flow, reducing the velocity. This serves to increase infiltration and reduce the depth of the water. Coarse particles are deposited and suspended particles filtered through leaf litter to the soil. Nutrients detained in the BZ soil are able to decay, to be taken up by plants or adsorbed onto soil particles before they reach surface waters.

The width of the BZ in relation to the size of the catchment is important. Generally speaking, the effectiveness of a BZ will increase with a reduction in the size of the catchment. Basin fens are often associated with topographic depressions and hollows being hydrologically sustained by surface and/or groundwater recharge. Formally glaciated landscapes, produced by the widespread deposition of till, are often characterised by undulating and hummocky terrain that lends itself to the formation of basin fens in relatively small and sometimes confined catchments. This is an advantage because the utility of the BZ is effectively increased.

Length of slopes and gradient of the fen catchment may influence BZ effectiveness. Runoff from a short slope will be of low volume and velocity and relatively easily slowed and detained in the BZ. A longer upstream slope, associated with a larger catchment, will have a large water yield and the velocity is likely to be greater. Runoff may not be stopped by the BZ. If runoff originates at some distance from the fen there is also a greater likelihood that it will be channelised into streams and runnels and could pass through the BZ surrounding the fen. Under this scenario, there is little of no retention and, therefore little opportunity for removal processes to work. In this case it may be beneficial to intercept the stream or runnel, to divert and disperse its flow through the BZ (Pinay and others 1994).

In short, the decrease in surface runoff coupled with increased surface hydraulic roughness associated with vegetation, is likely to lead to a significant decrease in surface flow velocity.

The resulting reduction in sediment transport capacity is the most often cited cause of sediment removal in vegetated buffer zones (Yates and Sheridan, 1983; Correl, 1997).

Plate 6. Land adjacent to Silver Tarn showing variable topography that might be suitable for creation of grassland buffer zone, and localised effects of enrichment

(B) Retention under conditions of subsurface runoff

The purpose of a vegetated BZ is, essentially, to discourage surface flow and divert nutrient enriched water below the surface. Slowing surface water velocity and increasing the infiltration capacity of the BZ soil encourages this and permanently vegetated areas tend to have better soil structure and thus, a greater potential for surface infiltration.

Nitrogen removal as a result of dentrification is usually greater than that achieved through plant uptake or microbial immobilization. The advantage of this process is that it represents the complete loss of N from the ecosystem as gaseous N whereas N taken up by plants will be returned following decomposition. In addition, in temperate regions like the UK, photosynthesis and nutrient uptake are arrested in the winter months but the conditions for sustained denitrification can be met throughout the year. Nitrogen exports from agriculture are greater in the winter months at a time when the bioassimilation of N by vegetation is not possible so that dentrification takes on a particularly vital role at this time of year (Pinay and others 1994).

Just as BZs may be traversed by surface drainage, so too subsurface flows in BZs are likely to decrease the rate of N removal. This can be done in two ways. Firstly, drains can have the effect of lowering the water table, which aerates the soil so that the reducing conditions necessary for denitrification are lost. Secondly, as with surface runoff, the contact time between water and soil is restricted so that there is less opportunity for removal by plants or bacteria. Artificial land drains and naturally occurring soil macropores can have this effect. If farmland is being decommissioned it may be worthwhile to disturb the drainage system by partial/complete removal or by simply blocking discharge outlets.

Martin and others (1999) point out that much of the research examines the lateral movement of groundwater and the denitrification process as it moves towards a river channel or wetland and the little attention has been given to the process working at depth. This may stem from the assumption that the complex process is affected by several factors such as oxygen content, carbon availability, pH and temperature and appropriate conditions cannot be met in deeper sediments. However, many examples are cited where denitrification is viable at considerable depths and they argue that more vertical sampling is required in order to characterise the denitrification capacity of soils and inform best management strategies for vegetated buffer zones. This is particularly pertinent in the case of basin fens that are fed by deeper groundwater sources where subsurface biological denitrification may be significant.

The great importance of soils and the degree of ground saturation is highlighted by Haycock and Muscutt (1995). Based on the research to date they point out the established view is that N is carried mainly in solution through the soil, whereas P is strongly retained in soils, and although it can occur in subsurface waters, it is primarily associated with sediment carried in surface runoff during heavy rain. Where surface flow is an important pathway, the BZ should be dry to promote infiltration and have a high hydraulic roughness eg grass. For N control, the BZ should be wet and have a high organic content to encourage denitrification. Where the control of both N and sediment-attached P is important then dry and wet buffers are needed in sequence. Totally saturated regimes are best for N removal and dry areas are best for P removal. Hedgerows and vegetated grass strips can be used for P removal (dry boundary landscapes); totally saturated areas like carr and fen margin for N transformation and removal (wet boundary landscape) and alternating moisture regimes to remove P and N (transitional wet-dry environment).

Box 3.3. Summary: nutrient retention processes in buffer zones

- Nutrient reduction occurs because BZs remove land adjacent to fens from intensive agricultural use.
- A vegetated strip reduces water velocity, promotes sedimentation and increases infiltration.
- N removed by denitrification is more effective than plant uptake and microbial immobilization.
- Denitrification occurs all year.
- There is evidence that denitrification occurs at depth.
- Dry boundary buffer landscapes, like hedgerows and grass strips, are better for P removal.
- Wet boundary buffer landscapes, with high carbon content like carr and wetlands, are better for N removal.

3.2.5 The effectiveness of buffer zones

It is widely accepted that vegetated BZs, when located adjacent to wetlands and water bodies improve water quality to some degree. What is less well understood are the site characteristics that promote the greatest amount of removal.

An early investigation by Yates and Sheridan (1983) looked at buffering of diffuse pollution from agriculture in vegetated alluvial floodplains finding that 96% N was retained along with 37% P. Peterjohn and Correll (1984) noted that losses of N and P in surface runoff in a riparian forest buffer was reduced by 83% and 81% respectively with sediment P falling, but soluble P showed little change. The ability of an alluvial swamp to assimilate and accumulate ammonium (NH_4), N and P was tested by Brinson and others (1984) who came to the following conclusions that have been largely supported by subsequent research:

- N loss by denitrification is rapid and persistent;
- NH_4 accumulated on cation exchange sites but was transformed to nitrates in summer when the swamp dried. NO_3 did not accumulate so it is assumed it changed to N_2 by denitrification;
- P accumulated with little sign of subsequent loss;
- uptake of N and P by vegetation was small in comparison to denitrification and sediment accumulation, and;
- capacity for swamp to remove nutrients – highest for N, intermediate for ammonium and poor for P.

Muscat and others (1993) described an 82% loss of NH_3 and 61% reduction of N in an alder wood BZ and small plot studies described by Muscat and others (1993) measured >50% reductions of total P and a very high 94% loss of organic forms of N in buffer sediments. Haycock and Pinay (1993) estimated a 99% N retention in a vegetated riparian strip.

There has been a great deal of interest in the Netherlands where farming is highly intensive and vegetated BZs have been established to reduce diffuse nutrient pollution. Hefting and de Klein (1998) measured high N concentrations at the boundary of maize fields of >40mg N 1^{-1} but this fell to 0.1-2mg N 1^{-1} having passed through the vegetated BZ and N concentrations in groundwater decreased by 95%.

Lowrance (2003) describes a comprehensive nine-year study has been conducted by the US Agricultural Research Service into N and P reduction by restored riparian buffer zones, next to agricultural fields. The BZs were found to remove at least 60% N and 65% P and another three-year study found reduced amounts of herbicides.

Box 3.4. Summary: the effectiveness of vegetated buffer zones

- It is widely accepted that BZs adjacent to wetlands provide a degree of nutrient buffering.
- The relatively small and sometimes confined catchments of some basin fens is an advantage because the BZ will be large compared to the catchment area.

3.2.6 Buffer zone vegetation

Basin fens may have a margin of woodland, which can have indirect impacts on the character of the fen. Shading may lower fen water temperature with a corresponding increase in dissolved oxygen. The effect would be greatest with densely wooded fringes around small basin fens whereas larger fens with wider areas of open water would be less influenced. Other microclimate effects may result from a reduction in wind speed. Allochthonous inputs from leaves and woody material will include woody, coarse and fine particulate organic matter. Woody material provides cover for organisms and may provide spawning and refuge areas for fish and a habitat for invertebrates. Leaf litter can supply energy subsidies for aquatic invertebrates (Yates and Sheridan, 1983).

The efficacy of vegetated buffer zones as a sediment trap for particulate matter depends on the hydraulic roughness of the ground surface. Even short herbaceous plants are sufficient to slow water flow and encourage deposition. The canopies of woodlands need to allow an ample amount of light through to the ground to enable a field layer to grow.

There have been a number of studies into the effectiveness of different vegetation types in nutrient removal. Burt and Haycock (1993) found no major difference between poplar dominant woodland and natural meadow although permanent pasture was found to be less effective. There was a slightly better performance with wooded floodplains that they attributed to the increased inputs of carbon from leaf fall. Haycock and Pinay (1993) examined winter N retention in grass and poplar vegetated riparian strips. N retention occurred at the edge of riparian zone especially in association with poplar woodland, where all hillside-derived NO_3 adsorbed within the first 5m of the buffer zone. The area of poplar was found to be the most effective with 99% N retention, while grass saw an 84% N retention. They stressed that for the optimal NO_3 reduction in winter by denitrification it is necessary to increase flow through sediments as opposed to the surface.

Plate 7. Existing shrub growth adjacent to Silver Tarn that could be expanded to form a woodland buffer zone.

Addy and others (1999) compared N loss in forested areas with a mowed herbaceous riparian zone. Substantial groundwater removal was recorded in both areas although rates could vary in similar sites. A correlation was found between removal and 'hotspots' of microbial activity in the subsoil where there were carbon-rich patches. This study and many others do suggest that there are slightly better removal rates for N in wooded buffer zones although others have measured significant removal in grassed sites (Hubbard and Lowrance, 1997; Correll*,* 1997). Addy and others (1999) offer a compromise solution, suggesting that a mix of wooded and mowed vegetation may be as effective as anything else. They also advise care in ascribing the removal of N to specific vegetation without considering other important site factors eg hydrology and adjacent land use.

Many who believe it can provide the benefits of both herbaceous grasslands and woodlands prefer a mixed BZ. This can take the form of a mosaic of vegetation types providing habitats and aesthetic enhancement to the fen margin. Some models suggest a clearer zonation whereby woodland immediately borders the fen, grading into a scrubland and finally an herbaceous perimeter.

The age of woodland is also important. It has been shown that young woodland has a higher nutrient uptake rate than mature woodland. This is because the plants within them are growing more rapidly, whereas, mature forests have created forest soils through leaf litter and root systems, which increase biomass on the forest floor (Lowrance, 2003). With maturity there may be a reduction in plant uptake but an attendant and compensatory increase in denitrification because of improved infiltration and permeability.

It may be desirable to extend the BZ. Decommissioned farmland can be left to regenerate naturally within the proposed BZ although this may be a slow process and it might be better to re-establish native vegetation by direct seeding, planting of seedlings and introduction of the desired seed and rootstock. Local native species should be used in rehabilitation, as they are most suited to the local conditions and in keeping with the existing communities.

Managed woodlands working with a short cropping period could also be an effective way to reduce nutrients. Fast growing willow, for example, is known to remove N and P and have the additional advantage of stripping metals, such as copper (Cu) and zinc (Zn). This benefit has to be balanced against the loss of carbon but the trade would seem to be favourable. Some management prescriptions eg Riparian Management System (RiMS, discussed later), advise the use of fast growing hardwoods, which can grow fast and be coppiced. These trees can be harvested for biofuels within 4-6 years.

The aquatic macrophytes of the basin fen fringe have a rapid growth rate and can accumulate nutrients at greater levels than most terrestrial plants (Preston and Croft, 1997). However, any system of removal relying on plant growth rates is likely to be limited because the conditions for rapid growth only exist in the growing season. Once photosynthesis stops and nutrient requirements of the plant are met, uptake will cease and annual recycling will return the nutrients. Engineered reedbeds can be harvested to remove nutrients but this is not a practicable solution for basin fens.

Box 3.5. Summary: buffer zone vegetation

- Wooded fen margins affect shading, dissolved oxygen levels and provide organic inputs.
- For BZs to be effective sediment traps, there must be a sufficient groundcover. Short grass is usually enough.
- Studies examining wooded and managed grass BZs suggest both are capable of pollution removal.
- There is evidence that denitrification is greater under woodland because of higher carbon inputs.
- Mixed BZs, consisting of a mosaic of vegetation communities are thought best by many authors.
- It is best to use native plants in BZs.
- Managed woodlands can be used to remove nutrients, metals and be harvested for biofuels.
- Fast growing aquatic macrophytes are only effective in the growing season.

3.2.7 Buffer zone widths

There have been many studies into BZ widths, and some of these are discussed below and summarised in Table 3.1. Most investigations suggest the effectiveness of BZs is attributable to physical properties of the zones, especially their width and slope. Many studies of small controlled runoff plots demonstrate BZs as narrow as 5-10m can remove pollution such as sediment, nutrients and chemicals from overland flow (Muscat and others 1993). Similarly, confined agricultural fields experiments show BZs are capable of removing nutrient and sediment loads. However, the reported effectiveness of BZs for water quality control on a broad catchment scale has been questioned. Larger catchments are likely to contain a variety of pollution sources, and BZs of changeable physical characteristics like soils, vegetation structure, width and slope (Norris, 1993).

The removal of dissolved pollutants depends on the capacity of the BZ soils to detain runoff to allow for the decay or transformation of nutrients, or uptake by plants. Soils of low permeability, for example, would need wider buffer strips than highly permeable soils, to enable the infiltration of surface runoff within the buffer area. A convex slope creates faster overland flow at its base than does a concave slope and so would need wider BZs to create the same effect of slowing surface runoff.

A number of authors have sought to define the desired width but there is no consensus as to what is an optimum. The width will depend on the circumstances within the catchment although Haycock and others (1993) suggest 10m either side of a river would be a minimum. Pinay and Decamps (1988) reported that all N had gone with a 30m vegetated buffer zone and Haycock and Burt (1993) noted that the majority of the N load was lost in the first 5–8m. Phillips (1989) estimated appropriate widths using a model of water retention and soil conductivity, soil moisture storage capacity, slope, Darcy's law and Manning's roughness coefficient. For the conditions in North Carolina the model suggested a buffer in the range of 15-80m wide. Where nutrients associated with the suspended load were the major concern, slope gradient and soil hydraulic conductivity were critical. Where dissolved nutrients were transported by surface and subsurface water, buffer width and soil moisture storage capacity were the most important factors, as both of these factors affect retention time in the BZ.

Determination of the BZ is complex and a great number of models have been devised to advise on correct buffer widths. Models have, to date, been used largely to calculate appropriate BZ width in the context of riparian corridors. If models are to be used for fen catchments there may need to be some modifications but the underlying principles remain the same. There has been a proliferation of mathematical simulation models, based on various physical processes involved. If all the variables are taken into consideration the model becomes too complex and in need of huge computer power to deal with algorithms included in the models. Some models are described in Appendix III. How useful these models are in practice is debateable but they do, at least, provide a tool to inform management guidelines for the design of buffer zones.

Box 3.6. Summary: buffer zone widths

- BZ width and slope are highly significant factors.
- Even narrow BZs have been shown to be effective at reducing sediment, nutrients and chemicals.
- Generally, the wider the BZ the greater the amount removed.
- Nutrient removal depends on the capacity of the soils to retain flows.
- There is a positive correlation between retention time and nutrient removal.
- Many studies have examined BZ widths. Suggestions range from 5m to over 100m. There is no consensus as to the optimum.
- Appropriate BZ width will be determined by local catchment conditions.
- There are many simulation models to help in the determination of BZ widths. Some are relatively simple whereas others are very complex and require huge computer power.

3.2.8 Alternative buffer sites

Many fens have a margin of woodland or grassland that act as BZs. However, these are effectively by-passed by streams that flow directly into the fen. There is little opportunity to deposit sediment loads or interact with sediments to enable denitrification. It has already been stated that it may be necessary to disperse flow to allow greater retention and infiltration. It is also important to maintain riparian buffer strips along the banks of the feeder streams. Pinay and others (1994) and many others, promote the creation of longitudinal buffer strips along stream corridors as a preferred alternative to constructed wetlands at the end of drainage networks.

Subsurface drains and soil macropores crossing fen margin buffers are likely to be less effective at N removal because the water table is lowered and there is restricting contact time. It may be necessary to introduce additional measures within BZs. Peterson and others (1992) suggest the creation of 'horseshoe wetlands' positioned at the surface outlets of subsurface drains. These are semi-circular excavations, within the more extensive BZ, consisting of about 10m by 8m strips of grass and shrubs.

Blackwell and others (1999) note that hydrological flows are often intercepted by ditches and drains. In these cases it may be more effective to establish BZs in association with ditches and other areas within the catchment where denitrification can be encouraged. BZs do not necessarily have to surround the fen itself but can be located in any part of the catchment where nutrient enrichment is a problem. Indeed, there are advantages if the pollution can be intercepted as close to the source as is practically possible. Alternative wetland BZs include footslope discharge areas and overland flow associated with a ditch system. Both sites were found to be efficient at N removal and it was shown that landscape features like oxbows, overland flow zones and other strategically located wetlands can be used to complement or even replace 'conventional' fen margin BZs.

Ditches are common features of the English landscape and they may be put into service to reduce nutrient enrichment. They are also relatively easy to create using equipment generally available on a farm. Two case studies serve to illustrate how ditches can be used to reduce nutrient inputs. The first concerns the management of agricultural runoff into Lake Massaciuccoli, north of Pisa, Italy. From the 1960s onwards it was converted from a macrophyte-rich lake to a eutrophic system, primarily because of P and N enrichment from intensively farmed adjoining arable land. The management prescription was based largely on the management of a network of reed-filled field ditches. Ditch profiles were modified to improve hydraulic performance and support in-channel vegetation to assist nutrient and sediment retention. A 1m wide permanent grass buffer was established either side of the ditches and management regimes that recycled sediments and vegetation from the ditches and grass buffer strips back onto adjacent fields introduced. It combined changes in agricultural practices and ditch management on an almost unprecedented catchment scale and was found effective in reducing nutrient inputs to the lake (Penny Anderson Associates and Nick Hancock Associates, 1997).

The use of BZs and ditches to combat diffuse pollution from pesticides has been studied by an alliance of environmental scientists at Cemagref (Public Agricultural and Environmental Research Institute) in France. Field experiments took place at La Jaillière in western France. The effectiveness of grassed strips has been demonstrated experimentally, with trials of different strip widths. Six different pesticide products were reduced. A 6m strip reduced water movements by 43-87%, rising to 85-99% when the width was increased to 18m. Suspended solids were also trapped, up to 99% in some trials. Migration of the six products tested was reduced by 44-99% with a 6m strip. The work is to be extended to encompass woods and wetlands. It is recognised that ditches, as well as acting to convey water between field and river, are playing an important role in pollution reduction. What happens to these products in the ditches is inadequately understood, but first trials in 1998 yielded interesting and encouraging results (Cemagref, 2000).

Box 3.7. Summary: alternative buffer sites

- Streams effectively by-pass BZs, providing little opportunity for transformation processes to operate.
- Riparian BZs along feeder streams are desirable.
- 'Horseshoe wetlands' at outlets of subsurface drains may be useful additions to BZs.
- BZs can be effective anywhere within a fen catchment eg. footslope discharge and overland flow areas, ditch systems and wetlands.
- BZs can be effective anywhere within a fen catchment eg. footslope discharge and overland flow areas, ditch systems and wetlands.
- Banks an Lake Massaciuccoli and Cemagref projects provide examples of how ditches and vegetated strips can be used to reduce agricultural pollution.

3.2.9 Constructed wetlands

Constructed wetlands are engineered systems designed to use the processes that occur in natural wetlands, but do so within a more controlled environment. Some systems are designed to treat wastewater, while others have multiple-uses, such as using treated wastewater effluent as a water source for the creation and restoration of wetland habitat for wildlife use and environmental enhancement.

Constructed wetlands treatment systems generally fall into one of two general categories: Subsurface Flow Systems and Free Water Surface Systems. Subsurface Flow Systems are designed to create subsurface flow through a permeable support medium. Such systems have also been referred to as root-zone systems and vegetated submerged bed systems. The media used are typically soil, sand, gravel or crushed rock. These greatly affect the hydraulics of the system having an open structure, a high density of plant roots and better potential for microbial nutrient removal. Subsurface Flow Systems provide limited opportunity for benefits other than water quality improvement. They are more common in the UK where there is a shortage of land and they occupy smaller areas than surface systems.

Free Water Surface Systems, on the other hand, are designed to simulate natural wetlands, with the water flowing over the support medium at shallow depths. Because the water flows over the surface there is less opportunity for nutrient removal processes to work. They tend, therefore, to be quite large and they are often used for the tertiary treatment of wastewater. However, they provide more opportunity to create wetland habitats. Both types of wetlands treatment systems typically are constructed in basins or channels with a natural or constructed subsurface barrier to limit seepage.

The native common reed (*Phragmites australis*) is often used in constructed wetlands. It is fast growing and can be harvested and used in thatching and weaving. Willow (*Salix* spp.) species are grown too. They have a high capacity for nutrient uptake and coppiced poles can be used as biofuel.

If constructed wetlands are utilised as part of farmland management the harvested materials can provide income, as well as an amenity and habitat. As an integrated element of water treatment they can prove cost effective, environmentally friendly and are more pleasing to the eye than traditional waste treatment plants. They can be built to process both animal waste and to treat cropland runoff. It is preferable that constructed vegetated water treatment is close to the source and within the area of the farm and not introduced as part of, or as an adjunct, to the fen itself. To plant within existing fen to supplement its BZ may lead to serious difficulties. Reeds and willow are highly competitive species and, once established, there is a danger they will spread and out-compete other fen species.

Box 3.8. Summary: constructed wetlands

- These are engineered systems that use natural wetland processes to reduce waste and pollution.
- Subsurface flow systems have a better potential for microbial nutrient removal but have less potential for habitat creation.
- Surface flow systems require larger areas of land than subsurface constructed wetlands but provide more opportunity to create wetland habitats.
- Constructed wetlands are best employed near to the pollution source, on farmland.
- The introduction of competitive species like *Phragmites* and *Salix* to fen margins could lead to these out-competing fen species, and therefore, the creation of constructed wetlands close to basin fens should be undertaken with care and consideration.
- There may still be problems with P accumulation.

3.2.10 Problems associated with P accumulation

BZs appear to be typically effective at short-term trapping of sediment-bound P but have lower dissolved P retention (Lowrance*,* 1997). Vanek (1991) found that total P was reduced in riparian zones but soluble and extractable P was variable. With time there was reduced infiltration, the nutrient requirements of the BZ vegetation was satisfied and soil sorption sites became saturated. In these instances, there is a potential for re-erosion of sediments and retained P could be transformed into more mobile forms and lost. Pinay and others (1992) looked at riparian nutrient retention and concluded that soil type was highly significant. Silt and clay soils tended to act as sinks for C, N and P whereas sandy soils could be potential nutrient sources during high water periods. A number of studies have shown sediment-bound P trapped by buffers may slowly leach out of the BZ (Mander and others 1997). This condition is not widely reported but it suggests that the long-term performance of BZs has yet to be proved and there are instances when they can become a source for P (Daniel and Moore, 1997).

It is known that P accumulates in soils and sediments and it will remain immobilised unless converted to SRP. Given that P may potentially be liberated and represent a nutrient 'time-bomb' one way to reduce levels more permanently would be to physically remove soils and mud. P and N-rich soils are removed for the purpose of habitat creation, translocation and restoration although this tends to be in confined to discreet areas and specific projects. It has been used on a larger scale at Barton Broad, East Anglia. A huge suction dredging operation removed 300,000m^3 of P-rich mud (50 tonnes of P) representing 20 years' worth of P loading. Mud was taken to settlement lagoons created on 22 hectares of nearby fields to dry out. Water flowed back to the broad, less its P, which adhered to the solid particles of silt. Mud was used as fertiliser, water quality improved, eutrophication reduced and now 60% less phosphorus is released from the sediment (Broads Authority, 2001). As a policy to be employed for basin fens it has obvious disadvantages. The cost would be prohibitive, the activity damaging to the fen ecosystem and a receptor site for dredgings would be difficult to identify.

Box 3.9. Summary: problems associated with P accumulation

- BZs have proved effective in trapping sediment-bound P but are less effective in reducing soluble P.
- Soils and sediments can reach P saturation and can become a source of P.
- It is possible to physically remove P enriched soils and sediments but it is expensive and receptor sites are needed.
- The removal of soils and dredging is not a viable option for the majority of basin fens.

3.3 The 'Prevention Model'

3.3.1 Introduction

This section examines methods to reduce diffuse nutrient enrichment by changing farming practices and the adoption of Best Management Practices (BMPs). Different farming systems present different degrees of threat. Crops like potatoes and brassicas (especially oilseed rape) are considered high risk in terms of N because of the relatively high rates of fertiliser applications and a nitrate balance where a greater amount is applied, than removed in the crop (Johnson and others 2002). The nutrients applied to intensively managed grassland and some forage crops eg maize, can also cause nutrient enrichment.

Because the chemistry and flow paths for P and N are different, there has tended to be different approaches to P and N control. Sharpley and others (2000) and Heathwaite and others (2000) point out that sometimes separate policies for P and N have been at odds with each other eg recommended application for FYM to control N leaching may lead to increases in soil P and increase the potential for P runoff. They advise an integrated approach in nutrient management, one based on defensible, scientifically based information that recommends a technically sound framework for agricultural management systems.

Studies into the effectiveness of BMPs have identified a number of important factors that should inform policies:

- Nutrient enrichment only becomes a problem when there are sources eg soil, FYM and/or inorganic fertilisers *and* transport mechanisms eg leaching, runoff and erosion. It is only when both of these occur that a problem exists. If water and soil are immobile so too will P and N.
- It is very important to understand spatial and temporal variations associated with different hydrological conditions.
- Not all fields contribute P and N. Most P is exported from a small portion of a catchment, and usually as a response to a few heavy storms and runoff events.
- Although there has to be an awareness of overall catchment conditions, strategies need to be site-specific even to the point of looking at individual fields.

- Knowledge of the potential impact on aquatic biota is important eg whether basin fens are P or N limited.
- Farmers need practical management tools to implement BMPs and Nutrient Reduction Programmes (NRPs).
- Remedial measures may be slow to take effect. For example, Foy and others (1995) saw little fall in lake productivity following conservation measures perhaps because of internal recycling from lake sediments, which were sufficient to sustain algal growth.

3.3.2 Potential methods for the control of diffuse nutrient enrichment

3.3.2.1 Farming restructuring

Nutrient problems may be related to stocking levels, FYM disposal and intensive arable production. Farm practices have led to the build up of P and the leaching of N. Permanent grassland provides a ground cover all year round so that soil erosion losses are limited and if stocking levels and manure spreading practices are managed appropriately, the overall nutrient balance can be restored. Johnes and Burt (1993) considered that the attempts to reduce N using methods prescribed in Nitrate Vulnerable Zones (NVZs) would only lead to an N concentration reduction of 20%. They recommended that the best option was to convert oilseed rape to permanent grassland, fertilised at a rate lower than 150kg N ha^{-1} $year^{-1}$, and that temporary grassland should become permanent grassland (English Nature and Environment Agency, 2003).

The complete conversion of arable to grassland is not a practical measure where the farm business concerned is an all arable farm, as grass will have no place in its system, and the cost and management implications of introducing livestock will be prohibitive. This will be even more difficult in an area dominated by arable cropping where the basic infrastructure needed to support livestock farming eg markets and veterinary practices, may be lacking. There are also counter-pressures on dairy farms, in which it is now accepted that feed from grass is more expensive than feed from arable/forage crops. However, this is a more acceptable measure in that it requires a marginal change rather than a system change.

3.3.2.2 Organic farming

This agricultural system adopts management strategies designed to maintain soil health and fertility without the application of agrochemicals, pesticides and artificial fertilisers that ensure stocking levels are generally low. There are also stringent animal welfare standards. There should, therefore, be a reduction in inputs known to cause diffuse nutrient enrichment. In addition, organic farms tend to have more hedges, a mixed range of crops, broader field margins and herb and clover rich grassland – all of which can be viewed as BZs (Soil Association, 2004).

Yet studies suggest that the mitigation effect is not always as good as it seems. Organic arable farming exploits organic N in manures so that nitrogen is 'fixed' by legumes – clovers, peas and beans etc. There is also a doubt as to the future of organic farming. There are fewer farmers wishing to convert because of a crisis in confidence about long-term security of the premium price that can be secured and a significant number intend to revert to conventional systems. Organic farming is not immune from economic pressures and it is likely that, in order to maintain profitability, organic farming will have to develop into large-scale farming; this means that some of the environmental benefits may be reduced. So too, some of the permitted pest controls used in organic farming eg the use of copper and sulphur, can also be damaging although they do not cause nutrient enrichment.

3.3.2.3 Control over crop type

Crops with higher demands for fertilisers and pesticides could be avoided. Crops like potatoes and oilseed rape are considered high risk in terms of N because of the relatively high rates of fertiliser applications and a nitrate balance where a greater amount is applied, than removed in the crop. Others eg strawberries, spinach and celery are associated with high pesticide residues and releases (Johnson and others 2002).

3.3.2.4 De-intensification

The general policy of de-intensification is seen as a means of encouraging environmentally-friendly farming practices. It involves a reduction in inputs per unit area of farmland. The 'Extensification Scheme' was initially introduced by the EC to help reduce farm surpluses created by other subsidy mechanisms like the Beef Special Premium Scheme, the Suckler Cow Premium Scheme and the Sheep Annual Premium Scheme. The extensification scheme is available to beef farmers who meet specific stocking levels. The Mid-Term review of CAP (announced in June 2003) will replace these schemes with a Single Farm Payment, based in England, on a flat rate payment/ha. The switch will be phased in over eight years, after 2005. It is anticipated that the effect of this change will be to remove the pressure on farmers to maintain high stocking levels to maximise their subsidy payments (Defra, 2003a).

3.3.2.5 Maintaining over winter ground cover and strip farming

Conventional tillage systems tend to leave soils bare and vulnerable to wind and water erosion. Maintaining vegetation cover helps prevent this loss. Strip farming is a practice used widely in the Midwest of America but similar practices can be usefully introduced in the UK where soils are very freely drained and dry quickly. It involves planting narrow strips at right angles to prevailing wind, or following the natural contours to prevent water erosion. There are also 'no-till' methods that leave soil undisturbed from harvest to planting.

3.3.2.6 Livestock management

In poultry farming P is a major mineral required for hens to maintain egg production and shell quality of the egg, as well as to promote skeletal formation and maintenance. P is usually overfed leading to increased P excretion. The same is true in pig rearing and milking cows where P is an important component of the diet but it is often given above requirement. Research shows a strong link between P intake and P excretion. In the event of manure spreading becoming regulated more strictly, there will additional pressure to limit the timing and the number of applications farmers can make onto fields, and the amount that can be applied. Reduction of the P content of manure is both cost-effective for the farmer and does less damage to the environment. This has been the focus of much government-funded research and forms a key part of Defra's livestock sector research programme (Defra, 2003a).

A synthetic form of P - phytase is available and can be added to the diet, which will greatly increase phytic acid use and decrease P in manure. This is true for poultry and pigs. There are a number of recognised benefits in egg production: dietary P is reduced; there are savings in feedstuffs; improvements in eggshell quality and significant reductions in P levels in manure. Research into the addition of phytase in pig production also saw many benefits eg growth was not impaired nor was there an increase in diet costs. There were also important reductions in P levels where liquid and solid levels were reduced significantly with phytase addition: P in liquids (–23.16%); P in solids (–17.60%); P_2O_5 in liquids (–22.11%); P_2O_5 in solids (–17.79%). A 22% fall in liquid manure P_2O_5 levels meant that a manure management plan based on P required 100 acres instead of 78 acres (Poulsen, 2000; McMullen and Hoyer, 2001).

Research initiated at the Agricultural Research Institute for Northern Ireland investigated the impact of diet nutrient content on animal performance and the effect of dietary change on nutrient excretion levels. It has shown that N and P excretion from pig units can be substantially reduced without reducing growth performance through changes in feedstuffs with up to 25% reductions in P (Henry and Beattie, 2003).

3.3.2.7 Manure management

It has already been noted that manures can lead to P build up in soils and N losses. Care needs to be taken to establish a rate of application that avoids the critical point at which needs are satisfied and additional applications become superfluous. Most agencies, including Defra, would prefer to adopt single values for all areas but although this might be easy to mandate, it fails to consider local conditions and prove too crude an approach. Risks are especially high following slurry applications to clay soils with surface and/or under-drainage. The best control method for N and P from FYM is to cultivate the land just after slurry applications. Autumn and winter applications result in higher levels of diffuse pollution. N loss is greatest in free draining soils in September and November. P losses are greatest in November and December when soils are at field capacity (Williams and others (2002), cited in Defra, 2002).

If total loading of fertiliser to fields is to be reduced, there will have to either be a change in the type of farming or FYM needs to be exported to other farms, something widely practiced in the Netherlands. It may be possible to move FYM around a farm from fields of excess to those of deficit. The transport of manure may bring with it problems of biosecurity and potentially be a public nuisance eg smell, soiling of roads.

Some of the issues relate to farming practice rather than knowledge. For example, maize is popular because many tonnes of manure can be applied prior to planting. Also, many farmers still do not make sufficient allowance for nutrients in manure when calculating what needs to be added in the form of artificial fertiliser.

Manure treatment before application can serve many useful purposes. Composting can inactivate pathogens provided temperatures are sufficiently high. High temperature during composting can also increase ammonia emissions. Composting tends not to remove P, while N and K can be lost. Moore and others (2000), cited in Sharpley and others (2000) note that the use of slaked lime or alum can reduce NH_3 volatilisation from manure and still achieve better animal health and weight gain; reduce solubility of P in poultry litter and decrease dissolved P, metals and hormone concentration in runoff. Experiments reported by Ingles (1994) showed that nitrate loss in the leachate was relatively low. Much of the nitrogen was likely to be lost to volatilisation. Conversely, potassium escapes mainly, if not exclusively, in a water-soluble form.

Livestock manures can be used to supply raw material to be pelletised, whereby poultry, swine, and cow waste are converted into granulated organic fertilisers. Pelletising manures also enables easier transport to other areas, for use as a fertiliser for agronomic, vegetable, horticultural crops and it can be used as a cattle feed supplement.

Another alternative is bioenergy production using FYM as a renewable fuel source. Animal wastes can be used to produce methane-rich biogas through the process of anaerobic digestion. It is possible to convert pig waste into methane and biodiesel vehicle fuel. There is, for example, a large Biogas development underway in North Devon, collecting manures from surrounding dairy farms, digesting it to produce methane, then returning the digested cake to the farmer for spreading (North Devon and Torridge District Councils, 1999). A problem could arise in the medium term future due to regulation. At present, FYM is outside the framework of controlled waste. This means that it can be transported without an audit trail or cost (other than transport costs). If it comes under the waste management regulatory framework, then there may be a need for licensing and audit trail, and this will mean the system becomes no longer economically viable.

FYM is produced all year, although when animals are grazed, the manure falls directly onto the soil. However, application of stored FYM should be avoided at certain times. This necessarily requires storage facilities to hold animal wastes, produced while stock are housed, until they can be disposed of.

Capital costs can be high for installation and there remains a biohazard should there be an accident, eg structural failure. The structural integrity for some installations is in doubt following low levels of profitability in livestock farming, since the mid-1990s. This has led to an under-investment in maintenance over the last 10 years. In addition, capacity will be an issue for many farms, especially those that have expanded to exploit economies of scale.

Ammonia losses from applying FYM and fertilisers can be most easily controlled with existing technology by immediate soil incorporation. The largest losses of N occur from surface applied unincorporated N sources whereas minimal losses occur if the N source is immediately incorporated into the soil. For example, studies have shown that ammonia losses from dairy slurries can be reduced from 45% to less than 5% by immediate incorporation through discing or moldboard ploughing. Likewise, ammonia losses from fertilisers can be reduced from 9-2% by soil injection. Where incorporation is difficult eg growing crops, forage crops the use of surface-band applications can reduce losses. However, incorporation may increase the survival rate of pathogens by reducing exposure to UV radiation, which encourages the decline of pathogens.

3.3.2.8 Soil management

Appropriate cultivation methods must be used to ensure good soil structure The term ‘structure’ refers to the arrangement of individual particles into larger aggregates or ‘peds’. Structure controls the process of water movement and root growth and is, consequently, of major importance. To maintain good soil structure is to farm using best farming practices, maintaining sufficient organic material, providing appropriate crop nutrients and ensuring soils have suitable water retention properties. In short, the system should be sustainable.

If soil is left totally undisturbed for several years or there is minimal cultivation, progressive changes take place whereby the crumb structure or natural tilth of the surface layers improves. This is because of the increase in soil organic matter and earthworm and other soil faunal activity improves porosity and structural stability.

Strip contour cultivation and contour tillage reduces runoff and helps reduce the risk of flooding.

Chemical stabilisers (soil binders or soil palliatives) provide temporary soil stabilization. Materials made of vinyl; asphalt and rubber are sprayed onto the surface of exposed soils to protect against erosion from runoff and wind. It may, though, encourage surface flow. Another temporary erosion control practice is mulching in which materials such as hay, wood chips, wood fibres, straw or gravel are placed on exposed soil. It is most effective when used in conjunction with vegetation establishment. In addition to stabilizing soils, mulching can reduce storm water runoff velocity.

Field drains can transport sediment-bound and dissolved pollution. To impede this movement may reduce diffuse pollution but it is not very practical and may present farmers with drainage and water logging problems. Ideally, underground field drains should stop short of basin fens to allow water to percolate through the ground and fen margins, which will provide a BZ (SEPA, 2000).

Drains and drainage ditches can be filled with calcium rich material, like limestone, to extract diffuse P. The material would need periodic replacement and this practice may prove costly and impractical.

The addition of calcite soil dressings to soils has been tested in an attempt to reduce Soluble Reactive Phosphate (SRP) concentrations in runoff from agricultural land. It has been shown that the addition of calcite can increase SRP adsorption by a soil (Freeman and Rowell, 1981; House and Donaldson, 1990; Standring, 1993).

3.3.2.9 Crop inputs management

It is important to establish the correct amount of organic and inorganic supplements required for healthy crop growth. There are several computer models available to farmers to do this eg MANNER for N and PLANET for P. The assessment of correct application rates for P is more difficult. There needs to be a simple and reliable measure of soil P that identifies P excess and not just the P shortfall for crops (Edwards and others 1997). In the past there has been 'insurance' fertilising because of this uncertainty. There is not a clear link between the P test calibration for crop response and P enrichment. There is a need to establish the critical point at which P leaching increases significantly (in 1998 the then MAFF estimated that 20mg kg^{-1} was a critical value).

There is no simple relationship between N application and leaching losses, as there are too many factors that serve to complicate the situation. N requirements for a given crop vary considerably, both spatially and seasonally. Nevertheless, there are some established responses to applications. Nitrate losses increase significantly when large amounts of N fertiliser are added. Cultivation tends to break up soil aggregates and increase microbial metabolism producing more N in the soil. Cultivation in autumn is known to release more nitrate, sometimes in excess of crop needs. The timing of application is important too.

Application of N in early spring is safer than an equivalent application in autumn because N is exposed for leaching for a shorter time (Burt and Hancock, 1993). Applications should be made when weather conditions are appropriate. Very wet ground and periods of heavy rainfall should be avoided.

3.3.2.10 Precision farming

This makes use of Global Positioning Systems (GPS) to link with a high level of accuracy farming operations and farm yields. This enables detailed yield maps to be produced, which can then be used to provide a closer link between crop demands and input supply to be established so that applications can be tailored accordingly, thus reducing surplus inputs of nutrients and chemicals.

3.3.2.11 Farm machinery management

As pesticides become more potent they require more care when handling and spraying. For example, spray nozzles should be chosen with care to avoid losses (Pesticides Safety Directorate, 2004). Farm machinery should aim to minimise the effects of trafficking causing ground compaction and runoff along tractor tracks.

Drivers and users of farm equipment must be able to exercise control and be environmentally aware.

3.3.2.12 Farmland management

Many farm management strategies to reduce the release of nutrients and other pollutants have already been discussed. They are not uniquely farm-based approaches and could be implemented anywhere within the fen catchment. They include:

- Buffer zones:
    - Buffer zones (creation and maintenance of existing).
    - Managed woodlands.
    - Scrubland development.
    - Mixed woodland and grassland.
    - Vegetative barrier strips eg grass.
    - Hedgerow creation and maintenance.
    - Riparian buffer zones along fen feeder streams.

- Hydrological management:
    - Wetland creation and maintenance.
    - Constructed reedbeds.
    - Vegetated ditch systems.
    - ‘Horseshoe’ wetlands.
    - Dispersal and baffling to disperse stream flow.
    - Reduction in watercourse management.
    - Footslope discharge areas.
    - Soil removal and dredging operations.
    - Blocking of drains and drainage impedance.
    - Ditch creation and maintenance.
    - Key trenching

- Grassed waterways.
- Overland flow zones.
- Establish ‘No Nutrient Zones’ near to watercourses.

- Landscape management:
  - Swales and berms.
  - Construction of sediment ponds.
  - Fencing to reduce livestock damage to plants and Poaching.
  - Provide bridges for stream crossings.
  - Create walkways for livestock.

4. Updating the fenbase database and evaluation of the basin fen resource in England

4.1 Introduction

FenBASE was developed by the Wetlands Research Group, University of Sheffield, to provide a comprehensive database of information pertaining to the fens within England. A similar database, BogBASE, has been developed for the bog habitats.

An aim of this part of the project was to update FenBASE with the additional information pertaining to basin fens held on ENSIS, English Nature's own protected sites database. ENSIS holds general information about the site, eg area, location, statutory designation, along with a summary of the assessment indicating if the site is in favourable or unfavourable condition in terms of the Joint Nature Conservation Committee (2004) Common Standards Monitoring.

Once collated, the updated FenBASE was interrogated to provide an evaluation of the basin fen resource in England. In addition, the FenBASE data were used to evaluate the potential issue of nutrient enrichment of basin fens at the regional level and to provide an overview of mitigation options applicable to those sites potentially at risk of nutrient enrichment, and to provide an indication of additional data that would be appropriate to further aid assessment and evaluation.

4.2 Methodological approach

4.2.1 Updating FenBASE

The first stage in the updating of the FenBASE database was to extract the relevant information from the ENSIS database. The ENSIS database categorises sites by their 'Level 1 Features' that describe the type of habitat on the site. The following Level 1 Features (plus variants were appropriate, eg 'Mire: valley mire with *Sphagnum* carpets') were used to extract an initial selection of sites from ENSIS:

- mire: valley bog;
- mire: basin mire;
- fen;
- fen: valley mire;
- fen: basin mire;
- fen: floodplain.

These sites were then reviewed and those listed on ENSIS as basin fen were selected. These sites are presented in Table 4.1. The ENSIS basin fen sites were then combined with the sites within FenBASE. The original version of FenBASE included a total of 92 sites that had been classified as basin fen. However, some of these sites were excluded from consideration in this project as they supported either primarily raised bog vegetation or primarily open water habitat. The specific reason for the exclusion of a particular site is noted within Table 4.2.

The 61 sites remaining from the combined ENSIS/FenBASE list were therefore identified as basin fens and included on the final list for analysis within this project. These are presented in Table 4.3. This list of sites was then returned to English Nature and used to extract further information from ENSIS on these 61 basin fen sites. Only 34 of the sites on the final list were registered on ENSIS as basin mire. Some of the sites did not have any type of wetland listed as their Main Habitat type or Level 1 Feature type (eg Blelham Tarn and Bog, Pilmoor and Thompson Common).

Work was undertaken to check and add the information provided from ENSIS to the FenBASE database as necessary, giving particular attention to site status and conservation issues. Some additional hydrological and geological information was also added to FenBASE from reports already held by the Wetland Research Group, and others sent on request by English Nature staff.

Specific details for all sites have not been verified with English Nature staff, but some individuals have been consulted by telephone for those sites for which there were obvious gaps or uncertainties.

Some of the larger SSSIs contain one or more basin wetland – where sufficient information was available, these have been entered on the FenBASE database as separate sites. Sites in East Anglia that contain numerous depressions (eg East Walton Common, Thompson Common) have not been subdivided. Details of composite sites are provided in Table 4.4.

The English Nature West Midlands team kindly provided a copy of the catchment map for each site (as an image file) from the GIS database prepared by ECUS in 2001. Catchment maps have been scanned for a further 12 sites in Sheffield. These images will be attached to the updated version of FenBASE to be provided to English Nature as part of this project.

4.2.2 Evaluation of the basin fen resource

Once the relevant information from ENSIS and other sources was combined into an updated FenBASE, the database was interrogated to enable the basin fen resource in England to be characterised.

The characteristics evaluated included geographical distribution, hydrotopography, ecohydrology, size, vegetation and site condition status. In addition, those data relating specifically to nutrient enrichment of basin fens were evaluated at a regional and site level, those sites potentially requiring boundary amendments to enable mitigation for the effects of enrichment were identified, and recommendations made for any further information that would aid this process. During this process the maps and citation schedules for each site were viewed on the English Nature web page, and catchment maps collated as part of the FenBASE update were also consulted to help place the site in its local and regional context. The results of the evaluation are presented below.

4.3 Results of the evaluation of basin fens in England

4.3.1 Geographical distribution

Sites can be divided into four main regions: East Anglia (10 sites), North West (20 sites), West Midlands (21 sites) and the North East (9 sites). There is only one site in the south of England: Emer Bog, part of Baddesley Common (Hampshire). Their distribution is presented in Figure 4.1.

4.3.2 Hydrotopography and ecohydrology

Hydrological and geomorphological site details have been entered onto FenBASE for the sites for which information was available. A summary and general discussion on the hydro-topography and ecohydrology of basin fens can be found in Appendix I of this report.

The size and shape of basin fens are discussed in Appendix I, and Table 4.5 ranks 43 of the basin fen sites according to the area of wetland (estimated in some cases), which ranged from approximately 1-80ha. Since data on the approximate area of wetland were not available for many sites, of the sites have been grouped by wetland size category as presented in Table 4.6. The majority of sites fall into size classes 1 or 2 indicating they are <20ha. Ten sites occur in 20-40ha size, and only five 740ha

Precipitation / evapotranspiration data have been obtained for some sites from the Environment Agency. Annual precipitation ranged from 561–1548mm whilst the range of annual potential evapotranspiration was 175–619 mm (Table 4.7).

4.3.3 Vegetation

The basin fens included in this study support a wide range of vegetation types, as illustrated in Table 4.8, with *Carex rostrata–Potentilla palustris* fen (S27) (Rodwell 1995) being the most commonly recorded community, present on 19 sites. Table 4.9 lists some of the uncommon wetland species supported by the basin fen sites. [Note that these data are likely to be incomplete as full vegetation/species lists are not available for each site.]

4.3.4 Site condition

Information regarding the condition of the basin fens has been collated from ENSIS (see Appendix II for full details and Table 4.10 for a summary). It should be noted that condition status is assigned to individual survey units within a site. A unit may include more than one basin fen, or may be one of several subdivisions of a larger wetland complex. Thus, there is a mismatch between the number of units and the number of sites.

Less than 50% of the resource is considered to be in favourable condition (*sensu* Joint Nature Conservation Committee 2004 based on English Nature site survey data within ENSIS), with the majority assessed as unfavourable. The reasons given for a site unit being in unfavourable condition are listed in Table 4.11, with the most common problem being management-related. At least 13 site units were assessed as being in 'unfavourable declining' condition, but at least 17 site units were considered to be 'unfavourable recovering'. Two sites were assessed as 'part destroyed': Bingley South Bog (West Yorkshire), due to the building of a by-pass flyover across the site, and Low Church Moss (Cumbria), by direct destruction (tipped over).

4.3.5 A regional assessment of the nutrient enrichment of basin fens

4.3.5.1 Identification of the main issues at the regional level

Out of a total of 61 basin fen sites, 37 sites (approximately 61%) have been identified as having some indication of diffuse nutrient enrichment issues. Within the four main regions, the sites are distributed as follows:

- *North West England* – 11 sites, all within Cumbria.
- *North East England* – eight sites within Northumberland and West Yorkshire.
- *West Midlands* – 14 sites in Cheshire, Staffordshire and Shropshire.
- *East Anglia* – three sites (Cornard Mere, Suffolk; Great Cressingham Fen and Middle Harling Fen both in Norfolk).
- *Southern England* – one site (Emer Bog, part of Baddesley Common, Hampshire).

The majority of the basin fens identified as having diffuse nutrient enrichment are considered to receive their nutrient inputs from agricultural run-off. Only three sites are an exception to this, Emer Bog (Hampshire) where the nutrient source is unknown, Abbots Moss (Cheshire) where the nutrient inputs appear to arise from a nearby nursery, and Bingley South Bog (West Yorkshire) where again the source of the nutrients is not known.

Many of these sites have associated land drainage issues noted alongside the nutrient enrichment and this is likely to be a major factor in the pathway of nutrient inputs to the fen sites. Land drainage is associated with 32 of the 61 basin fens assessed within this project (51% of sites), with 19 out of these 32 sites (60%) identified as also suffering from diffuse pollution.

However, there are also several other nutrient input sources identified in additional to diffuse nutrient inputs. Eight basin fens are identified as having some sewerage inputs to the sites, with the majority of these (six sites) within the West Midlands region. These sites are listed below, according to region:

- *North West England* – two sites (Blelham Tarn and Unity Bog both within Cumbria).
- *North East England* – no sites identified.
- *West Midlands* – six sites (Bagmere and Flaxmere Mosses, Cheshire; Brownheath Moss, Clarepool Moss, and Shomere Pool, Shropshire; Cranberry Bog, Staffordshire).
- *East Anglia* – no sites identified.
- *Southern England* – no sites identified.

All of these sites, with the exception of Shomere Pool (Shropshire), also suffer from diffuse nutrient enrichment as well as probable sewerage inputs. Such sites might, therefore, be considered a priority for nutrient enrichment remediation measures.

There are a further two sites identified where sewerage pollution was previously a problem but where the issue is now considered to have been adequately addressed. These are Forest Camp (part of Abbots Moss) and Wybunbury Moss, both within Cheshire and part of the West Midlands region.

A large number of basin fens (26 out of 61 sites, ie 43%) are noted to have 'other nutrient/pollutant issues' which include bird roosts/colonies, and unknown sources of enrichment. Not all of these relate to increased nutrient inputs, with some sites are identified as having other pollution issues such as road run-off or fly tipping.

In addition to nutrient and pollution inputs, water abstraction is noted as a potential issue for some sites although in many cases there is evidence to directly link known abstraction consents in the area and water drawdown on the basin fen site. A total of 16 out of 61 basin fens (26%) have abstraction noted as an issue in FenBASE. Of these 16 basin fens, five sites have both abstraction and diffuse nutrient enrichment issues, two sites have abstraction and drainage issues only, and six sites have all three issues: Cornard Mere, Great Cressingham Fen, Brown Moss, Chartley Moss, Wybunbury Moss and Skipwith Common. The remaining three sites have abstraction issue alone. Those sites with all three issues might be considered a priority for remediation measures.

At the regional level, the number of sites with abstraction issues is apportioned as follows:

- *North West England* – one site (Cliburn Moss, Cumbria)
- *North East England* – two sites (Campfield Kettle Hole, Northumberland; Skipwith Common, North Yorkshire)
- *West Midlands* – six sites.
- *East Anglia* – seven sites.
- *Southern England* – no sites identified.

4.3.5.2 Identification of possible options for remediation for sites with diffuse nutrient enrichment

An assessment was undertaken of the information held on FenBASE, the catchment maps, citations and site condition maps for each site with diffuse nutrient enrichment issues. Following this assessment a very broad indication is given on the suitability of each site for the application of the three remediation options, ie the protection model approach, the prevention model approach or the mixed model approach.

In addition, each site was evaluated for its suitability regards implementing a boundary change to enable the inclusion of adjacent land within the SSSI, with the assumption that this inclusion would enable more effective management and maintenance of remediation measures. Factors that pose possible constraints on boundary amendments comprised adjacent roads, rivers, railway lines, housing or other developments marked on the Ordnance Survey maps. However, even in circumstances where the adjacent land available outside the fen site is limited, literature suggests that a narrow (ie 5m) can achieve significant reductions in P and N. In addition, on large SSSIs where the basin fen appeared to form only a small area within the site, it was assumed that boundary changes would not be appropriate for the basin fen alone. No account was made for possible financial limitations/implications for changes to farm practices or land use in this exercise, and such issues would need to be resolved on a site-by-site basis. In addition, many sites have public rights of way marked close to the basin fen, and again any remediation measures would need to continue to allow public access.

In general, those sites that appeared to have the potential for boundary changes were assumed to also have potential for the application of the protection model for remediation (ie implementation of mitigation measures on or adjacent to the fen that could be included in an extended SSSI boundary). It is considered that English Nature Local Team Officers might be able to implement such measures over the short to medium term, assuming appropriate funding was available and negotiation with landowners was successful. This would then begin to address enrichment issues on those basin fens most at risk.

With regard to applying the prevention model, it was assumed that there was potential to reduce nutrient loadings to some degree within the wider catchment at all sites, which would therefore reduce nutrient loading to the surface and groundwater catchments of the fen. However, the development and application of measures within the prevention model are likely to be much longer term, due to the complexity of many landowners involved in sites with large catchments, uncertainty about the extent of many groundwater catchments, the possibility of large scale changes in farming systems and the need to consult more widely to successfully implement such changes. However, it is considered that these wider measures will provide a long term, strategic solution to nutrient enrichment of basin fens.

At the regional scale, the following numbers of basin fen sites are identified for the application of the protection model for remediation of nutrient enrichment (and summarised in Table 4.12):

- *North West England* – 10 sites, all within Cumbria.
- *North East England* – seven sites (Barlees Pond, Caw Lough and Campfield Kettle Hole, Northumberland; Hart Bog, Cleveland; Hardacre Moss, part of Newby Moors and Skipwith Common, North Yorkshire; Pike Whin Bog, County Durham).
- *West Midlands* – 12 sites in Cheshire, Staffordshire and Shropshire.
- *East Anglia* – three sites (Cornard Moss, Suffolk; Great Cressingham Fen, Norfolk; Middle Harling Fen, Norfolk).
- *Southern England* – one site (Emer Bog, part of Baddesley Common, Hampshire).

These 33 sites (out of the potential 37 basin fens identified as having diffuse nutrient enrichment issues within this project) would all benefit from application of options within the protection model to remediate nutrient enrichment. The majority of these (30 sites) would also be likely to benefit from boundary amendments to help implement such mitigation measures. The other three sites appear large enough for the mitigation options to be kept largely within the confines of the existing SSSI.

The remaining four sites have been excluded from the protection model, as there appear to be restrictions around the sites from roads, buildings or afforestation. These physical barriers are also likely to restrict any potential for extending the SSSI boundaries.

As indicated above, all 37 basin fens identified as having diffuse nutrient issues are expected to benefit from the application of the more strategic prevention model remediation measures. At a regional level this would be apportioned as follows:

- *North West England* – 11 sites, all within Cumbria.
- *North East England* – eight sites within Northumberland and West Yorkshire.
- *West Midlands* – 14 sites in Cheshire, Staffordshire and Shropshire.
- *East Anglia* – three sites (Cornard Mere, Suffolk; Great Cressingham Fen and Middle Harling Fen both in Norfolk).
- *Southern England* – one site (Emer Bog, part of Baddesley Common, Hampshire).

The protection and prevention measures can be applied together in a mixed model approach, although the detail of this will be dependant on the individual site.

4.4 A summary of the issues affecting the basin fen resource in England

4.4.1 Main issues

Information regarding the main issues affecting the basin fen resource has been collated in Appendix II, and is summarised in Table 4.13. Note that the details have been compiled from site-based information, and not just ENSIS, so that information on issues that are thought, but not proven, to be a problem are also included. These tables show clearly that the main issue identified was vegetation management, including undergrazing and overgrazing as well as scrub control.

There are only eight sites on which the current active management regime is considered appropriate (mainly adequate grazing levels). A further eight sites are identified as unmanaged. These are Campfield Kettle Hole, Brown Moss, Hardacre Moss (part of Newby Moor), Barlees Pond, Brown Stone Moss (part of Claife Tarn and Mires), Hollas Moss (part of Silver Tarn), Unity Bog and Tarn Moss. A policy of deliberate non-intervention is followed at five sites: Brownheath Moss, Hencott Pool, Shrawardine Pool, Sweat Mere, Caw Lough (part of Roman Wall Loughs).

Enrichment is thought to be a problem on many sites, although direct evidence is scarce. The main cause of enrichment is thought to be diffuse pollution from agricultural sources. Other sources of nutrients or pollution include road run-off, silage run-off, siltation and fly tipping. Several sites have been in the past, or are currently thought to be, affected by sewage discharges (from septic tanks). Tree litter inputs are considered to be a significant source of nutrients in only a few sites.

Water regime is considered to be an issue on several sites, although in many cases a link remains to be established between a possible cause (eg abstraction) and possible effect (site considered to be too dry). This is particularly the case for abstraction, and some sites are currently being monitored/studied for this purpose.

It is evident from these data that there are very few sites for which there is clear chemical or phytometric evidence of an actual nutrient enrichment problem. However, the presence on or around a site of certain species such as algae, patches of common nettle (*Urtica dioica*) and bulrush (*Typha latifolia*), and/or observations of vegetation change (for example, increase in abundance of rushes), mean that enrichment is suspected on many more.

4.4.2 Other issues

Issues other than water regime, enrichment/pollution and vegetation management identified through this evaluation include tipping, forestry within the catchment, disturbance from public recreation (trampling) and moss gathering, siltation, peat cutting, damage by Canada geese, puddling of the margins by livestock, pool dredging and a road fly-over.

4.4.3 A regional perspective on basin fen issues

4.4.3.1 A regional assessment of nutrient, drainage and abstraction issues relating to basin fens

North West England and the West Midlands hold the greater number of basin fen sites out of the five regions identified, and account for 67% of the resource in England. Basin fens are predominantly absent from the South West and South East, with only one example within Hampshire.

These same two regions also hold the largest number of basin fens affected by diffuse nutrient enrichment, with the West Midlands also having the majority of those sites affected by sewerage pollution. Those sites affected by both diffuse nutrient enrichment and sewerage inputs are, in the North West: Blelham Tarn and Unity Bog (both within Cumbria), and in the West Midlands: Bagmere and Flaxmere Mosses (Cheshire); Brownheath Moss and Clarepool Moss (Shropshire); Cranberry Bog (Staffordshire). These sites should be identified as primary sites for the application of remediation measures for nutrient enrichment.

Land drainage is associated with 32 of the 61 basin fens assessed within this project (51% of sites), with 19 out of these 32 sites (60%) identified as also suffering from diffuse pollution. Drainage into a fen from the surrounding land might therefore be an important route for nutrients to enter a fen. However, there are little data on the specifics of land drainage on which to base an assessment.

The West Midlands is also a primary region for basin fens with issues relating to water abstraction, along with many basin fen sites within East Anglia. Six sites were found to have potential diffuse nutrient pollution, land drainage and abstraction issues: Cornard Mere (Suffolk), Great Cressingham Fen (Norfolk), Brown Moss (Shropshire), Chartley Moss (Staffordshire), Wybunbury Moss (Cheshire) and Skipwith Common (North Yorkshire). These sites should also be considered a priority sites for the application of remediation measures, as they appear to be at high risk of degradation through a combination of nutrient inputs and hydrological changes.

4.4.3.2 A regional perspective on applying remediation options to reduce nutrient enrichment of basin fens

In terms of applying the mitigation measures for diffuse nutrient enrichment, all of the 37 basin fens with diffuse nutrient enrichment issues have potential for long term strategic remediation measures as detailed in the prevention model. It is considered that this approach will be the more successful in the long term, and lead to a sustainable reduction in diffuse nutrient inputs to these sites.

However, many sites would undoubtedly benefit from more immediate measures to alleviate the effect of nutrient inputs. These are the remediation options included in the protection model, considered to be short to medium term measures that could be applied at the site level and could also include an alteration in the SSSI boundary.

Again, the West Midlands is identified as a priority region for the application of the protection model approach, with the majority of sites being considered suitable for remediation measures and also therefore for changes to the SSSI boundary. Only two sites, Abbots Moss and Flaxmere Moss (both in Cheshire), are considered to be less suitable for both boundary changes and application of the protection model as these sites appear somewhat constrained by adjacent roads, buildings and afforestation.

North West England also has a large number of sites suitable for remediation measures and also therefore for changes to the SSSI boundary. Only one site, Tarn Moss (Cumbria) appears to have some restrictions on implementing the remediation measures and changes to SSSI boundaries due to adjacent afforestation and roads.

North East England has seven sites suitable for implementation of protection model remediation options, however not all sites are likely to require boundary amendments as three of these sites have basin fens within a larger wetland complex and mitigation options could be undertaken within the existing SSSI boundary. One further site, Bingley South Bog (West Yorkshire) appears to have little potential for either boundary amendments or extensive mitigation measures due to adjacent development.

All the basin fens with nutrient enrichment issues within East Anglia and Southern England have scope for the implementation of the protection model remediation options and for associated boundary amendments.

5. Case studies illustrating mitigation approaches for basin fens

5.1 Introduction

In order to review how remediation measures might be applied to protect basin fens, three sites have been selected as case studies for closer examination. The aim is to consider which methods might be applied in specific circumstances and what the management and financial effects there might be for the farming businesses involved. The case studies represent basin fens known to be adversely affected by nutrient enrichment associated with farming practices in the catchment area. They are: Wybunbury Moss NNR, Cheshire; Great Cressingham Fen SSSI, Norfolk; and Silver Tarn SSSI in Cumbria.

Each site is described, mapped and the surface and groundwater catchment area identified. The hydrological pathways operating in the catchment are also characterised. The land use within the catchment is determined using a number of means including aerial photography analysis, Phase 1 Habitat Survey data, English Nature SSSI citation information, FenBASE data commissioned reports and other sources. Having established the land use, a programme for remediation is devised.

There are three types of management prescription for remediation:

- 'Preventative Model' - which is a catchment-wide strategic approach aimed primarily at changing farming practices. It aims to stop the problem at its source.
- 'Protection Model' - aims to install protection measures at the margins of the SSSI, to bolster perimeter defences eg by the creation of buffer zones.
- 'Mixed Approach' - may combine elements of the other two.

The financial implications for each of the three types are appraised through a cost-benefit analysis exercise.

The wide range of measures available to help in the reduction of nutrient enrichment has already been described. Some suggestions involve the introduction of protection strategies that may be put in place near to the fen ('Protection Model') whilst others are concerned with measures specifically related to reductions arising from changes in agricultural practices ('Prevention Model'). Table 5.1 is based on a number of key publications and provides additional information concerning the latter.

The 'Prevention Model' is the most radical but ultimately the most effective long-term strategy. It is unlikely that wholesale changes can be introduced quickly and it would be more pragmatic to consider a series of measures applied progressively. The types of changes possible are going to be influenced by the environmental conditions eg soils, topography and climate. Another important factor will be the degree of cooperation within the farming community and the willingness of farmers to change traditional practices.

However, there is a general trend toward diversification in the agricultural sector and it is now, arguably, less conservative than before and open to new farming methods. One such change has been the switch to organic production. The minimum conversion period is two years and grants, under the Organic Farming Scheme (OFS[1]), have been available to help farmers over the transition period. Another relatively new option is the production of energy crops. For example, the tall perennial grass *Miscanthus* has been evaluated in Europe during the past ten years as a new bioenergy crop. Fertiliser requirements are much lower than for arable crops. *Miscanthus* is harvested annually and a single application of 40kg/ha each of N, P and K is recommended. Short rotation coppice is fertilised after each harvest ie every three years. The government is keen to promote the growing of energy crops on agricultural land and is offering grants to farmers who decide to make the change. A switch from arable to *Miscanthus*, or short rotation coppice, will attract a one-off establishment grant of £920 or £1000/ha respectively. The EC will also pay 45 euros (about £32)/ha/year for land released from agriculture for this purpose. However, to be worthwhile, it is vital that the grower has an outlet for the energy crop. Energy crops can also be grown on set-aside land.

Set-aside is arable land that has been temporarily removed from production as part of a supply control policy under the Arable Area Payments Scheme (AAPS) introduced in 1993. The AAPS allows farmers to claim area payments for growing certain eligible crops and for taking land out of food production as set-aside. It can provide many opportunities for environmental improvements including the reduction in fertiliser and manure applications. It could, undoubtedly, be an effective way of reducing N and P inputs and would be important consideration when devising a nutrient reduction programme. However, it has not been possible to establish if land within the hydrological catchment areas of the three case studies is currently set-aside land and it would be difficult to determine how much land, if any, would qualify for set-aside status. For this reason it is not used in the case study management prescriptions. In addition, the AAPS is soon to be abandoned and replaced with the Single Farm Payment Scheme; although set-aside is a requirement under this scheme, the exact details are not yet known and farmers will have more freedom to grow their chosen crops where they prefer.

Farmers are more likely to adopt different farming practices if there is a financial incentive. A significant proportion of a farmer's income now comes from state subsidies (such as AAPS). Farmers are also able to participate in voluntary schemes, such as the Countryside Stewardship Scheme (CSS), Environmentally Sensitive Areas (ESA) Scheme or the Farm Woodland Premium Scheme (FWPS). It is, therefore, important to consider what effect the proposed changes will have on the eligibility for, and participation in, these schemes and their imminent successors.

5.1.1 Subsidies

In October 2003, the European Commission (EC) produced regulations for reform of the Common Agricultural Policy (European Commission, 2003). This has become known as the Mid-Term Review. The most significant change proposed is a shift in support payments from one based on numbers of eligible livestock or hectares of eligible crops, to one based simply on the number of hectares farmed. The new payment is called the Single Farm Payment (SFP).

In February 2004, the Government announced that, in England, the SFP would be a flat-rate payment. There are to be two levels of payment – one for Severely Disadvantaged Areas

[1] Soon to be replaced by the Organic Entry Level Stewardship Scheme.

(SDAs) and one for everywhere else. The SDAs include approximately 1,627,037 hectares of land in England much of which is in the North-West (including Cumbria where there are 11 basin wetland sites registered on FenBASE). It has been suggested by Defra that the payments will be £75/ha and £220/ha respectively, but these rates have yet to be confirmed. There are many issues yet to be resolved and lobby groups seem to have combined to argue for three tiers, whereby moorland would get a much lower payment (eg £30/ha) and farms in the SDAs a higher payment about £130/ha. The situation is further complicated by Defra's decision to use modulation and not to utilise the National Envelope Option whereby Member States have the option of reducing producer entitlements by up to 10% to create funding to support specific environmental schemes.

The SFP will be introduced over a transitional period of eight years, starting in 2005. The payment is to be conditional on the land to which it relates being farmed in a manner that is sound in both agricultural and environmental terms. The exact terms of this conditionality (so called cross compliance) is subject to a consultation exercise but is expected to focus on management of the land and a range of existing EU requirements on the environment, public and plant health, animal health and welfare standards.

In practice, it is impossible to anticipate the post-reform situation. The values of many agricultural goods and services have an element of subsidy factored in to them. For example, there is general acceptance that land prices and rents are maintained at a higher level than the market justifies by subsidies. The approach taken in the subsequent analyses, therefore, is to remove subsidies from the gross margin calculations used to assess total farm income, in both the 'before' and 'after' scenarios, and to assume that other prices are unaffected.

5.1.2 Agri-Environment Schemes

As noted above, another aspect of the CAP reform package is a shift of funds from so-called Pillar I (ie the fund from which the SFP is paid) to Pillar II. Pillar II includes agri-environment schemes and other funding streams and mechanisms designed to encourage land management that protects and enhances the natural and cultural heritage of rural areas; it also is used to fund schemes intended to enhance rural development. In England, the money will be used, *inter alia*, to fund a new agri-environment scheme with three elements:

- Entry Level Stewardship (ELS).
- Organic Entry Level Stewardship (OELS).
- Higher Level Stewardship (HLS).

These schemes give practical manifestation to recommendations made by Sir Donald Curry (Curry, 2002) in his major strategic review of English agriculture after the 2001 Foot and Mouth Disease outbreak.

The ELS has been piloted in three areas of England and is likely to be available throughout the country from 2005 onwards. The intention is that virtually all farms will be eligible and will receive around £30/ha.

The HLS and OELS will replace the existing Organic Farming Scheme (OFS), the Environmentally Sensitive Areas Scheme (ESAS) and Countryside Stewardship Scheme (CSS). It will be more targeted, with a number of Tiers, similar to the structure used for

ESAS and CSS. It is not yet in place and its exact structure is not yet agreed. However, it is believed that targeting will be achieved through a scoring system designed to ensure that land is accepted where most benefits will accrue, and that scoring (and levels of incentive) will be allowed to vary regionally to reflect differences in regional priorities. Again, the details of possible variations are not yet known.

5.1.3 Forestry and Woodland Grants

Grants are also available to encourage the planting of trees. Again, the grants system is in a state of flux (following the devolution of the Forestry Commission in April 2003). A new England Woodland Grant Scheme (EWGS) is being developed to replace the Woodland Grant Scheme. The Farm Woodland Premium Scheme (FWPS) is to be replaced by the EWGS Farm Woodland Payment (FWP). Proposed payment terms for the Schemes are given in the Tables 5.2 and 5.3.

EWGS will be a one-off payment, whereas the EWGS-FWP will be paid annually for 15 years (for woodlands with more than 50% broadleaved) or 10 years (for woodlands with less than 50% broadleaved). The EWGS-FWP rates will be subject to review (Defra and Forestry Commission, 2003).

5.1.4 Implications for costings

A number of assumptions have been made in the subsequent costings in relation to subsidies and schemes. These are that:

- all the farming systems put in place to reduce nutrient enrichment by agriculture will qualify for SFP;
- the land will qualify for ELS in all cases;
- options for which land might currently qualify under CSS or ESA (eg resource protection measures) will also be eligible for HLS (ie any payments should not be included as additional income arising from the proposed remediation measures);
- in other respects, the current agricultural management practices within the catchment would **not** qualify for CSS/ESA but would qualify for HLS if the changes were made (as a consequence, the payments can be included as an additional income).

Consequently, there is no need to take the SFP and ELS payments into account (because they would be received in both 'before' and 'after' scenarios. Only the HLS and EWGS-FWP payments are significant when comparing scenarios. At the time of writing (July 2004) the likely payment rates have not been published. However, this is not thought likely to be significant; as a similar basis is to be used for calculating payments, ie income foregone, plus an element for incentivisation, then it could be assumed that payments would be of the same order of magnitude as the current CSS payments. Consequently, sums have been included in the calculations where appropriate to represent agri-environment scheme payments. Unless the new rates are radically different from the CSS/ESA payments, there is unlikely to be a major change in the attractiveness or ranking of different options on the grounds of costs. Nevertheless, it may be appropriate to review the assumptions when announcements are made on what payments are to be made available. Even so, if all 'after' scenarios are capable of entry into HLES, then this does not need to be included in the comparisons.

5.1.5 Approach used to calculating changes

Farm management accounts typically refer to gross margin income and fixed costs, the former minus the latter giving rise to the profit figure. The gross margin component is the sum of gross margins from the different enterprises maintained on the farm. Examples of such enterprises are wheat, barley, sheep rearing, dairy cows and so on. The gross margin is calculated from gross income eg sales of milk, minus variable costs such as the cost of concentrate fed to the cows and the cost of veterinary treatments. Variable costs are so named because they vary proportionally in relation to the size of the enterprise ie the more cows there are, the bigger the feed bill will be. In calculating the effects of proposed remediation measures, the changes are mainly to the gross margins, with the gross margin from one enterprise being substituted by that from another.

Fixed costs, in theory, do not vary with the sizes or mix of the enterprises. For example, labour costs are unlikely to vary if the dairy herd size changes by plus or minus 10%. In practice, many elements of fixed costs are not truly fixed, especially if the farm system changes significantly. For example, if a dairy herd is sold and replaced by a beef herd, there is likely to be a net release of capital meaning that interest charges will fall, a major reduction in labour costs and a much lower sundry property costs ie water rates, electricity etc. In assessing the financial implications of the proposed remediation measures, it will be necessary at times to examine changes in fixed costs as well, where more significant changes are envisaged.

In all cases, change is only assessed at the margin. This means that it is not intended to prepare a complete set of management accounts for each farm for the ‘before remediation’ scenario and for the ‘after remediation’ scenario. Not only would it be very time-consuming to prepare full accounts, but also it would suggest a level of knowledge about the affected businesses that is not available. Therefore, the calculations are based on the following formula:

Cost of Remediation Measure = Σ(Costs incurred + income lost)

Minus

Σ(Costs saved + income gained)

Calculating each component of this equation requires a variety of assumptions to be made, with varying degrees of confidence. In most cases, standard costs are used, drawn from various publications. Any significant assumptions are noted and sources of data referenced where they occur.

The following sections present an assessment of three different basin fens, all known to be suffering from nutrient enrichment. The three different mitigation approaches (ie Prevention, Protection and Mixed) are applied to each site, and the cost: benefit evaluated.

5.2 Case Study 1: Wybunbury Moss NNR, Cheshire

5.2.1 Background

Local Planning Authority:	Cheshire County Council, Crewe & Nantwich Borough Council.
National Grid Reference:	SJ 697502;
Area:	23.3 (ha.) 57.6 (ac.)
Ordnance Survey Sheets	1:50,000: 118 1:10,000: SJ 64 NE, SJ 65 SE, SJ 74 NW, SJ 75 SW
Condition Assessment Feb. 2004:	Units 3,9,10,11,12,14 favourable; Units 1,6 unfavourable recovering; eight unfavourable no change.

Wybunbury Moss NNR was declared in 1956 and includes a range of wetland habitats. It is a nationally important site as it is one of the finest examples in the country of a ‘schwingmoor’ (oligotrophic floating raft of *Sphagnum* peat 3-7m thick over up to 17m of water) and supports an outstanding assemblage of invertebrates including many nationally and locally rare species. Current evidence suggests that the origin of the lake basin containing the schwingmoor was a secondary process associated with the solution and subsidence of the underlying salt bearing strata. This is a very rare occurrence and can be seen at only one other British site (Chartley Moss NNR in Staffordshire). The central floating raft is surrounded by fen and mixed woodland (English Nature, 2004; Page and Reilly, 1986 revised 1991).

5.2.1.1 Catchment land use

The eastern part of the catchment is mainly agricultural (Figure 5.1), but it includes part of the village of Hough and the A500 road. Most of the fields are improved pasture but there is some arable farming, mainly barley and maize. A few sheep-grazed fields nearer to the NNR are semi-improved. This part of Cheshire is characterised by a mix of dairy farming, other livestock enterprises and some arable. It is one of the leading areas of dairy production in England.

5.2.1.2 Catchment hydrology

There is general uncertainty concerning the nature of the catchment hydrology for Wybunbury Moss. The surface catchment is relatively large and extends to the east for over 1.5km but there is no inflow stream entering the Moss (Figure 5.1). The majority of the water entering the site is the product of overland and subsurface flow from the surface catchment, or rainfall. Springs from the groundwater catchment may also enter the mire basin below the peat and contribute to the reservoir of water beneath the peat raft. A number of springs along the northern side suggest a general north-south movement of water just below the surface level.

There is a ditch running along the eastern boundary, which receives water from an underground field drain at the northern end and flows in a southerly direction. The surface water catchment outlined on the accompanying map includes the area that could potentially contribute to the boundary drain.

Work undertaken during the Environment Agency's hydrogeological assessment (Ingram, 2003) suggests the contribution from groundwater inflow is likely to be significant, particularly from the groundwater from the sand deposits lying to the north of the moss. The approximate extent of the groundwater catchment suggested by the Environment Agency's assessment is also indicated on the map. This is much smaller in extent than the surface catchment. As there are no surface inputs into the Moss it is likely that this area is highly influential on the water quality of the Moss.

An outfall drainage ditch drains from the eastern side of the Moss and has sluice gates, which can be closed to maintain water levels on the moss.

Although there are licensed groundwater abstractions within a 3km radius the ECUS report indicates they have no impact on groundwater levels in the vicinity of the moss (ECUS, undated).

Plate 8. Wybunbury Moss

5.2.1.3 Issues

There has been a history of pollution at Wybunbury Moss dating back to the 1970s when foul storm water was piped into the basin from properties to the north. Subsistence, related to salt extraction, fractured drainage pipes below the surface and effluent broke out onto the surface facilitating the development of fen vegetation, killing trees and turning the outfall ditch into an open foul sewer. Action was taken to locate and collect the effluent into a tank near Moss Nook Farm. This has been achieved and now foul water is pumped from here to the main sewer, which serves the village of Wybunbury.

The mire is still very vulnerable to run off containing fertiliser from adjacent agricultural land and from receiving eutrophic water from domestic properties in the surrounding catchment.

Sampling of groundwater in the sand deposits to the north of the basin shows high levels of nitrate, possibly from both sewage and agricultural practices.

As a result of the influx of highly eutrophic groundwater, some of which was polluted by human sewage, parts of the Moss are now considered to be extremely unstable and fragile. The worst affected area is to the north, where nutrient enriched waters have flowed across the Moss in a south and south-westerly direction. Eutrophic water has moved westwards along the lagg ditch affecting much of the north-western section of the mire. The north-eastern part is also receiving enriched water and eutrophic water has now reached the reservoir beneath the floating peat raft. Another nutrient input, of unknown significance, may be a large winter pigeon roost.

As a consequence of eutrophication, the area of wet, unstable fen woodland has increased at the expense of pine woodland and the open *Sphagnum* lawn with the replacement of acidophilous vegetation by alder swamp. The mire surface has degenerated and smaller pools have coalesced to form areas of open water (Reilly and Page, 1984; Wheeler and Shaw, 2003)

5.2.2 Remediation measures

The farmable area of the Moss' catchment is assumed to be 158ha. The catchment comprises land of Grades 2 and 3, the latter presumed to be 3A, according to Defra's Agricultural Land Classification. This means it is flexible in terms of farm management practices, and so land quality is assumed not to be a limitation to remediation possibilities. Current agricultural uses of land within the catchment are reported to be a mix of:

- arable (barley) – assumed to be 26ha;
- forage cropping (maize) – assumed to be 26ha;
- improved grassland – assumed to be 100ha;
- semi-improved sheep grazing (near to the NNR) – assumed to be 6ha.

No information is available about how these crops are managed or about the number and structure of businesses affected, and so it has been assumed that the farmers follow conventional farming practices.

A number of further assumptions are required:

- There is some rotation of cropping. It is assumed that the:
    a. 100ha of improved grassland is permanent;
    b. the cropped area is rotated - two years' barley, two years' maize;
    c. the barley is spring sown (as the maize is usually harvested too late for winter sowing).
- The barley is sold.
- Maize is used as a source of food for cattle. Any reduction in output from the remediation measures is made good through purchased barley.
- Use of the permanent grassland does not change.

It is assumed that the threat to the conservation quality of the Moss stems from excessive run-off of nutrients (N and P) arising from agricultural applications, both organic and inorganic.

There are three nutrient management proposals based on the Prevention, Protection and Mixed approaches described in the introduction.

5.2.2.1 Applying the Prevention Model

The surface water catchment lies largely to the east of the fen. It consists of improved grassland and a mix of barley and maize.

Action:

- **Option 1** involves a reduction in fertiliser used with barley.
-
- **Option 2** requires the remove all arable production (52.02ha) east of Wybunbury Fen to be replaced with permanent grassland (presently 105.96ha).

Each of the options is summarised in Box 5.1 and assessed in turn below.

Option 1: Switch to low input arable farming

This option would entail adopting a reduced input regime on the barley crop. The same principle could, in theory, be applied to the maize crop but, as the majority of the nutrient inputs to this crop are likely to be organic, the option is unlikely to be available. The change in the barley management would mean a small net change.

Income prior to switch	Gross margin from 26ha of 'average input' barley is:	26 x £240 = £6,240
Income after switch to low input	Gross margin from 26ha of 'low input' barley is:	26 x £177 = £4,600
The loss in income is:		£6,240 - £4,600 = £1,640

This assumes a 22% reduction in fertiliser costs, in line with suggested reduction in yield. Environmental benefits will be small and probably insufficient to make a significant difference to nutrient enrichment.

Option 2: Switch to grassland

Under this option, it is assumed that the arable and maize area is switched into permanent or long-term grassland. The method of farming applied is for low intensity grazing or cutting. This presents a number of options:

- Option 2a -the grass is harvested for hay or silage and the conserved grass sold;
- Option 2b - the grass is rented for grazing by hill sheep and young cattle (dairy heifers being reared as replacements or beef animals being reared for slaughter);
- Option 2c - the existing lowland sheep enterprise is expanded to make use of the additional grassland.

In each of these options, the income lost is the gross margin value of the barley and maize. This has been estimated as being £14,390/year.

Option 2a: Sale of grass as a crop

Grass can be sold either as a standing crop for harvest or as bales (either hay or big-baled silage). Assuming a fresh weight yield of around 12 tonnes of hay and 29 tonnes of silage/ha (both crops sold as big bales), gross margin income would be about: £182/ha for hay (£9,464 for 52ha) and £273/ha for silage (£14,196 over 52ha).

The net cost of a switch to selling hay or grass silage would be about £4,925 or £200 respectively. The yield, particularly of silage, may be lower if fertiliser usage is significantly reduced.

Option 2b: Rent the land for grazing

It is not uncommon in this area for farmers to let land for grazing, either for sheep (typically hill sheep from Wales, for over-wintering and returning home before lambing in late February/early March) or for other cattle (dairy herd replacements or beef cattle). Rent for over-wintering sheep is usually calculated on a per ewe per week basis (typically around 13-14p/ewe/week). The period of let would be over the winter, meaning that the land could also be rented out over the summer for young stock/beef cattle. Based on a stocking rate of 1.5 Livestock Units (LSU)/ha, the land could carry around 150 head of young stock. The exact numbers will vary through the season and with the size of the animals grazed.

Indicative figures from Nix and others (2003) suggest that short term grazing would attract around £103/ha, whilst Farm Business Tenancies (FBT), typically for a 10 or 15-year period, would attract rents of around £156/ha. In practice, this option would only offer remediation if restrictions were in place on the level of stocking and fertiliser. Consequently, rents obtainable are likely to be lower, say about £75 and £115 respectively.

A significant additional element of renting rather than farming the land is the savings in fixed costs that can be made. It needs to be noted, though, that whoever rents the land will incur fixed costs as a result of expanding their farmed area, although they would enjoy certain economies of scale. A change of this nature would only occur if both parties believe that there will be a net gain in economic efficiency. The net benefit (in the form of costs reduction) to the agricultural economy is a function of the individual circumstances of the landowner and the tenant. Nix and others (2003) indicates that, for a sheep/cattle/arable farm with between 50 and 100ha, fixed costs for labour, power and machinery would amount to around £350/ha. In practice, it is considered appropriate to reduce this to approximately half ie £175/ha, the balance representing the increased efficiency that might be expected from the change.

The net effect is therefore:

		£	
Income lost from loss of barley and maize	=	-14390	
Income gained/saved on fixed cost (56ha x £175)	=	9100	
Loss	=	5290	(£9100 - £14390)
If assume annual let income	=	3900	
Overall loss	**=**	**-1390**	**(£3900 - £5290)**
If assume Farm Business Tenancies income	=	5980	
Overall gain	**=**	**690**	**(£5980 - £5290)**

Option 2c: Expand the sheep enterprise

There is evidence to suggest that there is a sheep enterprise operated by one of the farmers with land in the Moss' catchment. Under this scenario, the sheep enterprise would be expanded to occupy the 52ha released from cessation of the barley and maize enterprises. The land released would be sown to conservation-standard grass mixtures. Nix and others (2003) suggests that a gross margin for a lightly stocked, lowland, spring lambing sheep enterprise, after forage costs, is around £65/ha. On the 52ha released, this would give a gross margin income of £3,380 from a flock of around 415 ewes. This would represent a net cost of £11,010 compared to the current system.

It is likely that there would be some fixed cost changes too, together with a major shift in managerial skills required. However, indications from Nix and others (2003) are that the overall cost/ha would be similar, although different in composition.

5.2.2.2 Applying the Protection Model

The Environment Agency's assessment is that groundwater inflow from the sand deposits to the north of Wybunbury Fen is very significant and the northern end of the fen is worst affected by nutrient enrichment. The strategy is to add buffer zones to the north and east of the fen and the effects on farming systems and therefore on business performance would be limited.

Action:

- **Option 1.** As illustrated in Figures 5.2 and 5.3. Excavate a key trench with an infill of impermeable clay *c.*0.5m wide by 2.0m deep, to run parallel to the northern SSSI boundary. This will act to lift through-flow to the surface before entering a 45m buffer zone of mixed semi-natural woodland. There will be a loss of 0.3ha of arable land and 2.27ha of permanent grassland to woodland. The loss also includes a wetted fringe (3-5m), which will be created to the north of the key trench.

- **Option 2.** As illustrated in Figure 5.4. Immediately to the east of the site is a 5.24ha field of poor semi-improved grassland (Area 2). This is to be removed from grazing and developed as an extension of the adjacent field of semi-natural neutral grassland (Area 3). This may need some management eg seasonal mowing or light grazing.

Each of the options is summarised in Box 5.2 and assessed below:

Option 1: Loss of land to buffer zone

Loss of arable gross margin from the barley and maize crops will be:

0.15ha at £240/ha	
0.15ha at £313.5/ha	
Total	**= £83**

No information is available about the way the permanent grassland is farmed. Reference is made to sheep grazing, and so it is assumed that the land is used for average intensity sheep production. A gross margin of about £155/ha is given as typical for an average lowland, spring-lambing sheep flock. Therefore, losses will be around £350/annum (£155 x 2.27 ha) (from a reduction in numbers of about 25 ewes).

The effect on fixed costs will be negligible.

Much of the buffer zone is to be planted with trees. Assuming that the mix of species is predominantly broadleaved, and the block size is sufficient to meet the eligibility criteria, the planting is likely to qualify for EWGS and FWP. The EWGS is intended to meet the full cost of establishment, and so can be used to offset planting costs.

FWP is intended to provide compensation for income foregone. Using the current FWPS rates, annual payments over the next 15 years would be:

0.3ha of arable x £300	= £90
2.27ha of improved grassland x £260	= £590
Total	**= £680**

The net effect of offsetting the gross margin income foregone by the FWPS payments received means that the net effect of creating the buffer zone is a gain of about £250/ annum (£680- (£83 + £350)) for the 15 years of the FWPS payments and, thereafter, a cost of £433 (£83 + £350).

Option 2: Loss of semi-improved grazing land

Assuming that the 5.24ha in question is used to produce lambs under a spring lambing, average intensity system, the loss of gross margin will be: 5.24ha x £155/ha = £812. The lost grazing would require a reduction in numbers of around 60 ewes. There may be a small saving in fixed costs, but these are not likely to be significant.

If land is to be mown once every year, then a cost of around £20/ha would be incurred if done by the farmer or £23.50 if done by contractor. This gives an additional cost of between £105 and £125/annum.

If land is to be grazed lightly, then some income can be derived. One option is to graze the land over-winter, using away wintered ewes from the Welsh hills. However, this does not coincide with the period when grass growth is at its peak, and so does little to control surplus vegetation. A better alternative would be to let the land for summer grazing by cattle, insisting on a low fertiliser/low stocking regime. A short term let is likely to secure around £75/ha/year, including a requirement on the lessee to maintain fences in stock-proof condition. This gives an income of around £400/annum.

The net effect of removal of grazing is:

- around £930 (ie £812 + £105/125) (if sheep remove and subsequent growth is mown)
- around £410 (ie £812 - £400) (if sheep are removed and subsequent growth is let for light grazing by cattle)

5.2.2.3 Mixed approach

Action:

- **Option 1:** Replace the 12.3ha of arable production to the north of the fen with permanent grassland, with an increase in sheep able to graze this area.
- **Option 2:** Create a 10m buffer zone of mixed woodland along the northern perimeter with no key trenching. There will be a smaller loss of land from production. With a 10m buffer zone there will be a loss of 0.26ha from permanent grassland and no loss of arable land.

Each of these options are summarised in Box 5.3 and presented below:

Option 1: Replacing maize with permanent grassland

This would require changes similar to those described for the 'Preventative Model' options 2a, 2b and 2c but at a small scale ie 12.3ha as opposed to 52ha.

Option 2: Creating a 10m buffer zone

All farms operate at below maximum efficiency and such a marginal change is likely to result in a small increase in efficiency. However, it is worth considering *increasing* the size of the buffer zone so that the area taken is over 1ha (say 1.1ha). By doing so, the block of woodland would qualify for FWPS. Consequently, the effect would be a loss of grazing for around 12 ewes and a reduction of £170 in gross margin income, but a gain of £286 (1.1ha x £260) from FWPS payments. This gives a net gain of £116, assuming WGS covers all establishment costs. This situation would apply for 15 years; thereafter, annual costs would be £170.

5.2.3 Conclusions for Wybunbury Moss

The preceding sub-sections have attempted to assess the financial implications of modifying the current farming systems operated in the Wybunbury Moss catchment to achieve remediation of the basin fen. Three different strategies have been explored, and various options within each, reflecting the different management issues that will arise as a result. The assessments are very crude in that:

- they are based on standard data;
- there is a lack of precise data about current systems;
- no site visit has been made;

- the future of various subsidy and grant schemes is uncertain.

Subject to these caveats, it can be seen that the prevention model is likely to be the most costly, irrespective of the particular sub-option followed. The Protection Model is almost cost neutral, provided that EWGS/FWP can be obtained. The mixed approach lies somewhere between the other two. In all cases, no attempt has been made to quantify the scale of the anticipated beneficial effect on the nutrient content of water in-flows to the Moss.

5.3 Case Study 2: Silver Tarn SSSI, Cumbria

5.3.1 Background

Local Planning Authority:	Copeland Borough Council
National Grid Reference:	NX 998068
Area:	5.30 (ha) 13.00 (ac)
Ordnance Survey Sheets:	1:50,000: 89 1:10,000: NX 90 NE, NY 00 NW
Condition Assessment Feb. 2004:	Units 1, 2, 3 favourable; Unit 4 unfavourable recovering

This wetland site lies within 0.5km of the West Cumbrian coast, midway between the villages of Nethertown and Braystones and approximately 4km south of Egremont. The site comprises a suite of three separate but related features originating as postglacial hollows in boulder clay and later forming kettlehole tarns. The site exhibits typical stages in the development of kettlehole vegetation from open water, represented by Harnsey Moss, through to the acid poor-fen of Silver Tarn, to a transitional basin fen stage reflected in the Hollas Moss communities. Additional associated communities include: inundation, tall fen/emergent vegetation, acid flush and carr.

These wetland habitats are becoming increasingly scarce in the intensively farmed lowlands both locally and nationally. This is one of only two known examples in the country of a suite of intact, small, kettlehole formations, the other being Whitlaw Mosses NNR in the Borders Region of Scotland. Together these mosses support a mosaic of poor-fen communities. The broad range of communities supported by this small site complement those of other lowland wetlands in West Cumbria. In addition, Harnsey Moss is the best example of a small, nutrient rich tarn.

Silver Tarn is the largest mire of this kettlehole complex lying across two hollows forming linked units referred to as Silver Tarn east and west. Silver Tarn East is the larger of the two mires occupying a deep hollow with steeply rising hill slopes on all sides except at the southwestern corner. The eastern moss is particularly wet comprising only a thin mat of vegetation (schwingmoor) overlying open water or semi-liquid peat. Silver Tarn west, although quaking in places, is generally firmer (English Nature, 2004a).

5.3.1.1 Catchment land use

The University of Sheffield completed a Fen Habitat Condition Land Use Survey in 1989. It provides detailed land use at that time for a number of fields surrounding Silver Tarn, and this is presented in Table 5.4.

Plate 9. Silver Tarn

5.3.1.2 Catchment hydrology

The surface water catchment for all three sites (including Hollas and Harney Moss) is estimated at 0.32km^2 (Figure 5.5). The site is on a major aquifer, recharged predominantly from high ground to the east. Groundwater contour maps indicate that groundwater flow is from the NE to SW and groundwater level is estimated as being between 5m and 13m below ground level (ESI Ltd, 2002).

Groundwater springs, surface seepage and rainfall maintain the permanently high water table. There are water inputs from field drains and, most likely, some seepage from the surrounding slopes, especially on the southern end. Subsurface groundwater discharges directly in to the basin.

There is a drain connecting Hollas Moss and Silver Tarn. The eastern basin is largely closed, with water leaving via an artificial outfall through a channel cut into the rock in the southeast corner. There are no open ditch water flows evident although a land drain flows into a pool at the eastern end. This collects water from several fields to the east of the basin. Inflow from land drains is suggested by a stand of willow carr at the eastern end (Wheeler and Shaw, 2003a).

The western basin lies between steep slopes on the north and west sides and has an axial drain from the inflow at the eastern end down to the outflow at the western side. From here it flows through a narrow cleft in the hillside and into the sea less than 300m away.

There are a number of groundwater abstractions within 3km of the site but vulnerability to licensed abstraction is considered to be low.

5.3.1.3 Issues

Silver Tarn is surrounded by highly fertilised agricultural land. It receives water drainage water from fields around the site as runoff and via field drains which enter at the eastern end, after collecting drainage water from a number of fields to the east. Livestock have access to both basins although the northern end of the basin appears to be grazed to the greatest extent. The western basin has suffered from some poaching by cattle, particularly along the north-eastern boundary by the road.

There are clear signs of eutrophication in the vegetation of both Silver Tarn East and West. The source of the enrichment is thought to be connected to the outflow from the drain connecting Hollas Moss with Silver Tarn, although Hollas Moss is not demonstrating signs of eutrophication in the vegetation. This may be because there is sufficient drainage around the Moss to take away any eutrophic water and into Silver Tarn or that the carr that fringes the Moss may act as a buffer to protect against excess nutrients (Sue Evans, pers. comm.).

The eastern basin has benefited from alder, willow, and birch carr woodland at its eastern end, which may be helping filter out any nutrients from the surrounding agricultural catchment. The condition assessment suggests occasional grazing by cattle may be beneficial in controlling any scrub encroachment. The condition statement suggests that options for reducing fertiliser applications to the surrounding catchment should be explored and that English Nature should press for inclusion of the surrounding land within the boundary of the SSSI (English Nature, 2004a).

It is known that a number of farmers who own and farm surrounding land are interested in entering into agri-environment schemes although at this stage the cost implications have not been thoroughly investigated.

5.3.2 Remediation measures

Although Cumbria is noted for its upland livestock, the west Cumbrian Plain offers ideal conditions for more intensive stock rearing and dairying, plus some arable cropping. Indeed, the mild climate alongside the coast ensures early grass growth and opportunities for early harvesting of root crops like potatoes. However, growing of potatoes has become concentrated into fewer growers, each producing larger tonnages, in response to market demands.

The farmable area of the tarn's catchment is estimated to be around 32.4ha. Land quality is likely to be in the higher grades, although the Agricultural Land Classification maps cannot reflect local variations. Given the nature of the topography and drainage, it is likely that wetness may limit flexibility on at least part of the catchment.

Current agricultural uses of the land are reported to be a mix of:

- Arable land (potatoes and barley) – 10.35ha.
- Improved grassland for silage and grazing – 14.77ha.
- The Tarn itself (assume no agricultural use) – 5.3ha.
- Other – 7.28ha.

No information is available about how these crops are managed or about the number and structure of businesses affected, and so it has been assumed that the farmers follow conventional farming practices. Nothing is known about the tenure of the land, whether there is an owner-occupier or tenant, so it has been assumed that this is not a material factor.

A number of further assumptions are required:

- There is some rotation of cropping. It is assumed that:
  - 10.35ha is the maximum amount of arable cropping feasible
  - the cropped area is rotated – one year of potatoes and four years of barley[2]
  - the barley is spring sown (as the potato crop will usually be harvested too late for winter sowing).
- Both the barley and potato crops are sold, the latter as ware.
- Contractors are used for specialist potato growing tasks.
- Grass is used as a source of food for beef and sheep. Any reduction in output from the remediation measures is made good through purchased forage.
- Use of the permanent grassland does not change.

5.3.2.1 Applying the Prevention Model

Action:

Option 1 is to exclude all arable farming with a reduction in arable land of 10.35ha and turn this over to unimproved grazing for sheep at low stocking levels.

This option is assessed either with our without subsidy input from an agri0environment scheme, and is summarised in Box 5.4. Using standard data in the Farm Management Pocketbook (Nix and others 2003), current gross margin income (excluding subsidies) can be estimated as follows:

Barley: assuming the average crop, grown for feed, spring sown. Crop occupies 80% of arable area each year ie 8.28ha.

Excluding income from subsidies, gross margin income = 8.28ha x £240 = £1,987.20

Potatoes: Assuming the average crop, main-crop. Crop occupies 20% of arable area each year ie 2.07ha

Gross margin income = 2.07ha x £1,225 = £2,535.75
Total current gross margin income (£1987.2 + £2535.75) = £4,522.95

Capital cost element: It is unlikely that stopping the growing of crops on 10.35ha of land would release any capital. Therefore, switching to grassland and sheep production will

2 Unless it is possible to grow first early potatoes, a five-year rotation is needed to avoid potato disease problems, especially potato eelworm. The suggested rotation is not a conventional one, which would normally be expected, in this area, to include some wheat and/or maize. However, it is considered wiser not to introduce crops that have not been reported as being grown in this area.

require a net investment of capital to establish the grass and acquire the sheep. The capital costs are assessed as being:

Establish grassland one-off cost of 10.35ha at £370[3]/ha =	£3,829.50
Assuming this investment is spread over 10 years and the interest rate is 6%, this represents an annual cost of	£520.74
Acquire sheep – assuming a stocking rate of eight ewes/ha, then a flock of 83 ewes would be required. Given a cost of c £70/ewe, then the one-off capital cost is	£5,810
Assuming this investment is spread over five years and the interest rate is 6%, this represents an annual cost of	£1,342.11
The annual cost of the capital investment is (£520.74 + £1,342.11).	**£1,862.85**

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Future gross margin income: If eutrophication is a problem, the soil itself is likely to have high levels of nutrient. This means that there may be a need for a transitional period during which the nutrients are deliberately depleted. One way of achieving this would be to sow grass seed and take hay or silage crops with little use of fertiliser. However, as this would only be a transitional arrangement, the financial implications have not been assessed.

The gross margin income, excluding subsidies, from a flock of 83 sheep, kept at low levels of stocking and management intensity would be (Nix and others 2003):

Lowland, spring lambing, no special premium for sales. Low level of stocking intensity:	83 ewes x £8	664.00

Effect on income: The net effect of the change would be:

Current GM Income lost	£4,522.95
Plus - Annual cost of capital incurred	£1,862.85
Less - Sheep gross margin	£ 664.00
Net loss	£5,721.80

Potential income from Agri-Environment Scheme: As yet, we do not know what payment will be provided in the HLES, especially as regional variation in payments is expected. However, payment would need to be in the region of £550/ha for the farmers to breakeven. It is unlikely that payment would be so high.

Current payment rate for 2004 under CSS for re-creating grassland on cultivated land is £280/ha (CSS Ref R1). Supplementary payments of £250/ha are also available for using seeds mixtures of local provenance (CSS Ref GS), which would help defray the costs of establishing the grassland. If a CSS application were made and accepted, and payments made at the above rates, the deficit would reduce by

£280/ha x 10.35ha for payments under R1	= £2,898
£351.90 in reduced annual cost of establishment	
The resulting deficit would be reduced from (£5721.80 - £2,898 - £351.90)	£5,721.80- £2,471.90

[3] Assumes a conservation-type seeds mix is used, and includes all machinery costs.

Effect on nutrient inputs: One of the key aims of the proposed change of farming practice is to reduce the amount of nutrients being added to the catchment. In order to calculate the change, it is necessary to estimate what is currently being applied and what would be applied in future, and subtracting one from the other.

Some data have been obtained about application rates in 1988 and 1989 although these may have been subject to change. In order to make an assessment, it has been assumed that:

- the figures quoted are in kg/ha (not units/acre);
- the same application rates would be used today;
- no allowance has been made for applications of farmyard manure.

The figures given for potatoes in Field 1 for 1989 look erroneous, unless large amounts of manure had been applied and allowance made for its nutrient value. The data given for barley look much more typical. It has been assumed that applications of fertiliser under a lightly stocked sheep system would be 125kgN/ha, 30kgP/ha and 23kgK/ha. The net changes are shown in Table 5.5.

It should be noted that these figures relate to the reduction in inputs applied. This does not necessarily translate into a reduction in run-off. It has to be assumed that the farmers are using good practice and so aim to match applications with crop needs, and avoid applying fertiliser at times when run-off may be exacerbated eg in wet weather. Therefore, the percentage reduction in applications may not be reflected in terms of reduced run-off; indeed, the reduction in run-off (ie the amount that is surplus to plant needs) may be at a higher proportion than the reduction in applications.

5.3.2.2 Applying the Protection Model

It has been commented that the eastern basin benefits from some nutrient buffering from willow carr woodland at eastern end.

Action:

Option 1 is to impede drainage of the western margin where 'eutrophic vegetation' is indicated to create a wetland buffer zone of willow carr (Figures 5.6 and 5.7). To also establish a buffer zone around the eastern and western fen of mixed grassland/scrubland to fen. The buffer zone and wetland buffer zone would together result in the loss of 3.6ha of improved grassland. One source of enrichment is thought to be outflow from the drain connecting Hollas Moss and Silver Tarn. It is proposed that a ditch and riparian buffer zone is developed with some dispersal mechanism and impedance to flow eg small check dams. The riparian buffer zone of scrub and mixed woodland 15m either side of the ditch would remove 0.15ha of permanent grassland.

The Protection Model requires the loss of 3.75ha of improved grassland, in two blocks of 3.60ha and 0.15ha. The impact of the proposed change is therefore the loss of the production from this land. The land to be lost is described as ‘improved grassland’, and it is assumed that it is land that is currently being used for the production of silage and aftermath grazing ie grazing of grass that re-grows after cutting.

The key question, therefore, is how much will it cost to replace the production from the lost ground. There are several options as summarised in Box 5.5 and presented below:

- Option 1a - Rent extra land.
- Option 1b – Buy in lost feed as forage.
- Option 1c – Buy in lost feed as concentrate.

Option 1a Rent extra land

One option is to rent 3.75ha of grassland from elsewhere. It may be difficult to find a suitable block close enough to the main block of land to facilitate grazing. It is not practical to rent grazing land many miles from the home base, as it is difficult to keep appropriate watch over the animals. Therefore, it is more likely that land would need to be rented for cutting. Such land tends to be let on more of a short-term basis, and may require the lessee to apply fertiliser. Rents are likely to be of the order of £100/ha, plus fertiliser costs of around £65-£70, giving £170/ha. The total extra cost would be £640 (3.75ha x £170).

Option 1b Buy in lost feed as forage

The production from the 3.75ha could be replaced by buying in silage grown by others. Assuming a typical annual yield of 29 tonnes of silage/ha, and a typical price of £27.50/tonne, the cost of buying in the required amount of silage to replace the lost production would be around £3,000.

Option 1c Buy in lost feed as concentrate

Rather than replace the lost production with purchased silage, it may be feasible to buy in the lost production in the form of concentrated feed (mainly barley). It is estimated that this would cost around £4,500. It is unlikely that this option would be adopted unless forage was in generally short supply eg in a drought year, and silage price would be high. The breakeven cost would be around £41/tonne for silage.

The best option to replace the 3.75ha lost to the buffer zones would be to rent in extra land. Failing this, the second best option would be to purchase big-baled silage.

5.3.2.3 Applying the mixed approach

Action:

Option 1: de-intensification through set-aside of the fields in the surface catchment area that border Silver Tarn (East and West). This would remove 12.21ha of improved grassland. Best Farming Practices to be applied to existing farming systems – new manure and fertiliser management, N usage down by 30% so that reduced inputs on 10.35ha of arable, and 2.56ha grassland (14.77–12.21ha).

The options are summarised in Box 5.6 and there are three factors to consider:

1**. Stopping production from improved grassland**

The nature of the change is the same as that for the Protection Model, but on a rather larger scale (12.21ha compared to 3.75ha). A simple scaling up of the estimated costs reveals that:

a. renting in additional land would cost around £2,075 (12.21ha x £170);
b. buying in replacement forage would cost around £9,740 (12.21ha x 29t/ha x £27.50/t);
c. buying in replacement feed in the form of purchased concentrates would cost around £14,100.

Setting aside ie stopping farming, on 12.21ha of improved grassland could lead to a reduction of fertiliser application of about:

N = 3,175 kg
P = 610 kg
K = 1,600 kg

2. Reduced inputs – arable area

The most effective way of reducing fertiliser inputs will be to stop growing potatoes and grow barley across the whole of the area. This would also be in accord with trends in the market, in which potato-growing is being concentrated into areas where a large amount of high quality land is available, relatively close to mass markets eg Vale of York, Lincolnshire. The effect of this change is to reduce inputs by:

d. 6% of N
e. 41% of P
f. 48% of K

In order to bring the N usage down to 30% lower than the current level on the arable land, N applications onto barley would need to reduce to around 100kgN/ha (compared to the current assumed level of 150kgN/ha). If it is assumed that the effect would be to reduce output from ‘average’ to ‘low’. The implication in gross margin terms is assumed to be a reduction from £240/ha - £181.5/ha (assuming that N costs £0.33/kg).

3. Reduced inputs – improved grassland

If fertiliser applications are reduced on the remaining area (2.56ha) of improved grassland, then it is likely that yields would be reduced. Grass is particularly responsive to applications of N, whereas short-term impacts of changes to P and K are less significant. If it can be assumed that a reduction of 30% in nutrient applications would result in a loss of second cut silage, then the reduction in yield would be of the order of 2–2.5 tonnes of grass dry matter (for a productive ley). The cost of replacing the lost production over 2.56ha, in the form of purchased replacement silage, would be between £470 and £590.

5.3.3 Conclusions for Silver Tarn

Several options have been suggested for alleviating the flow of nutrients into Silver Tarn SSSI arising from farming activity. The Prevention Model is a cost effective option if CSS payments can be obtained, but requires the most significant system changes (from arable to sheep). The Protection Model offers the least cost solution, especially if land is available in the area for rent. Even so, a small amount of replacement silage could be purchased to replace the lost forage. The Mixed Approach is most costly, although achieves the largest reduction in nutrient inputs.

5.4 Case Study 3: Great Cressingham Fen SSSI, Norfolk

5.4.1 Background

Local Planning Authority:	Breckland District Council
National Grid Reference:	TF 848022
Area:	13.69 (ha) 33.85 (ac)
Ordnance Survey Sheets:	1:50,000: 144
	1:10,000: TF 80 SW
	1:10.560: TF 80 SE
Condition Assessment Feb. 2004:	Unfavourable no change

Great Cressingham Fen is a component of the Norfolk Valley Fens and a cSAC. It contains internationally important M13 and M9 mire stands dependent on base-rich groundwater. It is located in a small side-valley of the River Wissey and considered to be one of the best remaining examples of calcareous spring-fed valley-fen in west Norfolk. It has retained the full series of vegetation types, which range from dry unimproved grassland on the highest slopes, through wet, species-rich fen grasslands where springs emerge to tall fen vegetation in the valley bottom. The site supports a very large number of plants including several uncommon species (English Nature, 2004b).

5.4.1.1 Catchment land use

The site itself is grazed and considered to be generally well-managed by the owner. The surface catchment extends to the west and north west of the fen (Figure 5.8) and is largely agricultural. Table 5.6 refers to a survey completed in 1985/6 to characterise the land use and fertiliser application levels in the fields that surround the fen.

The sub-surface catchment is a much larger area but the farming practices are similar. The area is low-lying fen and very fertile. This part of East Anglia is noted as one of the most fertile in the country and is characterised by large-scale/intensive arable farming. All types of crops are found in this area; as well as the more ubiquitous cereals and oil seeds, growing of root crops and field vegetables has tended to concentrate into areas such as the fens. The Brecklands have also become an area for outdoor pigs, whilst some grazing livestock enterprises (beef and sheep, rather than dairy) still remain (MAFF, 2000). The land grade is likely to be 1 or 2 and, as such, is very flexible in agricultural terms. Flexibility may be reduced if the Fen lies wet, thus limiting tractorability. Land that is on the Breckland type soils rather than fen peat may have different characteristics (Steven Rothera, pers. comm.).

5.4.1.2 Catchment hydrology

The climate of the region is semi-continental, being the driest in the British Isles and subject to great extremes of temperature.

The groundwater input from the chalk appears to be mainly at the north-western edge, where there are groundwater spring fed streams from the drift deposits. Observations in winter months confirm the importance of inflow from the west where surface flow in marshy areas is visible. These flow into a rectangular drainage system, which in turn, discharges via an outlet drain into the southeast corner of the fen site. There are no surface water inflows into Great Cressingham Fen (Anglian Water, 2003).

The extent of the surface water catchment is indicated on Figure 5.8. There is uncertainty as to the extent of the groundwater catchment. If conservative estimates of buried valley hydraulic conductivity are assumed, the area is about 21km^2, described as the Minimum Groundwater Catchment on the map of the area. If the groundwater area is estimated using summer water table contours, it is much more extensive and totals about 66.5km^2, described on the map as the Maximum Groundwater Catchment. Which ever is considered to be the most representative, it is clear that the groundwater catchment is considerably larger than the surface catchment area.

5.4.1.3 Issues

The almost unique nature of the fen and its dependence on calcareous groundwater makes it very vulnerable to groundwater fluctuations. The impact of local groundwater abstraction and the potential effect on fen ecology has been a concern for many years. For example, it was concluded by the National Rivers Authority in 1990 that springs and the fen dried up earlier and for longer in 1989 than would have been the case if abstraction for spray irrigation had not taken place. Consequently, in 1992, spray irrigation under licence was banned, although replaced in 1993 (Environment Agency, 2000). Abstraction licenses are held by farmers for irrigation and by Anglia Water Services (AWS) who use a source at North Pickenham for public water supplies. The borehole is 3.9- 4.5km north of the fen.

AWS commissioned an investigation to assess the potential impact of the North Pickenham Chalk groundwater abstraction on the levels of water and the ecology of Great Cressingham Fen. It concluded that there is no measurable impact from abstraction and it could not be connected directly to the deterioration of the fen community (Anglia Water, 2003). If this view were to be accepted then compensation through the AMP4 process would not be available to English Nature for ecological damage to the fen or to farmers who felt AWS activities were detrimentally affecting their agricultural operations. There remain some uncertainties regarding the long-term hydrological impacts of abstractions but vegetation and soil surveys suggest that over the past 18 years abstraction at North Pickenham has had no significant impact on the ecology of the fen. English Nature now has a policy of refusing further abstractions and do not see major conflicts of interest between water management and the effect of groundwater abstractions on spring flows and water table drawdown (Hydrological Services International Ltd, 1998; Environment Agency, 2000; Entec, 2003).

However, the hydrological data indicated the fen exhibits nutrient enrichment, which has brought about observed changes in vegetation. A number of vegetation surveys have been carried out: Wheeler and Shaw (1987); Smart (1992); Wheeler and Shaw (2001a) and

Wheeler and Shaw (2003b). A change in the community vegetation had been attributed to falling water levels from 1985-1992 but, more recently, it has been suggested that the cause is agricultural nutrient enrichment. Wheeler and Shaw (2003b) analysed soil fertility and concentrations of N, P and K. Comparisons of chemical composition were made between 1985 and 2001 and although there were a limited number of samples, a number of observations were made:

- Fertility had increased in most areas.
- Nutrient enrichment had occurred and led to the development of *Phragmites* perhaps caused by surface run off routed through the south drain.
- P concentrations in the soil had doubled between 1985 and 2001.
- Nitrate concentration in the soil had increased threefold in the north area between 1985 and 2001.
- K concentrations in the soil had increased in all samples, especially in the western basin.

5.4.2 Remediation measures

Uncertainty as to the extent of the groundwater catchment makes the development of a realistic management prescription to reduce nutrient levels difficult. This is the case despite the catchment having been subject to intensive hydrological investigation in order to ascertain if water abstraction was causing water table drawdown and drying of the fen. It is relatively easy to determine surface drainage inputs but groundwater pathways are much more difficult to model. Ascertaining a realistic idea as to the extent of groundwater catchments for other basin fens will, no doubt, often be a problem.

Great Cressingham Fen relies on calcareous groundwater aquifers to the north and east but the contribution these make to the total hydrological budget is unclear. It has also been impossible to obtain Phase One Vegetation Survey data for the area. It is for these reasons that the remediation prescriptions are based on the smaller surface water catchment area to the north of the fen. It becomes a much more manageable exercise and if it is assumed that this area is representative, points made can be seen as applicable to the wider region.

Nevertheless, an effective prevention strategy would need to encompass a much more extensive area, even beyond that of the groundwater catchment. The whole region is farmed intensively and the nutrient problem is widespread and endemic. Any long-term mitigation action must tackle the issue at a regional level and this prompts a number of general comments.

- There are no data available concerning water nitrate levels but given the nature of the agriculture it can be assumed to be high. An important option available would be to encourage the comprehensive adoption of policies to reduce nitrates. Much of the area was designated as a Nitrate Vulnerable Zone in December 2002. However, the limits imposed by this are unlikely to have a significant effect on nitrogen application rates (Farmers Weekly, 2004[4]). The key regulations require farmers to:

[4] On 14th May, 2004 (page 8) quoting an Environment Agency spokesman.

- limit the application of nitrogen from organic sources (eg manures) to 210 kg/N/ha (reducing to 170kgN/ha in 2007)
- limit application of inorganic nitrogen to a level consistent with the needs of the growing crop. This level is not precisely defined.

- There is problem of soil loss by wind erosion and enrichment of surface waters directly by nutrients adsorbed to soil particles. This results in chronic aerial deposition of low-level nutrient inputs. There is a need, therefore, to introduce practices to reduce wind-lift throughout the region.
- Regional de-intensification, possibly achieved through set-aside agreements, sensitive N, P and K management and the encouragement of Best Farming Practices could all be instrumental in achieving bio-diversity objectives and reducing nutrient loadings.

A special note is warranted about the assumptions concerning cropping. Farming in this area is best described as being highly flexible. Rotations are not necessarily followed, as cropping from year to year may change in response to market conditions. Opportunities are often available for intermediary crops, and the normal 'rules' of rotation may be disregarded if disease is not apparent. Therefore, it is particularly difficult to produce a typical rotation. Nevertheless, the cropping patterns presented in Table 5.7 are suggested based on wider consultation (Makowiecki, pers. comm.). It is quite likely that this rotation will be deviated from.

It is also assumed that grassland would not be included in such a rotation, as it would not be so profitable as arable. Consequently, it is suggested that the grass is only grown on the Breckland soils, ie non-fen peat. It is also assumed that this is where the outdoor pig enterprise would be located. This is because outdoor pigs need firm, well-drained soil, which would be more likely to correspond with the Breckland soil rather than fen peat. It is assumed that the pigs would occupy the ground for two years before being moved while grassland areas would be used for beef cattle.

The implications of the above for the costings are that:

- the arable and vegetable areas are treated as being part of the same block;
- the arable/vegetation and grassland areas are considered to be separate and non-interchangeable for cropping decisions;
- the fifth year in the rotation is divided equally between carrots, onions and cauliflowers, although, in practice, 'other vegetation' covers a arrange of possibilities;
- output is considered to be 'high' for all crops, as distinct from the Wybunbury Moss and Silver Tarn case studies, where 'average' output levels were assumed within the baseline position, and;
- output from the semi-improved grassland will be 'average' to reflect a lower level of assumed inputs.

It should be noted that most of the crops in the rotation are not supported by the AAPS, the main exception being wheat. Consequently, there is little requirement for land to be set-aside. Given the productivity of this type of land, it is assumed that any set-aside requirement is met from land outside this catchment. However, all the land used to grow these crops will qualify for the Single Farm Payment after the Mid-Term Review reforms have been implemented.

Consequently, it is assumed that these payments can be ignored. The price of sugar beet is supported through subsidy arrangements, which will cease once SFP is fully introduced. This means that the price received for sugar beet will drop; however, this is assumed to have no effect on cropping patterns.

It needs to be recognised that these are fairly bold assumptions made necessary in the absence of other data. To further complicate matters, yields and prices received for many of the crops grown are highly volatile, although usually inversely proportional. Given the eclectic nature of cropping in this part of the world, these assumptions may be found to be inappropriate in some circumstances.

5.4.2.1 Applying the Prevention Model

The surface water catchment area is farmed intensively. The total area, excluding the SSSI is 217.8ha. The largest single land use is classed as arable covering 93.6ha. The next largest is improved grassland at 68.4ha and vegetable crops occupy 23.4ha. Woodland and scrubland together account for 16.5ha and housing, gardens, ponds and other miscellaneous uses add up to 15.9ha.

Action:

Option 1: to remove all arable (93.6ha) and vegetable production (23.4ha) and convert half to semi-improved grassland for livestock (58.5ha) and half for broadleaved deciduous woodland (58.5ha) to add to the patchwork of woodland in the area. Woodland would be managed for timber production.

Baseline position

In order to develop a baseline position against which change can be measured, it is necessary to make assumptions about the gross margin income derived from the current cropping. Using the assumptions on cropping and gross margins, the gross margin income from the 117ha of arable land is as described in Table 5.8, drawn from Nix and others (2003).

Loss of the arable production would mean a reduction in gross margin income of £115,520. It is possible that the reduction in root-crop growing envisaged may release capital in the form of machinery that is surplus to requirements and buildings not needed for storage. Further, working capital needed to establish these types of crop (as indicated by the variable costs) are high, and this will benefit cash flow by reducing working capital demands by some £144,000.

Growing root crops is particularly demanding on machinery, even on easily-worked peat land. Nix and others (2003) suggest that a 200ha+ mixed cropping farm spends around £205/ha on power and machinery costs, whereas a sheep/cattle farm would spend around £135/ha – a saving of £70/ha. Given that costs on woodland are likely to be minimal, the savings on power and machinery costs would be reduced by around £15,200. Similarly, labour costs would be expected to fall, and a reduction of around £20/ha could be expected, giving a total saving of £10,500.

Option 1: Remove all arable and vegetable production and convert to semi-improved grassland for livestock and broadleaved deciduous woodland.

The are a number of possibilities explored related to land conversion, and these are summarised in Box 5.7 and discussed below:

1. Semi-improved grassland for beef production

It is assumed that the semi-improved grassland proposed as a replacement for the arable cropping would be used for rearing store cattle. These would be bought in at three to six months old and sold as finished animals (ie ready for slaughter) at 18 months to two years old. Although there is the potential for the enterprise to be highly productive, it is assumed that a lower level of inputs will be used and so productivity will be nearer the average. Net of forage costs; this would give a gross margin of around £707/ha, excluding subsidy payments. Over the 58.5ha proposed for conversion to semi-improved grassland, this would give a gross margin income of £41,360. If the land is successfully entered into the Countryside Stewardship Scheme, payments of around £280/ha are available for land converted from arable production to grassland. This would attract a further income of £16,380.

The introduction of beef cattle imposes a capital requirement to establish the grassland and purchase the first batch of calves. Variable costs for the beef enterprise amount to around £43,000. Further, on an 18-month system, capital is invested for 1.5 years before the asset is cashed, whereas crops generally run on an annual cycle. Therefore the working capital requirement is around £65,000 (ie £43,000 x 1.5). The grassland will also place a demand for capital (for initial establishment), amounting to around £21,600. If the land is successfully entered into the Countryside Stewardship Scheme, payments of around £250/ha are available for establishing grassland using a native seeds mixture. The net cost of establishment would thus be reduced to around £5,250.

Given that the intensive cropping, albeit over the whole area, needed £144,000 of working capital, a requirement for £70,250 (£65,000 + £5,250) represents a saving of £73,750. But, it is likely that some buildings will be needed to house the beef cattle for some of the winter period. For simplicity, it is assumed that additional buildings will not be needed for housing as those used to store the crops no longer being grown will be capable of housing beef cattle without any significant cost in adaptation. There is, however, likely to be a need for some waste handling facilities and silage storage. If it is assumed that about £50,000 is needed to satisfy this need, the capital required can be provided by the savings in working capital. The balance of £23,750 is assumed to represent a saving in interest payments (at say 7%) of about £1,660/annum.

2. Grassland for rent

Another option is to make the grassland available for rent. This is only likely to be feasible if reasonable demand for the land exists, which may not always be the case in a predominantly arable area. Based on standard data, rental income for a 15-year FBT could realise around £9,125/annum. In addition, there would be major savings in fixed costs of around £25,400 and demand for working capital of £5,040 (half of £144,000 at 7%). Together, these would reduce costs by around £30,440. However, the net effect would be a drop in annual income of around £18,200 ((£115,520/2) – (9,125 + £25,400 + £5,040)). If CSS were included as part of the package, whilst rental income may drop, as the incoming tenant would no doubt argue that his use of the land would be restricted by the CSS management prescriptions, there would be a substantial income to be added.

3. Broadleaved woodland

Establishment of 58.5ha of woodland is a major task as most woodlands on farms are less than 3ha (John Clegg & Co. and others 2002). Yet, many of the benefits of woodland are dependent on woodland being of a sufficiently large scale. As such, it can be assumed that an application under the England Woodland Grant Scheme would be successful. It is also assumed that the woodland creation scheme would be accepted into the Farm Woodland Payment Scheme.

If it is assumed that the EWGS grant is sufficient to meet all the establishment costs, there is no effect on capital requirements. The FWPS would provide annual payments for a period of 15 years for broadleaved planting. Non-LFA land taken from arable production attracts payments of £300/ha under the current scheme. Over the 58.5ha site, this amounts to £17,550/annum.

Whilst the woodland will, in the long-term, produce a saleable crop, this is so far in the future (70+ years for any significant income) that it has been ignored.

4. Biomass Production

The government is keen to promote the growing of energy crops of agricultural land and is offering grants to farmers who decide to make the change. A switch from arable to the bio-fuel crop *Miscanthus* or short rotation coppice will attract a one-off establishment grant of £920 or £1000/ha respectively. The EC will also pay 45 euros (c £32)/ha/year for land released from agriculture for this purpose. However, to be worthwhile, it is vital that the grower has an outlet for the energy crop. Energy crops can be grown on set-aside land.

Contracts are usually arranged through producer groups. Up to now, these have been established mainly on the eastern side of the country. Consequently, energy crops may be a feasible proposition. Also, it seems likely that more outlets will emerge as people respond to these government incentives. If and when market conditions evolve so that the switch becomes feasible, the financial implications would be as follows. Because of the longer timescale involved, the calculation are based on annual average gross margins for a longer period.

Income Lost	Gross margin income lost from the growing of arable crops would be	£115,520/year
Income gained	Gross margin on SRC averaged over six years (based on Nix and others 2003) 117ha x £110	= £12,870/year
OR	Gross margin on *Miscanthus* averaged over 15 years (based on Nix and others 2003) 117ha x £113	= £13,221/year

The net effect on gross margin income of a change to growing energy crops would be a loss of income of £102,650 or £102,300 for *Miscanthus* and SRC respectively. However, in both cases, the one-off establishment grant is deemed sufficient to provide for the establishment costs, and has been taken into account in the gross margin figure. In addition, the net working capital needed would reduce by some £100,000, saving around £7,000/annum in interest charges. Even so, there is a major reduction in gross margin (£95,650 and £95,300 for *Miscanthus* and SRC respectively) and so production of energy crops is unlikely to be a practical option.

5.4.2.2 Applying the Protection Model

The surface water catchment lies to the west and north of the fen and the threat from the groundwater catchment is largely from the north and east. The aim of the Protection Model is to introduce woodland and grassland buffer zone protection. Each option is also summarised in Box 5.8.

Action:

- **Option 1:** extend the existing tree-lined roadside hedge to create a 50m wide buffer zone of mixed woodland incorporating a 5m band of *Phragmites* wetland around the edge of the woodland (Figures 5.9 and 5.10). The outside edge has a key trench to bring water to the surface before entering the *Phragmites* wetland. The trench would also create a narrow zone of wetland on the 'field-side' of the trench. The buffer zone and trench extend along the north-west and north-east perimeter of the fen to the River Wissey. This will provide a wildlife link with the riparian corridor. A total of 6.75ha new woodland and wetland is created.

- **Option 2:** two fields adjoining the fen on the northern edge, which are currently used for arable production, are to be converted to semi-improved grassland with a light-grazing regime (Figure 5.11). This presents an opportunity to create botanically diverse calcareous grassland. 18.12ha of arable land would be lost.

- **Option 3:** to include both options 1 and 2.

Option 1: Introduction of a buffer zone

It is not known what type of land will be lost in the proposed conversion. Firstly, it is assumed that the outdoor pigs will be unaffected, as the areas they use are unlikely to be the lower-lying land. Secondly, it is assumed that the land taken is of the same productive capacity as all the other land. Whether land is lost from the beef or arable enterprises, the change is relatively small and so is unlikely to have a significant effect on fixed costs or capital requirements. Therefore, changes can be considered at the gross margin level alone. Also, it is reasonable to assume that the converted land would be eligible for CSS (wetland) and EWPS-FWP (woodland).

If the land used to create the wetland and the woodland is taken from arable production, then the loss of gross margin income, using the same assumptions as used in the Prevention Model, will be £6,665 (ie 115518/117 x 6.75). If the land taken is from beef production, assuming a level of production similar to that envisaged for the Prevention Model, the loss of gross margin income will be £4,770 (£707 x 6.75).

The 6.75ha of woodland and wetland will not yield any income from production, but should be able to attract incentive payments from FWPS and CSS respectively. Assuming half the land is woodland, and half the land is wetland, these payments could amount to:

3.375ha of woodland at £300	= £1,012.50 (if taken from arable)
or	
3.375ha of woodland at £260	= £877.50 (if taken from imp. grassland)
and	
3.375ha of wetland at £380*	= £1,282.50

* Assumes grant available is £280 for conversion from arable to grassland + £100 for fen

The net effect, therefore, is a net loss of:

£4,370 (£6,665 – (£1,012.50 + £1,282.50)) if taken from arable production;
or
£2,610 (£4,770 – (£877.50 + £1,282.50)) if taken from grassland/beef production.

Option 2: Arable land converted to semi-improved grassland

This option calls for the loss of 18.12ha of arable cropping, to be replaced by an equivalent area of semi-improved grassland. In order to be consistent with the earlier assumptions, it is assumed that this would be used for average output beef production, using an 18-month system. Although the change is more marked than for Option 1 (18.12ha represent 8% of the surface catchment), it is unlikely that such a change would have a significant effect on fixed costs and capital investment, given that the catchment is believed to be only part of a larger holding. Therefore, the changes can be estimated at the gross margin level alone.

The loss of gross margin from the arable cropping would be about £17,900 (£115518/117ha x 18.12ha). The gain in gross margin from beef would be £12,800 (£707 x 18.12ha). If CSS payments are secured, a further £5,100 (£18.12ha x £280/ha) could be obtained. This, too, sums £17,900 (£12,800 + £5,100). It can be assumed, therefore, providing CSS payments are obtained, that Option 2 is budget neutral.

Option 3: A combination of Options 1 and 2

If Options 1 and 2 are combined as Option 3, then the financial effects will be cumulative. This would mean that the combined effect would be a net loss of gross margin income of:

£4,370 if land is taken from arable production;
or
£2,610 if land is taken from grassland/beef production.

This simplistic approach is realistic provided there is no significant effect on fixed costs. The area of land that experiences a change of use represents 11.5% of the surface catchment. If this were the total holding of the farm business, this change could have a significant effect on fixed costs. However, as noted above, it is believed that the catchment forms part of a bigger farm business. Consequently, it is assumed that Option 3 will not bring about any major fixed cost changes.

5.4.2.3 Applying the mixed approach

Action*:*

Option 1: Convert arable fields closest to the north and east of the fen to semi-permanent grassland. This would involve the loss of 57.04ha of arable production. Add a 25m-perimeter buffer zone of mixed woodland including a key trench at the outer margin. This would create 3.38ha of mixed woodland.

The scale of the proposed change (nearly 30% of the surface catchment) is thought likely to affect the fixed cost levels. Therefore, it is preferable to use the estimates prepared for the Prevention Model, but scaled down accordingly, although the major difference is in the amount of woodland created. The results are summarised in Box 5.9.

5.4.3 Conclusions for Great Cressingham Fen

The catchment of Great Cressingham Fen appears to be intensively cropped and evidence suggests it is highly productive agriculturally. The baseline position is therefore one of high inputs and high outputs. Making accurate assessments is, however, confounded by the highly volatile nature of cropping in this area and the gross margins won for these crops. It can be said with reasonable confidence, though, that changes from this baseline position are likely to be highly dramatic in financial and managerial terms. This would certainly be true of all options if no agri-environment/farm woodland grants were secured. If applications for CSS and EWGS-FWP are successful under each of the options, then the Protection Model exerts the least dramatic effect on farming incomes. The Mixed Approach represents a more costly option, whilst the Prevention Model is the most costly.

6. Developing a process to identify appropriate mitigation measures to combat nutrient enrichment of basin fens

6.1 Introduction

This section provides a framework to help identify basin fen nutrient enrichment and select suitable remediation measures. Figure 6.1 is a flow diagram indicating important considerations when applying mitigation strategies. The nature of the problem must be understood if it is to be tackled effectively and the success of any mitigation strategy is likely to depend on the accuracy and relevance of data available. If this is assured the likelihood of success is greatly increased.

6.2 Evaluation of the site

6.2.1 The physical setting: topography, geology and soils

The topography will be a reflection of the geology and the processes of denudation and deposition that have acted to produce the landscape. For example, the meres and mosses of the Shropshire and Cheshire Plains have developed in the kettleholes, hollows and hummocky terrain of glacial deposits. Glacial drift has effectively provided a topographic setting that has encouraged wetland development. Gradients affect water movement in the catchment, whereby steeper slopes are shedding sites and water flow is accelerated. In contrast, flat land arrests water movement. Consequently, the topography exerts an important control on the residency time of water within the fen catchment.

The underlying geology is highly significant. It will affect the background pH and nutrient status of the fen water as well as the inherent fertility and water retention properties of the soil. The hydraulic conductivity is, in part, governed by the porosity and permeability of the rocks. Some are efficient aquifers and are capable of transferring groundwater to sustain water levels. Others are less permeable aquitards, which inhibit groundwater flow and promote surface runoff. An understanding of the geology may give an indication of the likely water delivery mechanisms. Solid geology maps, paper and digitised, are available from the British Geological Survey (BGS) at different scales. It should be remembered that many basin fens are located in areas where glacial drift is widespread. Quaternary covering is not indicated on solid geology maps but the extent of drift, sands and gravels, loess and other glacial and periglacial products are indicated on the BGS Quaternary maps.

The substrate weathers to yield the mineral component of soils. A poorly drained clayey soil will develop on shales and mudstones while freely drained, coarse-grained soil will form on sandstones. Other soils may be a mixture of mineral particles, ranging from fine clays to coarse grits. Not only does the mineral composition influence the hydraulic properties but it also has important implications to nutrient transfers. For example, P adsorbs strongly to soil clay minerals and in a poorly drained catchment, underlain by impermeable clays, the erosion of soil-bound P can result in enrichment. If this is thought to be the case it might suggest mitigation measures, in this instance, to decrease runoff and increase the hydraulic roughness by introducing BZs to promote deposition and reduce sediment transport. In the event of soils being highly permeable wide BZ may be required to retain water and allow time for denitrification and plant uptake to take place. Soil maps are available from the Soil Survey of England and Wales at 1:250 000 for the whole of the UK and at lower scales for some areas.

6.2.2 Fen catchment hydrology

Establishing the hydrological processes that feed a fen and the extent of the surface and groundwater catchment is an important prerequisite to effective remediation. It may, though, be the most formidable of tasks. Although the surface catchment may be relatively easy to determine using a detailed topographic map and a site survey, the delimitation of the groundwater catchment is much more complex and in most cases will require a specialised hydrogeological assessment. Case study 3, Great Cressingham Fen (described in section 5.4) illustrates this point, where the surface and groundwater catchments were found to be significantly different in extent and location. There was also doubt as to the extent of the groundwater area and two contrasting maps were produced when applying different methods and assumptions. If a rigorous hydrological investigation still leaves such uncertainties it suggests that it will be a struggle to confidently outline the hydrology of other fens.

The water supply mechanism forms the basis of the Wetland Framework Classification System (Wheeler and Shaw, 2001) referred to earlier in section 2.4. It serves to remind us of the great variety of situations where nine hydrological units or Wetland Supply Mechanisms (WETMECs) are identified. These typologies may be a useful diagnostic tool and help to understand the hydrological functioning of a fen.

6.2.3 Catchment land use

In order to assess the threat posed by activities within the whole of the fen catchment, sources of information concerning land use are required. Phase 1 Habitat Surveys provide a standardised system for classifying basic habitats and make a number of distinctions that can be used to examine land use. It is primarily concerned with broad habitat types, which would not generally present a nutrient threat. The classification for arable land is generic and includes cropland, horticultural land and recently reseeded grassland. Other grasslands are variously described as unimproved, semi-improved and improved reflecting changing levels of agricultural inputs. The latter category represents pastures heavily affected by the application of fertilisers, slurry and/or high doses of manure. Areas may have been subject to change since the survey was completed but the survey is a very useful tool in assessing potential nutrient hazards. Other data might be obtained directly from local English Nature staff knowledge, farm records, indirectly from public accounts and subsidy applications.

6.2.4 Vegetation types on site

English Nature SSSI citations can provide general vegetation information, as can ENSIS. The length and detail can vary but they always include a site description incorporating flora and fauna. Much information of this type is now collated into the revised FenBASE database. Further information may be available from commissioned reports, journal papers and material gathered to support applications for a change in status eg to be accepted as a Special Area for Conservation (SAC). Initial surveys for notification may be out of date and in need of revision in which case, a review of vegetation may be required. In this instance, local knowledge is important.

6.3 Identification of diffuse nutrient issues

6.3.1 Factors indicating diffuse nutrient enrichment

Changes in the plant community may be a sign of nutrient enrichment. This might be change in species abundance, community composition and variety as well as overall plant productivity. The onset of a eutrophic state may be marked by increases in planktonic algae and water discolouration, dense weed, growth in marginal and emergent plants, a fall in species diversity and an appreciable reduction in invertebrates and fish. Some plant species associated with enrichment are bulrush (*Typha latifolia*), common reed (*Phragmites australis*), water horsetail (*Equisetum fluviatile*) and common nettle (*Urtica dioica*). Dependable long-term floristic records are invaluable and monitoring procedures should be maintained, as some changes may be gradual and difficult to detect over a short time period.

The chemical composition of soils and water may provide evidence of enrichment. For example, tests for soluble P and N compounds may show levels over 'normal' ranges. Fens suffering from eutrophication may also demonstrate low oxygen levels and high Biological Oxygen Demand (BOD). Peat 'fertility', measured by comparing growth rates of a phytometric indicator species, has also been used (Wheeler, 1988, 1990 and 1991; Wheeler and Shaw, 1987), and provides an indication of the relative amounts of bio-available nutrients within the peat substrate.

An examination of the factors mentioned in the site evaluation in conjunction with the catchment land use may give the clearest indication that enrichment is either improbable or likely.

6.3.2 Possible sources of enrichment

Point sources are the easiest to detect and cure. Abatement measures for Sewage Treatment Works (STW) emissions, which used to cause major P and N contamination of rivers, have been very successful. However, the mechanisms of transport and deposition of diffuse pollution are not totally understood and the provenance is difficult to pinpoint. However, there is overwhelming agreement that agriculture is a major factor. Diffuse nutrient enrichment is almost wholly attributable to external sources related to farming. Intensive arable farming, with its reliance on artificial chemical fertilisers, persistently loads soil with nutrients in excess of crop needs. So too, dairy cattle, pigs and poultry feedstuffs can be high in P and animal manure adds to the problem. Some farming activities might be considered as nutrient neutral eg semi-improved pasture with a light grazing regime, while other enterprises may even be nutrient traps eg. managed woodland.

6.4 Identification of constraints in applying mitigation measures

The majority are basin fens are in receipt of water from an area much larger than the extent of the SSSI and land that is most probably privately owned. If there is a cost burden to landowners and farmers when remediation measures are applied they will be reluctant to participate. If this is the case how can they be encouraged, or forced, to participate? The Countryside and Rights of Way Act 2000 (CRoW Act) may help resolve this problem.

It states that it is preferred if a condition of 'positive management' of SSSI sites can be achieved through constructive dialogue and partnership arrangements between English

Nature and landowners. A Management Scheme is prepared by English Nature in consultation with the landowners, which outlines the best ways of managing the land to conserve and restore the SSSI's special features. As well as providing advice and guidance English Nature can assist with costs of introducing conservation management through payments under Management Agreements with the owners. A Management Agreement is where an agreement is made between the owner and English Nature as to the management of the area, including carrying out work. English Nature may make payments as apart of the Management Agreement to compensate for lost income, additional costs incurred and by way of incentive to encourage good practice. Payment can also be made to:

- Provide payment based on a standard habitat payment.
- To secure the management of the land as a nature reserve.
- For the purpose of conserving valuable features, including land management activities outside the SSSI which may be in the interest of the SSSI. However, owners outside the SSSI boundary are not obliged to agree management activities.

The CRoW Act now provides additional powers to protect SSSIs. English Nature has powers to refuse consent for damaging activities, additional powers to enter land, power to serve a Management Notice, which will require the owner to carry out specific work within a specified time. Where there has been a breach of agreement eg where the work has not been completed satisfactorily, English Nature can withhold payments. In addition, there are more flexible powers for the compulsory purchase of land, public bodies now have a statutory duty to attend to the conservation of SSSIs and the penalties for deliberate damage to SSSIs have increased.

The provision that financial support can be given for activities outside the boundary of the SSSI is significant because, for the most part, it is here that the threat from enrichment lies. The Defra Code of Guidance specifies that treating SSSIs as 'isolated pockets' may not address the issues that affect the site. It effectively, invites officers and managers to look beyond the boundaries of the site and provides English Nature with legal powers to enter into voluntary management agreements on land not notified but important in sustaining the features of special interest on the SSSI. This may include agricultural land so that English Nature should consider the management of the SSSIs on a 'whole farm' basis. For wetlands, agreements should examine issues in terms of the hydrological pathways to identify areas within the catchment that are sources of problems. This catchment perspective is essential in the context of the basin fen protection and English Nature has greater powers to reward landowners for introducing better practice and take issue with those who do not comply with reasonable requests.

6.5 Identification of potential mitigation approaches

A comprehensive list of mitigation measures is provided in Table 6.1. Some of them can be used to reduce the impact of both N and P inputs whereas others are more effective at reducing either N or P. A three-tiered rating system is used to give an indication of the potential a remediation measure has for nutrient reduction. It should be remembered that this is a rough guide and should be used to inform general approaches, not prescribe detailed programmes. The rating code is not used with 'Economic Instruments' at the end of Table 6.1 as these relate to indirect ways of achieving reductions by obtaining the funding to implement changes.

When choosing approaches it is useful to bear in mind a few simple but highly relevant rules of thumb. If the problem is essentially one related to N enrichment, any activity that is going to prolong the residency time of water in the catchment before reaching the fen is beneficial. N is carried primarily in solution and N transformation processes operate under anaerobic conditions acquired through waterlogging. If this is found in conjunction with high levels of organic material the potential for denitrification is great. In these circumstances a wetland buffer zone eg carr woodland, would be a particularly appropriate measure. In contrast, P adheres to particulates and measures that promote sedimentation and action to reduce sol loss would be effective. In this case grassland buffer zones, silt traps and cropping regimes that do not expose soils to water erosion would be suitable measures.

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Boxes

Box 5.1 Summary: Financial effect of the different 'Prevention Model' options for Wybunbury Moss, Cheshire

Option		Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Switch to low input arable	6240	4600	-1640	*	Environmental benefits likely to be small
2	Switch to grass					
	a. (i) Hay	14390	9464	-4926	***	Greater potential to reduce fertiliser, and nutrients removed when crop is sold
	a. (ii) Silage	14390	14196	-194	**	Income highly dependent on price for silage - which will vary depending on forage supply generally - but nutrients removed when crop is sold
	b. (i) Annual	14390	13000	-1390	*	Grazing by cattle and sheep, and fertiliser inputs in hands of 3rd party so may be difficult to achieve nutrient reductions
	b. (ii) FBT	14390	15080	690	*	Grazing by cattle and sheep, and fertiliser inputs in hands of 3rd party so may be difficult to achieve nutrient reductions
	c. Low intensity sheep	14390	3380	-11010	**	Major shift in skills required and income loss

Key: * Low ** Medium *** High

Box 5.2 Summary: Financial effect of the different 'Protection Model' options for Wybunbury Moss, Cheshire

	Option	Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Create buffer zone					
	a. Without Farm Woodland Premium Scheme	433	0	-433	***	Small loss of production but large effect on nutrient inputs.
	b. With Farm Woodland Premium Scheme	433	680	247	***	Minimal effect on profitability or nutrient input.
2	Loss of semi-improved grassland					
	a. Mown	812	-115	-927	**	Assumes grass is mown and not removed.
	b. Grazed	812	400	-412	**	Assumes light grazing by cattle and income helps offset losses.

Key: * Low ** Medium *** High

Box 5.3 Summary: Financial effect of the different ''Mixed Approach' options for Wybunbury Moss, Cheshire

	Option	Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Maize to grassland					
	a. (i) Hay	3404	2239	-1165	**	Similar to Prevention Model but at a smaller scale.
	a. (ii) Silage	3404	3358	-46	*	Similar to Prevention Model but at a smaller scale.
	b. (i) Annual	3404	3075	-329	**	Similar to Prevention Model but at a smaller scale.
	b. (ii) FBT	3404	3567	163	**	Similar to Prevention Model but at a smaller scale.
	c. Low intensity sheep	3404	800	-2604	**	Similar to Prevention Model but at a smaller scale.
2	Create buffer zone					
	a. With Farm Woodland Premium Scheme	304	420	116	***	Similar to Prevention Model but at a smaller scale.
	b. Without Farm Woodland Premium Scheme	304	134	-170	***	Similar to Prevention Model but at a smaller scale.

Key: * Low ** Medium *** High

Box 5.4 Summary: Financial effect of the different 'Prevention Model' options for Silver Tarn, Cumbria

Option		Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Switch arable to low intensity sheep					
	a. Without agri-environment scheme	4523	-1199	-5722	***	Change of system would lead to significant reduction in inputs and income.
	b. With agri-environment scheme	4523	2051	-2472	***	Changes of system would lead to significant reduction in inputs and income reduction mitigated by agri-environment payments.

Key: * Low ** Medium *** High

Box 5.5 Summary: Financial effect of the different 'Protection Model' options for Silver Tarn, Cumbria

Option		Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Create buffer zone					
	a. Rent in replacement land	0	-640	-640	***	Area is too small for nutrient applications to be significantly reduced
	b. Buy in lost feed as forage	0	-3000	-3000	***	Area is too small for nutrient applications to be significantly reduced
	c. Buy in lost feed as concentrate	0	-4500	-4500	***	Area is too small for nutrient applications to be significantly reduced

Key: * Low ** Medium *** High

Box 5.6 Summary: Financial effect of the different 'Mixed Approach'+ options for Silver Tarn, Cumbria

+ In this case, Options 1, 2 and 3 are accumulative not either/or

	Option	Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Stopping production from imp grass					
	a. Rent in replacement land	0	-2075	-2075	***	Stopping production leads to significant drops in nutrient inputs, with relatively small effect on income.
	b. Buy in lost feed as forage	0	-9740	-9740	***	Stopping production leads to significant drops in nutrient inputs, but at significant cost.
	c. Buy in lost feed as concentrate	0	-14100	-14100	***	Stopping production leads to significant drops in nutrient inputs, but at considerable reduction in income
2	Reduced inputs to arable	2484	1879	-605	*	Small change in nutrient inputs and income.
3	Reduced inputs to grassland	0	-530	-530	**	Small change in nutrient inputs (but from a higher starting point than arable) and income.

Key: * Low ** Medium *** High

Box 5.7. Summary: Financial effect of the different 'Prevention Model' options for Great Cressingham Fen, Norfolk

	Option	Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Switch from arable to grass and trees+					
	a. (i) Grassland for beef without agri-environment	57760	43020	-14740	**	Assuming low intensity grassland, from high intensity arable, means significant nutrient reduction and fall in income.
	a. (ii) Grassland for beef with agri-environment	57760	64650	6890	**	Assuming low intensity grassland, from high intensity arable, means significant nutrient reduction; agri-environment income means that there could be a net gain in income.
	b. (i) Grassland for rent without agri-environment	57760	39565	-18195	**	Assuming low intensity grassland, from high intensity arable, means potentially significant nutrient reduction (if tenant follows proposed regime) but significant fall in income.
	b. (ii) Grassland for rent with agri-environment	57760	55032.5	-2727.5	**	Assuming low intensity grassland, from high intensity arable, means potentially significant nutrient reduction; agri-environment income reduces the scale of loss.
2	Trees entered to EWGS/FWPS+					
	a Without EWGA/FWPS	57760	0	-57760	***	Large reduction in nutrient input but at a large cost.
	b. With EWGS/FWPS	57760	17550	-40210	***	Large reduction in nutrient input but at a large cost, even after receiving woodland scheme payments.
3	Biomass production					
	a Short rotation coppice	115520	19870	-95650	***	Large reduction in nutrient input but at very large cost.
	b Miscanthus	115520	20221	-95299	***	Large reduction in nutrient input but at very large cost.

Key: + Options 1 and2 are accumulative, whereas there is a choice between Option 1 and 2 or 3
* Low ** Medium *** High

Box 5.8. Summary: financial effect of different 'Protection Model' options for Great Cressingham Fen, Norfolk

	Option	Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Create woodland buffer zone (with FWPS)					
	a. Land taken from arable	6665	2295	-4370	***	Assumes no fertiliser applied.
	b. Land taken from beef enterprise	4770	2160	-2610	***	Assumes no fertiliser applied.
2	Arable switched to semi-improved grass					
	a Without agri-environment	17900	12800	-5100	*	Change in nutrient inputs is relatively small.
	b. With agri-environment	17900	17900	0	*	Change in nutrient inputs is relatively small and agri-environment payments offset reduction in income.
3	Combination of 1 and 2	11435	4455	-6980	**	Something of a halfway house between Options 1 and 2 in nutrient reduction terms, but at greater loss of income.

Key: * Low ** Medium *** High

Box 5.9. Summary: financial effect of the different 'Mixed Approach' options for Great Cressingham Fen, Norfolk

Option		Income (£) Before Remediation	Income(+) or Cost(-) (£) After Remediation	Difference (£)	Nutrient input reduction	Comment
1	Switch some arable grass and create buffer zone	72575	62860	-9715	**	Combination of small and large reductions in fertiliser use at, overall, relatively small change in income.

Key: * Low ** Medium *** High

Tables

Table 2.1. A summary of the effects of eutrophication on aquatic and wetland systems

The effects of eutrophication
Excessive algal growth that may result in oxygen depletion of the hypolimnion.
Low oxygen levels, the result of plant respiration, may lead to the death of invertebrates and fish.
Concentration of particulate matter and increases in zooplankton, bacteria, fungi and detritus.
The growth or decay of benthic mats of macro-algae can also lead to the deoxygenation of sediments.
Microbial population produces organic substances affecting water taste.
Some algae produce toxins eg. genera of blue-green algae such as *Aphanizomen, Nodularia* and *Synechocystis.*
Dense weed growth may reduce fish populations.
Species composition changes, eg from salmonoids to cyprinids.
Emergent and marginal plants provide good habitat for beetles, dragonflies and damsel flies but may also encourage unwanted pests like mosquitoes.
Undesirable aesthetic impacts with increased turbidity, discolouration, unpleasant odours, slimes and foam formation.
Diminishes attractiveness and recreational value.

Table 2.2. Summary of water supply mechanism types (WETMECs)
(Shaw and Wheeler 2000)

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

Table 3.1. Summary of the percent nitrogen removal measured in different vegetated buffer zone widths

Author(s)	Buffer zone width (m)	% N reduction
Osbourne and Kovacic (1993)	16	96
Haycock and Pinay (1994)	16	84
Haycock and Pinay (1994)	20	99
Mander and others (1997)	20	81
Mander and others (1997)	28	80
Hubbard (1997)	30	78
Hanson and others (1994)	31	94
Osbourne and Kovacic (1993)	39	95
Jordan and others (1993)	60	95
Lowrance (1992)	60	94

From Wenger 1999

Table 4.1. Sites listed on ENSIS as Basin Fen / Basin Mire

Region	Site name	Region	Site name
Cumbria	Claife Tarns And Mires	South	Herstmonceux Park
Cumbria	Cropple How Mire	W Mids	Betley Mere
Cumbria	Greendale Mires	W Mids	Brookhouse Moss
Cumbria	Moorthwaite Moss	W Mids	Flaxmere Moss
Cumbria	Newton Reigny Moss	W Mids	Gleads Moss
Cumbria	Tarn Moss	W Mids	Linmer Moss
Cumbria	Temple Sowerby Moss	W Mids	Oakhanger Moss
E Anglia	Cornard Mere, Little Cornard	W Mids	Bomere, Shomere and Betton Pools
Lancs	White Moss	W Mids	Brown Moss
Northumbria	Hart Bog	W Mids	Clarepool Moss
Northumbria	Hell Kettles	W Mids	Hencott Pool
Northumbria	Pike Whin Bog	W Mids	Lin Can Moss
Northumbria	Barelees Pond	W Mids	Betley Mere
Northumbria	Campfield Kettle Hole	W Mids	Coleshill and Bannerly Pools
Northumbria	Ford Moss	W Mids	Stubbers Green Bog
Northumbria	Harbottle Moors	Yorks	Attermire
Northumbria	Newham Fen	Yorks	Newby Moor

Table 4.2. Sites listed as basin fen/mire/wetland on ENSIS or FenBASE which have been excluded from consideration in the current context

***

Region	Site name	Comments
Southern England	Herstmonceux Park	Some artificial ponds with fringing fen vegetation, in a valley context.
East Anglia	Sea Mere, Hingham	Open water with drained grazing marshes.
North West	Biglands Bog	Deep basin, but hydrological regime mainly dominated by beck/flooding.
North West	Cumwhitton Moss	Complicated site! Part ombrotrophic, most cut-over, a beck flows through the site. Drained.
North West	Finglandrigg Woods	Former raised bog - much modified by drainage throughflow. Now mainly woodland.
North West	Greendale Mires	Small '"basins" lie within a general context of a flushed soligenous mire system.
North West	Harnsey Moss	Mainly open water
North West	Orton Moss	Former raised bog - much modified by peat cutting and drainage. Now mainly woodland.
North West	Skelmerghs Tarn	Mainly open water, with marginal carr. (No information regarding status of Otterbank Carr)
North West	Stagmire Moss	Watershed / valley mire
North West	Thornhill Moss	Valley mire
North West	White Moss	Ombrotrophic centre – considered as raised bog.
North East	Austwick and Lawkland Mosses	2 raised bogs, + flushes and valley mire.
North East	Newham Fen	Peat-filled hollow in valley context.
North East	Quarryhouse Moor Ponds	Pools with marginal fen veg.
North East	Scotton and Laughton Forest Ponds	Pools with marginal fen veg.
North East	Swarth Moor	Raised bog
North East	The Carrs	Glacial melt-water channel.
North East	Ford Moss	Raised bog
North East	Harbottle Moors	Lakes, blanket mire and flushes
North East	Hell Kettles	Mainly pools
South Mids	Blackend Spinney Fen	Not SSSI (and now drained). Formerly a permanent seepage basin.
South west	Breney Common	The site "lies in a shallow basin". Wetland areas are apparently created from tin-streaming, and many streams drain across the site. ENSIS gives habitat as wet heath.
South west	Max Bog	Called a spring-fed "valley basin", but not really a basin wetland.
South west	The Moors, Bishop's Waltham	Not really a basin wetland.
West Mids	Betley Mere	Mainly open water, with some fen.
West Mids	Byton and Combe Moors	Old kettle hole in river valley.
West Mids	Coleshill and Bannerly Pools	Mainly open water
West Mids	Danes Moss	Raised bog
West Mids	Norbury Meres	Mainly open water
West Mids	Stubbers Green Bog	Small pool with fringing fen vegetation. (Basin created by mining subsidence)

Region	Site name	Comments
West Mids	Wem Moss (inc. Cadney Moss)	Raised bog
Yorkshire	Attermire	Upland

Table 4.3. Final working site list of basin fens

"Region"	**Site name**
Southern England	Emer Bog
East Anglia	Cornard Mere
East Anglia	Cranberry Rough
East Anglia	East Harling Common
East Anglia	Foulden & Gooderstone Commons
East Anglia	Great Cressingham Fen
East Anglia	Middle Harling Fen
East Anglia	Old Buckenham Fen
East Anglia	Scoulton Mere
East Anglia	Thompson Common
West Midlands	Abbots Moss (South Moss & Shemmy Moss)
West Midlands	Bagmere
West Midlands	Brookhouse Moss
West Midlands	Brownheath Moss
West Midlands	Brown Moss
West Midlands	Chartley Moss
West Midlands	Clarepool Moss
West Midlands	Cranberry Bog
West Midlands	Flaxmere Moss
West Midlands	Forest Camp
West Midlands	Gleads Moss
West Midlands	Hencott Pool
West Midlands	Lin Can Moss
West Midlands	Linmer Moss
West Midlands	Loynton Moss
West Midlands	Morton Pool and Pasture
West Midlands	Oakhanger Moss
West Midlands	Shomere Pool
West Midlands	Shrawardine Pool
West Midlands	Sweat Mere
West Midlands	Wybunbury Moss

"Region"	**Site name**
North East	Barelees Pond
North East	Bingley South Bog
North East	Campfield Kettle Hole
North East	Caw Lough
North East	Hardacre Moss (Newby Moor)
North East	Hart Bog
North East	Pike Whin Bog
North East	Pilmoor
North East	Skipwith Common
North West	Blelham Tarn and Bog
North West	Burney Tarn Mire
"Region"	**Site Name**
North West	Cliburn Moss
North West	Cropple How Mire
North West	Great Candlestick Moss
North West	Great Ludderburn Moss
North West	Hallsenna Moor
North West	Highs Moss (Claife)
North West	Hollas Moss
North West	Low Church Moss
North West	Moorthwaite Moss
North West	Newton Reigny Moss
North West	Nor Moss (Claife)
North West	Outley Mosses
North West	Peat Moss
North West	Silver Tarn
North West	Tarn Moss
North West	Temple Sowerby Moss
North West	Unity Bog
North West	Ustick Moss (Claife)

Table 4.4. Composite SSSIs included in this study

SSSI Name	Region	Basin wetland(s)
Abbots Moss	West Midlands	Abbots Moss (South Moss and Shemmy Moss) Forest Camp (esp. Lily Pond)
Baddesley Common	Southern England	Emer Bog
Bomere, Shomere and Betton Pools	West Midlands	Shomere
Claife Tarns and Mires	North West	Brown Stone Moss? Highs Moss Nors Moss Ustick Moss
East Harling Common	East Anglia	Numerous pingos in various stages of succession
Foulden and Gooderstone Commons	East Anglia	Numerous pingos in various stages of succession
Ludderburn and Candlestick Mires	North West	Great Ludderburn Moss Great Candlestick Moss Peat Moss
Newby Moor	North East	Hardacre Moss (Also includes Sniddle Moss, for which no specific information was available)
Outley Mosses	North West	A complex wetland 'site', including topogenous and soligenous mires.
Roman Wall Escarpments	North East	Caw Lough
Silver Tarn, Hollas and Harnsey Mosses	North West	Silver Tarn (East and West basins) Hollas Moss
Skipwith Common	North East	Numerous depressions in various stages of succession
Subberthwaite, Blawith and Torver Low Commons	North West	Burney Tarn Mire
Thompson Water, Carr and Common	East Anglia	Numerous pingos in various stages of succession

Table 4.5. Area of some basin fens (ranked by size)

Site Name	Region	Area (ha)
Hollas Moss	North West	1.00
Nor Moss (Claife)	North West	1.20
Pike Whin Bog	North East	1.25
Shomere Pool	West Midlands	1.30
Barelees Pond	North East	1.35
Lin Can Moss	West Midlands	1.60
Hart Bog	North East	1.79
Sweat Mere	West Midlands	1.96
Linmer Moss	West Midlands	2.35
Gleads Moss	West Midlands	2.75
Campfield Kettle Hole	North East	2.93
Peat Moss	North West	3.50
Morton Pool and Pasture	West Midlands	3.63
Silver Tarn	North West	4.00
Bingley South Bog	North East	4.30
Brownheath Moss	West Midlands	5.18
Low Church Moss	North West	5.90
Cornard Mere	East Anglia	6.09
Temple Sowerby Moss	North West	6.53
Flaxmere Moss	West Midlands	6.55
Hardacre Moss (Newby Moor)	North East	8.50
Moorthwaite Moss	North West	8.60
Cropple How Mire	North West	9.34
Brookhouse Moss	West Midlands	9.96
Unity Bog	North West	10.10
Hencott Pool	West Midlands	11.88
Middle Harling Fen	East Anglia	12.70
Newton Reigny Moss	North West	13.30
Oakhanger Moss	West Midlands	13.59
Great Cressingham Fen	East Anglia	13.69
Loynton Moss	West Midlands	13.80
East Harling Common	East Anglia	14.90
Clarepool Moss	West Midlands	15.62
Tarn Moss	North West	16.80
Shrawardine Pool	West Midlands	17.89
Wybunbury Moss	West Midlands	22.97
Caw Lough	North East	30.00
Hallsenna Moor	North West	31.23
Outley Mosses	North West	33.74
Scoulton Mere	East Anglia	34.06
Old Buckenham Fen	East Anglia	34.80
Cliburn Moss	North West	36.60
Cranberry Rough	East Anglia	81.85

Table 4.6. Area of some Basin Fens (ranked by size category)

Site Name	Region	Size category*
Barelees Pond	North East	1
Bingley South Bog	North East	1
Campfield Kettle Hole	North East	1
Hart Bog	North East	1
Pike Whin Bog	North East	1
Burney Tarn Mire	North West	1
Hollas Moss	North West	1
Nor Moss (Claife)	North West	1
Peat Moss	North West	1
Silver Tarn	North West	1
Gleads Moss	West Midlands	1
Lin Can Moss	West Midlands	1
Linmer Moss	West Midlands	1
Morton Pool and Pasture	West Midlands	1
Shomere Pool	West Midlands	1
Sweat Mere	West Midlands	1
Cornard Mere	East Anglia	2
East Harling Common	East Anglia	2
Great Cressingham Fen	East Anglia	2
Middle Harling Fen	East Anglia	2
Hardacre Moss (Newby Moor)	North East	2
Blelham Tarn and Bog	North West	2
Cropple How Mire	North West	2
Highs Moss (Claife)	North West	2
Low Church Moss	North West	2
Moorthwaite Moss	North West	2
Newton Reigny Moss	North West	2
Tarn Moss	North West	2
Temple Sowerby Moss	North West	2
Unity Bog	North West	2
Ustick Moss (Claife)	North West	2
Emer Bog (Baddesley Common)	Southern England	2
Bagmere	West Midlands	2
Black Firs and Cranberry Bog	West Midlands	2
Brookhouse Moss	West Midlands	2
Brownheath Moss	West Midlands	2
Clarepool Moss	West Midlands	2
Flaxmere Moss	West Midlands	2

Site Name	Region	Size category*
Hencott Pool	West Midlands	2
Loynton Moss	West Midlands	2
Oakhanger Moss	West Midlands	2
Shrawardine Pool	West Midlands	2
Old Buckenham Fen	East Anglia	3
Scoulton Mere	East Anglia	3
Caw Lough	North East	3
Pilmoor	North East	3
Cliburn Moss	North West	3
Hallsenna Moor	North West	3
Outley Mosses	North West	3
Abbots Moss (South Moss & Shemmy Moss)	West Midlands	3
Brown Moss	West Midlands	3
Wybunbury Moss	West Midlands	3
Chartley Moss	West Midlands	4
Cranberry Rough	East Anglia	5
Foulden & Gooderstone Commons**	East Anglia	5
Thompson Common**	East Anglia	5
Skipwith Common**	North East	5

* 1 = < 5 ha; 2 = 5 – 20 ha ; 3 = 20 – 40 ha; 4 = 40 – 80 ha; 5 = > 80 ha.
** sites made up of many small, wet depressions. Area of wetland not precisely known.

Table 4.7. Range of annual precipitation and potential evapotranspiration

Annual average (mm)	Precipitation (number of sites)	Potential evapotranspiration (number of sites)
<400		1
400–499		4
500–599	4	13
600-699	9	8
700-799	15	
800-899	5	
900–999	3	
>1000	3	

Table 4.8. Vegetation Types (NVC) recorded from Basin Wetlands
Records taken from FenBASE

NVC code	NVC name	No. of sites
S27	*Carex rostrata – Potentilla palustris* fen	19
M23	*Juncus effusus / acutiflorus – Galium palustre* rush pasture	15
M09	*Carex rostrata – Calliergon cuspidatum* mire	13
S09	*Carex rostrata* swamp	12
M02	*Sphagnum cuspidatum/recurvum* bog pool	11
M25	*Molinia caerulea – Potentilla erecta* mire	11
M05	*Carex rostrata – Sphagnum squarrosum* mire	10
W04	*Betula pubescens – Molinia caerulea* woodland	10
M06	*Carex echinata–Sphagnum recurvum/auriculatum* mire	9
M18	*Erica tetralix – Sphagnum papillosum* raised & blanket mire	9
M22	*Juncus subnodulosus – Cirsium palustre* fen meadow	9
W05	*Alnus glutinosa – Carex paniculata* woodland	9
M21	*Narthecium ossifragum – Sphagnum papillosum* valley mire	8
S12	*Typha latifolia* swamp	8
M04	*Carex rostrata – Sphagnum recurvum* mire	7
M15	*Scirpus cespitosus – Erica tetralix* wet heath	7
S01	*Carex elata* sedge swamp	7
S04	*Phragmites australis* swamp & reed–beds	7
S28	*Phalaris arundinacea* fen	7
M01	*Sphagnum auriculatum* bog pool	6
S03	*Carex paniculata* sedge swamp	6
M00	Unclassified	5
M13	*Schoenus nigricans – Juncus subnodulosus* mire	5
S02	*Cladium mariscus* sedge swamp	5
S25	*Phragmites australis – Eupatorium cannabinum* fen	5
S26	*Phragmites australis – Urtica dioica* fen	5
M10	*Carex dioica –Pinguicula vulgaris* mire	4
M16	*Erica tetralix – Sphagnum compactum* wet heath	4
M27	*Filipendula ulmaria – Angelica sylvestris* mire	4
M30	Vegetation of seasonally inundated habitats	4
S10	*Equisetum fluviatile* swamp	4
W01	*Salix cinerea – Galium palustre* woodland	4
M24	*Molinia caerulea – Cirsium dissectum* fen meadow	3
S05	*Glyceria maxima* swamp	3
S14	*Sparganium erectum* swamp	3
S24	*Phragmites australis – Peucedanum palustre* fen	3

NVC code	NVC name	No. of sites
W02	*Salix cinerea – Betula pubescens – Phragmites australis* woodland	3
W06	*Alnus glutinosa – Urtica dioica* woodland	3
A07	*Nymphaea alba* community	2
A24	*Juncus bulbosus* community	2
M19	*Calluna vulgaris – Eriophorum vaginatum* blanket mire	2
M29	*Hypericum elodes – Potamogeton polygonifolius* soakaway	2
S06	*Carex riparia* swamp	2
S07	*Carex acutiformis* swamp	2
S20	*Scirpus lacustris* ssp. *tabernaemontani* swamp	2
W03	*Salix pentandra – Carex rostrata* woodland	2
A22	*Littorella uniflora – Lobelia dortmanna* community	1
CMt	*Cladio-Molinietum* typicum	1
M35	*Ranunculus omiophyllus – Montia fontana* rill	1
S08	*Scirpus lacustris* ssp *lacustris* swamp	1
S11	*Carex vesicaria* swamp	1
S13	*Typha angustifolia* swamp	1
S19	*Eleocharis palustris* swamp	1
S22	*Glyceria fluitans* swamp	1
W07	*Alnus glutinosa – Fraxinus excelsior – Lysimachia nemorum* wood	1
W10	*Quercus robur – Pteridium – Rubus fruticosus* woodland.	1
W11	*Quercus petraea – Betula pubescens – Oxalis* woodland	1

Table 4.9. Uncommon wetland plant species recorded from Basin Fens.

Records taken from FenBASE

Species name	Site name	Vice county
Andromeda polifolia	Abbots Moss (South Moss & Shemmy Moss)	Cheshire
	Brookhouse Moss	Cheshire
	Chartley Moss	Staffordshire
	Clarepool Moss	Shropshire
	Flaxmere Moss	Cheshire
	Great Ludderburn Moss	Westmorland
	Moorthwaite Moss	Cumberland
	Newton Reigny Moss	Cumberland
	Peat Moss	Westmorland
	Tarn Moss	Cumberland
	Wybunbury Moss	Cheshire
Blysmus compressus	Thompson Common	Norfolk West
Calamagrostis canescens	Bagmere	Cheshire
	Chartley Moss	Staffordshire
	Hencott Pool	Shropshire
	Scoulton Mere	Norfolk West
Calamagrostis stricta	Cranberry Rough	Norfolk West
Calliergon giganteum	Cliburn Moss	Westmorland
	Thompson Common	Norfolk West
Calliergon sarmentosum	Burney Tarn Mire	Westmorland
Campylium elodes	Newton Reigny Moss	Cumberland
	Silver Tarn	Cumberland
Carex acuta	Hart Bog	Durham
	Pike Whin Bog	Durham
Carex appropinquata	Cranberry Rough	Norfolk West
	Middle Harling Fen	Norfolk West
	Thompson Common	Norfolk West
Carex aquatilis	Outley Mosses	Westmorland
Carex diandra	Cliburn Moss	Westmorland
	Great Cressingham Fen	Norfolk West
	Newton Reigny Moss	Cumberland
	Temple Sowerby Moss	Westmorland
	Thompson Common	Norfolk West
Carex dioica	Great Candlestick Moss	Westmorland
	Nor Moss (Claife)	Westmorland
	Outley Mosses	Westmorland

Species name	Site name	Vice county
Carex elata	Blelham Tarn and Bog	Westmorland
	Cornard Mere	Suffolk West
	East Harling Common	Norfolk West
	Great Cressingham Fen	Norfolk West
	Hencott Pool	Shropshire
	Middle Harling Fen	Norfolk West
	Scoulton Mere	Norfolk West
	Thompson Common	Norfolk West
Carex elongata	Brownheath Moss	Shropshire
	Hencott Pool	Shropshire
	Loynton Moss	Staffordshire
Carex lasiocarpa	Cliburn Moss	Westmorland
	Lin Can Moss	Shropshire
	Middle Harling Fen	Norfolk West
	Newton Reigny Moss	Cumberland
	Thompson Common	Norfolk West
Carex limosa	Clarepool Moss	Shropshire
	Cliburn Moss	Westmorland
	Hardacre Moss (Newby Moor)	Yorkshire Mid West
	Silver Tarn	Cumberland
	Tarn Moss	Cumberland
	Wybunbury Moss	Cheshire
Cicuta virosa	Black Firs and Cranberry Bog	Staffordshire
	Cranberry Rough	Norfolk West
	Hencott Pool	Shropshire
	Loynton Moss	Staffordshire
	Scoulton Mere	Norfolk West
	Shrawardine Pool	Shropshire
Cladium mariscus	East Harling Common	Norfolk West
	Gleads Moss	Cheshire
	Middle Harling Fen	Norfolk West
	Newton Reigny Moss	Cumberland
	Silver Tarn	Cumberland
	Thompson Common	Norfolk West
	Wybunbury Moss	Cheshire
Dactylorhiza praetermissa	Cornard Mere	Suffolk West
	East Harling Common	Norfolk West
	Emer Bog (Baddesley Common)	Hampshire South
	Middle Harling Fen	Norfolk West
Dactylorhiza purpurella	Outley Mosses	Westmorland
	Temple Sowerby Moss	Westmorland

Species name	Site name	Vice county
Dicranum undulatum	Clarepool Moss	Shropshire
Drosera intermedia	Burney Tarn Mire	Westmorland
	Great Ludderburn Moss	Westmorland
	Nor Moss (Claife)	Westmorland
Drosera longifolia	Abbots Moss (South Moss & Shemmy Moss)	Cheshire
	Nor Moss (Claife)	Westmorland
Dryopteris cristata	Scoulton Mere	Norfolk West
Eleocharis multicaulis	Burney Tarn Mire	Westmorland
	Great Candlestick Moss	Westmorland
	Outley Mosses	Westmorland
Eleocharis quinqueflora	Burney Tarn Mire	Westmorland
	Outley Mosses	Westmorland
Epipactis palustris	East Harling Common	Norfolk West
	Great Cressingham Fen	Norfolk West
	Middle Harling Fen	Norfolk West
	Thompson Common	Norfolk West
Eriophorum latifolium	Caw Lough	Northumberland South
	Great Cressingham Fen	Norfolk West
	Temple Sowerby Moss	Westmorland
Juncus subnodulosus	Cornard Mere	Suffolk West
	East Harling Common	Norfolk West
	Great Cressingham Fen	Norfolk West
	Middle Harling Fen	Norfolk West
	Thompson Common	Norfolk West
Myrica gale	Blelham Tarn and Bog	Westmorland
	Cliburn Moss	Westmorland
	Great Ludderburn Moss	Westmorland
	Hardacre Moss (Newby Moor)	Yorkshire Mid West
	Loynton Moss	Staffordshire
	Peat Moss	Westmorland
Oenanthe lachenalii	Silver Tarn	Cumberland
Osmunda regalis	Black Firs and Cranberry Bog	Staffordshire
	Clarepool Moss	Shropshire
	Cranberry Rough	Norfolk West
	Cropple How Mire	Cumberland
	Hallsenna Moor	Cumberland
	Low Church Moss	Cumberland
	Nor Moss (Claife)	Westmorland
	Shomere Pool	Shropshire
	Shrawardine Pool	Shropshire
	Silver Tarn	Cumberland

Species name	Site name	Vice county
Parnassia palustris	Caw Lough	Northumberland South
	Temple Sowerby Moss	Westmorland
	Thompson Common	Norfolk West
Peucedanum palustre	Cranberry Rough	Norfolk West
Plagiomnium elatum	Great Cressingham Fen	Norfolk West
Ranunculus lingua	Bagmere	Cheshire
	Gleads Moss	Cheshire
	Hart Bog	Durham
	Hencott Pool	Shropshire
	Newton Reigny Moss	Cumberland
	Pike Whin Bog	Durham
	Temple Sowerby Moss	Westmorland
	Thompson Common	Norfolk West
Rhynchospora alba	Abbots Moss (South Moss & Shemmy Moss)	Cheshire
	Black Firs and Cranberry Bog	Staffordshire
	Burney Tarn Mire	Westmorland
	Cropple How Mire	Cumberland
	Forest Camp	Cheshire
	Moorthwaite Moss	Cumberland
	Nor Moss (Claife)	Westmorland
	Peat Moss	Westmorland
	Wybunbury Moss	Cheshire
Salix phylicifolia	Newton Reigny Moss	Cumberland
Schoenus nigricans	East Harling Common	Norfolk West
	Great Cressingham Fen	Norfolk West
	Newton Reigny Moss	Cumberland
	Silver Tarn	Cumberland
	Thompson Common	Norfolk West
Selaginella selaginoides	Burney Tarn Mire	Westmorland
Sium latifolium	Great Cressingham Fen	Norfolk West
Sparganium natans	Brown Moss	Shropshire
	Thompson Common	Norfolk West
Sphagnum contortum	Burney Tarn Mire	Westmorland
	Great Ludderburn Moss	Westmorland
	Outley Mosses	Westmorland
	Temple Sowerby Moss	Westmorland
Sphagnum imbricatum	Cropple How Mire	Cumberland
Sphagnum molle	Hallsenna Moor	Cumberland
Sphagnum subsecundum	Tarn Moss	Cumberland

Species name	Site name	Vice county
Sphagnum teres	Chartley Moss	Staffordshire
	Tarn Moss	Cumberland
	Temple Sowerby Moss	Westmorland
Sphagnum warnstorfii	Great Ludderburn Moss	Westmorland
Stellaria palustris	Great Cressingham Fen	Norfolk West
	Pike Whin Bog	Durham
	Skipwith Common	Yorkshire South East
	Temple Sowerby Moss	Westmorland
	Thompson Common	Norfolk West
Thalictrum flavum	Cornard Mere	Suffolk West
Thelypteris palustris	Cranberry Rough	Norfolk West
	Great Cressingham Fen	Norfolk West
	Linmer Moss	Cheshire
	Morton Pool and Pasture	Shropshire
Utricularia minor	Abbots Moss (South Moss & Shemmy Moss)	Cheshire
	Forest Camp	Cheshire
	Peat Moss	Westmorland
	Tarn Moss	Cumberland
Vaccinium oxycoccos	Abbots Moss (South Moss & Shemmy Moss)	Cheshire
	Black Firs and Cranberry Bog	Staffordshire
	Brookhouse Moss	Cheshire
	Burney Tarn Mire	Westmorland
	Clarepool Moss	Shropshire
	Cranberry Rough	Norfolk West
	Cropple How Mire	Cumberland
	Flaxmere Moss	Cheshire
	Hallsenna Moor	Cumberland
	Hardacre Moss (Newby Moor)	Yorkshire Mid West
	Hollas Moss	Cumberland
	Lin Can Moss	Shropshire
	Moorthwaite Moss	Cumberland
	Oakhanger Moss	Cheshire
	Peat Moss	Westmorland
	Silver Tarn	Cumberland
	Tarn Moss	Cumberland
	Unity Bog	Cumberland

Table 4.10. Summary of condition of Basin Wetlands
(Data from ENSIS or English Nature website)

Condition	No of 'sites'*
Unfavourable declining	13
Unfavourable, no change	12
Unfavourable recovering	17
Part destroyed	2
Favourable	30

* Note that condition status is assigned to individual site units. A unit might include more than one basin mire, or may be part of a site. Where a site has been split into different units, with different conditions, each of the relevant conditions has only been scored once.

Table 4.11. Reasons given on ENSIS for sites/units being in unfavourable condition

Reason	No. of times reason given
Water supply	
Drainage	1
Inappropriate ditch management	1
Water abstraction	3
Flooding	1
Nutrients / pollution etc	
Diffuse pollution	4
Direct pollution	1
Fertiliser use	2
Siltation	2
Agriculture (other)	1
Management	
Undergrazing	5
Overgrazing	4
Tree/woodland management	2
Inappropriate scrub control	11
Inappropriate cutting/mowing	1
Forestry	1
Inappropriate weed control	1
Planning permission	1

Table 4.12. Summary of the options for remediation of basin fen with diffuse nutrient enrichment

Key: Y = option applicable; N = option not applicable; N* = option not applicable due to large site area

Region	County	Site name	Grid ref	Boundary amendment	Protection model	Prevention model
North West England	Cumbria	Blelham Tarn and Bog	NY365005	Y	Y	Y
	Cumbria	Cliburn Moss	NY576256	Y	Y	Y
	Cumbria	Cropple How Mire	SD131975	Y	Y	Y
	Cumbria	Hallsenna Moor	NY066007	Y	Y	Y
	Cumbria	Hollas Moss	NX999070	Y	Y	Y
	Cumbria	Low Church Moss	NY016057	Y	Y	Y
	Cumbria	Moorthwaite Moss	NY511511	Y	Y	Y
	Cumbria	Newton Reigny Moss	NY478309	Y	Y	Y
	Cumbria	Silver Tarn	NX999068	Y	Y	Y
	Cumbria	Tarn Moss	NY400275	N	N	Y
	Cumbria	Temple Sowerby Moss	NY616270	Y	Y	Y
North East England	Northumberland	Barelees Pond	NT872384	Y	Y	Y
	West Yorkshire	Bingley South Bog	SE115386	N	N	Y
	Northumberland	Campfield Kettle Hole	NT862381	Y	Y	Y
	Northumberland	Caw Lough (Roman Wall Loughs)	NY770691	N*	Y	Y
	Cleveland	Hart Bog	NZ452334	Y	Y	Y
	North Yorkshire	Hardacre Moss (Newby Moor)	SD717692	N*	Y	Y
	Durham	Pike Whin Bog	NZ415334	Y	Y	Y
	North Yorkshire	Skipwith Common	SE655373	N*	Y	Y
West Midlands	Cheshire	Abbots Moss (South Moss & Shemmy Moss)	SJ595688	N	N	Y
	Cheshire	Bagmere	SJ795643	Y	Y	Y
	Shropshire	Brownheath Moss	SJ460300	Y	Y	Y
	Shropshire	Brown Moss	SJ562395	Y	Y	Y
	Staffordshire	Chartley Moss	SK027283	Y	Y	Y

Region	County	Site name	Grid ref	Boundary amendment	Protection model	Prevention model
	Shropshire	Clarepool Moss	SJ435343	Y	Y	Y
	Staffordshire	Cranberry Bog (Black Firs and Cranberry Bog)	SJ748501	Y	Y	Y
	Cheshire	Flaxmere Moss	SJ556723	N	N	Y
	Cheshire	Gleads Moss	SJ821685	Y	Y	Y
	Shropshire	Hencott Pool	SJ490160	Y	Y	Y
	Shropshire	Lin Can Moss	SJ375211	Y	Y	Y
	Shropshire	Shrawardine Pool	SJ398162	Y	Y	Y
	Shropshire	Sweat Mere and Crose Mere	SJ438305	Y	Y	Y
	Cheshire	Wybunbury Moss	SJ696503	Y	Y	Y
East Anglia	Suffolk	Cornard Mere, Little Cornard	TL888389	Y	Y	Y
	Norfolk	Great Cressingham Fen	TF848022	Y	Y	Y
	Norfolk	Middle Harling Fen	TL989853	Y	Y	Y
Southern England	Hampshire	Emer Bog, part of Baddesley Common	SU396215	Y	Y	Y

Table 4.13. Summary of main issues affecting basin wetlands

Issue	Definite effect	Possible effect
Land drainage	15	16
Abstraction	0	17
Diffuse pollution	7 (incl. Blelham)	29
Septic tank discharge	1	7
Other nutrient / pollution sources	8	17
Other issues*	10	0
Vegetation management	39	1

* Specific details are given in Appendix II.

Table 5.1. Measures available for reducing agricultural pollution

Nitrogen	Phosphorus
Avoid autumn N fertilizer applications unless there is a definite crop need and ensure that the crop can use the applied N	Reduce stocking rates to reduce manure loadings/ha
Avoid autumn applications of slurries, poultry manures and liquid digested sludges	Restrict livestock access to watercourses
Reduce stocking rates to reduce manure loadings/ha	Reduce P inputs through animal feedstuffs where possible
Restrict livestock access to watercourses	Reduce fertilizer and manure P inputs where possible
Reduce N inputs through animal feedstuffs where possible	Placement of P fertilizer in the soil has potential to reduce inputs because of more efficient use and less vulnerability to surface run-off
Use a reliable N recommendation system that takes account of all N sources	Incorporate manures into soil soon after application
Irrigate drought-prone crops to maximize N use efficiency	In-field and riparian buffer strips (but also need complementary in-field control practices to control run-off)
Maintain green cover over winter (including use of cover crops)	Introduce cropping that accommodates ploughing in the cycle
Split spring N fertilizer applications on soils prone to leaching	Barrier ditch and reed-beds for trapping silt
Restrict manure application rates and timings to safe time windows, also avoiding periods of high rainfall when soils are excessively wet	Restrict manure application rates and timings to safe time windows, also avoiding periods of high rainfall when soils are excessively wet
Introduce riparian buffer strips (but also need complementary in-field control practices to control run-off)	Adopt methods to minimize soil erosion
Avoid liquid manure application on drained cracking soils, especially grassland	Avoid liquid manure application on drained cracking soils, especially grassland

Sources: RPA Ltd 2003; ADAS 2002; Environment Agency 2002.

Table 5.2. Proposed initial woodland creation grant (of EWGS)

	Rate (£/ha) – Broadleaved	Rate (£/ha) - Conifer
Standard, Native and Community woodland categories Woodland establishment	£1800	£1200
Special broadleaved woodland category	£700	N/A
Woodland established within 5 miles of 100,000 people or within the Community and National Forest areas OR Woodland establishment with agreement to provide for public access and where there is an identified need	£500 extra	
Woodland establishment meeting both of the above criteria	£1000 extra	

Table 5.3. Current payments under FWPS

Agricultural land category	Non-LFA £/ha/year	LFA(DA) £/ha/year	LFA(SDA) £/ha/year
Arable land	£300	£230	£160
Other improved land	£260	£200	£140
Unimproved land	Ineligible	£60	£60

Table 5.4. Farming practice in surrounding fields in 1989 at Silver Tarn, Cumbria

		Field 1		Field 2	Field 3
Land use	1989	Arable		Permanent grass: grazed and mown	Permanent grass: grazed and mown
	Pre-1989	Potatoes		Barley	Potatoes & Barley
Fertilisers	N	40 ('89)	130 ('88)	155 3x/year (& 2 tonnes mag. lime)	148 3x applications/ season
	P	20 ('89)	130 ('88)	55 3x/year	45 3x applications/ season
	K	20 ('89)	200 ('88)	55 3x/year	45 3x applications/ season
Drainage		Partly drained directly to fen		Partly drained	Field well drained
Farm Management	1989	Cattle and sheep grazed		Cattle and sheep grazed	Cattle and sheep grazed and mown for hay, one cut silage
	Pre-1989	Cattle and sheep grazed and mown for hay. After 2nd cut silage		Cattle and sheep grazed and mown for hay, and barley	Cattle and sheep grazed and mown for hay, two cut silage

Table 5.5. Estimated change in nutrients applied to fields* adjacent to Silver Tarn, Cumbria

Nutrient	Current (kg)	Proposed (kg)	Reduction (kg)
N	1656	1294	-362
P	787	311	-476
K	890	238	-652

*Applied to 10.35ha

Table 5.6. Levels of fertiliser applications 1986 in fields adjacent to Great Cressingham Fen (supplied by Scott Pickerham Estates)

Field number	Land use	Fertiliser Applications		
		N	P	K
1	Cattle grazed	Area within the SSSI		
2	Cattle grazed			
3	Pasture	200 N units/acre/year		
4	Sugar beet & rotation grass	100	40	300
		10 tonnes/acre of manure		
5	Rye	90	35	65
6	Rye	90	35	65
7	Maize	120	50	50
8	Barley	120	40	40

Table 5.7. Assumed 'Typical' crop rotation on Fenland soils applied to Great Cressingham Fen, Norfolk

Year	Crop
1	Potatoes
2	Wheat
3	Sugar Beet
3	Wheat
5	Carrots/onions/other veg

Table 5.8. Gross margin income from arable for Great Cressingham Fen

Crop	Area (ha)	Gross margin	Total
Wheat	46.8	510	23868
Potatoes	23.4	1225	28665
Sugar Beet	23.4	1550	36270
Carrots	7.8	1500	11700
Onions	7.8	1075	8385
Cauliflower	7.8	850	6630
Total	**117**		**115518**

Table 6.1. A summary: potential mitigation methods for nutrient enrichment

Key Possible reductions in N or P: * = low; ** = medium; *** = high; ? = Difficult to assess

Method	Comments
Farming restructuring	
Change from arable to permanent grassland P*** N***	Permanent grassland provides good year round grass cover and reduction in soil erosion and P loss. With appropriate stocking levels and manure spreading practices should see reduction in P and N loss. May remove good arable land out of production. Not a practical measure where the farm is all-arable, as grass will have no place in its system, and the cost and management implications of introducing livestock will be prohibitive. Now accepted that feed from grass is more expensive than feed from arable/forage crops. However, this is a more acceptable measure in that it requires a marginal change rather than a system change.
Organic farming P**? N**?	No agrochemicals, pesticides and low stocking levels should lead to a reduction in diffuse pollution. Environmentally-friendly farm landscape. Effect on N loss uncertain as organic arable exploits organic N in manures. Crisis in confidence as to longer-term viability.
Control over crop type P*? N***	Avoid crops needing high inputs of pesticides and/or fertilisers. Loss of income if abandoned.
Genetically modified crops P? N?	Prospect of engineered pest resistant crops. One leading GM strategy is to produce glyphosate (Roundup) resistant crops – so that environmentally-damaging and costly pesticides can be dropped in favour of glyphosate, which is cheap and less damaging. Controversial and licensing yet to occur. Possible reductions or increases in pesticides and fertilisers.
De-intensification P*** N***	Can reduce surpluses – money available to farmers if adopted. CAP reform is expected to encourage de-intensification.
Maintaining winter ground cover and strip farming P*** N*?	Conventional tillage makes soils vulnerable to soil erosion. Strip farming useful in area where free-draining soils. Potential with no-tillage or minimal tillage ('mintill') methods. Winter wheat and other crops require autumn ground preparation.
Livestock management	
Change feed composition P*** N*?	Feed for poultry, pigs and dairy cattle affects level of P and N in wastes. Great deal of research completed and demonstrated as successful approach. Further gains will arise as technology advances. Because margins are tight and the feed costs are such a high proportion of production costs, any opportunities are already being exploited by most farmers so that potential gains in this area are likely to be low.

Method	Comments
Manure management	
Application rates and timing P*** N***	Manures provide a means of recycling valuable organic material and N. Needs careful management eg best to cultivate the land immediately following spreading and avoid autumn and winter applications. Exporting manure to areas of deficit may be possible provided issues of biosecurity risk and public nuisance can be addressed. Important to establish 'critical' values when leaching begins to occur. Rates that may be appropriate in terms of N loss may not be correct for P loss. Adoption of single recommended levels difficulty because it is dependent on a range of factors. Many farmers do not make sufficient allowance for nutrients in manure when calculating what needs to be added in the form of artificial fertiliser
Manure treatment P*** N**	Good potential if adopted more widely. Composting inactivates pathogens provided sufficiently high temperatures. Treatment reduces NH_3 volatilisation; reduces P solubility and dissolved P, metals and hormones. Leachate losses relatively low. Pelletization reduces bulk for transport; provides fertilizer and feedstuffs. Bioenergy using manures under utilized and great potential. At present, farm manures are outside the framework of controlled waste. This means that it can be carried around without an audit trail or cost (other than transport costs); if it comes under the waste management regulatory framework, then there may be a need for licensing and audit trails.
Ensure sufficient storage capacity P*** N**	Needed to store until most appropriate spreading period. High capital costs. Structural integrity of the structures in doubt because of under-investment in maintenance over last 10 years.
Soil incorporation of manures P** N**	Reduction in ammonia losses and can be implemented with existing technologies and farm equipment. Immediate incorporation preferred by ploughing or injection. May increase levels of pathogens.
Soil management	
Use of appropriate cultivation methods for good soil structure P*** N***	Good soil structure is the product of good soil management – practicing soil conservation methods, adopting BFPs and sustainable methods.
Minimal cultivation P** N**	Minimal cultivation and fallow improves soil fertility. CAP reform still has a set-aside requirement. Reduction/loss of production and reduction in N mineralisation.

Method	Comments
Contour cultivation P*** N**	Part of sensible land management – reduction in surface runoff and flood risk.
Use of chemical soil stabilizers P*?	Reduction in soil erosion. Not always applicable to cultivated land because of contamination. Better if use biodegradable mulching in conjunction with vegetation establishment.
Minimise field drainage flow P* N***	May reduce subsurface loss. Lead to reduction in subsurface loss but encourage overland flow. May cause waterlogging. Not likely to find favour with farmers. Costs to farmer could be considerable in dealing with ensuing problems.
Absorbent drain and ditch-fill P*** N**	Used with some success with stripping P in aquatic systems eg constructed wetlands Not widely tested. Infill absorbent material needs periodic replacement.
Soil dressings ?	Potential yet to be demonstrated.
Crop inputs management	
Nutrient management planning P*** N***	Important to establish correct fertiliser application rates but need reliable means to test levels of excess nutrients and not just shortfalls. There are several computer models available to farmers to do this eg MANNER for N and PLANET for P. No simple relationships between N applications and leaching loss. Nevertheless, some things understood – N losses increase with increases in fertilizers; cultivation in autumn releases N; application of N fertilizers are safer in the spring; applications should not be made during heavy rain and when the ground is saturated.
Precision Farming P** N**	Use of GPS and yield mapping to provide a closer link between crop demands and input supply, thus reducing surplus inputs of nutrients and chemicals. Additional equipment requirement and operator competence in correct use.
Farm machinery management	
Appropriate application equipment P*	For example, nozzles to reduce spray loss; properly maintained machinery so that spreading is as intended ie uniform; vehicles should not compact ground and encourage overland flow.
Operator training P* N*	Operators should be competent and aware of environmental implications of their action. Additional training requirement.

Method	**Comments**
Farmland management	
Buffer zones	
Buffer zones (creation and maintenance of existing) P*** N***	Tried and tested means of nutrient reduction. Still some contention as to how to determine what is the appropriate width in any given situation.
Managed woodlands P*** N***	Can be used as part of a buffer zone. Poles/lumber can be sold as biofuels. Trees remove metals as well as nutrients. Under-managed woodland is a feature of many farms, so anything involving trees has to be a low-labour requirement if it is to work.
Scrubland development P*** N***	Can act to deter trespassing; create habitat; left to develop naturally if farmland decommissioned. Removes land from production.
Mixed woodland and grassland P*** N***	Considered best approach by some. A mosaic or zonation has been shown to be effective at P and N removal.
Vegetative barrier strips eg grass P*** N***	Cheap to establish. Thin strips of just a few metres shown capable of reducing surface runoff and encouraging sedimentation.
Hedgerow creation and maintenance P*** N***	Good dry buffer zones. Reduces wind erosion. Important component of ecosystem - wildlife corridors and stepping-stones.
Riparian buffer zones along fen feeder streams P*** N***	Streams and ditches may pass through buffer zones unaffected. Fen protection must ensure that feeder streams are buffered otherwise a vegetated fen margin will have little positive effect. May involve planting. Loss of productive land.
Hydrological management	
Wetland creation and maintenance P** N***	Wetlands important as areas of denitrification. Existing wetlands should be guarded and opportunities sought for wetland habitat creation. At odds with traditional view where seen as a problem requiring drainage.
Constructed reedbeds P*** N***	Known to be effective at nutrient stripping. Problem of reed and willow species out-competing fen species. Best if established in conjunction with the farming operation rather than on the fen site.

Method	Comments
Vegetated ditch systems P*** N***	Ditches are common features of the British landscape. Can be used to impede flow and vegetated to encourage nutrient removal. Great unutilised potential. Costs in creating new ditches and long-term maintenance commitment.
'Horseshoe' wetlands P** N**	May be used within existing buffer zones at surface and subsurface drainage entry points. Creation within fen margins may be difficult without disturbance of existing habitat.
Dispersal and baffling to disperse stream flow P** N**	Method to encourage infiltration. Relatively easy to install control structures. Opportunities for implementation may be limited.
Reduction in watercourse management P**? N**?	This reduces sediment disturbance and the loss of fast-growing macrophytes. May cause flooding problem and impede effectiveness of field drainage
Footslope discharge areas P? N***	Naturally wet ground can be useful in N reduction. Needs to be integrated into drainage system to be most effective.
Soil removal and dredging operations P***?	Has been tried with some success in the Norfolk Broads where the P levels were excessive and sediments were long-term source of P. Need not effect farm operation. Radical and expensive intervention not likely to be useful method for basin fens. Major disturbance to fen habitat and difficulty in identifying disposal sites.
Blocking of drains and drainage impeding P**? N**?	May reduce subsurface but increase overland flow. Much depends on which is the biggest issue. Possibility of exchanging one problem for another.
Key trenching P*** N***	Cheap to install and maintain. A narrow clay-filled trench is positioned, often at the edge of a vegetated buffer zone, to bring groundwater to the surface. The impermeable clay forces the water to rise and forms an additional wet buffer.
Grassed waterways and Overland flow zones P** N**	Grassed waterways control erosion and drain storm water and outlets for the concentrated water coming from terraces, diversions, or adjacent farmland. Grassed parabolic waterways – small flows of water are not as likely to meander in parabolic waterways. Cost of introduction and loss of production.

Method	Comments
Establish 'No Nutrient Zones' near to watercourses P*** N***	Prevent manure and fertiliser applications within an agreed distance from streams feeding fens. Loss of production.
Landscape management	
Swales and berms P** N**	These are surface features introduced into a landscape to control surface flow patterns and encourage infiltration. Both are earth mounds located usually between areas of the same elevation. Cost of introduction and loss of production.
Construction of sediment ponds P*** N*	Important to reduce silt movement. Cost of introduction and maintenance.
Fencing P* N?	Reduce livestock damage to plants, trespassing and erosion of fen margins and feeder streams by poaching. Tool to direct visitors and avoid sensitive areas of fen. Cost and can be difficult on common land.
Provide bridges for stream crossings P* N?	Will protect riparian margin from poaching damage. Cost of building bridges.
Walkways P* N?	Walkways can be helpful in reducing poaching by dairy herds and runoff into watercourses.
Economic Instruments (based on Oxera, 2003)	
Information instruments	Examples: Training and education Demonstration farms Decision tools Information technology training Product labelling schemes Publication of performance indicators Benchmarking Facilitation of information exchange Teaching measuring and monitoring methods CoGAP
Voluntary instruments	Examples: Quality assurance schemes Voluntary pollution or environmental management standards Agreements between water companies, nature conservation organisation and farmers

Method	**Comments**
Regulatory instruments	Examples: Expand NVZs and probably apply to other pollutants Establish and expand Water Protection Zones Extend IPPC to smaller farms Apply SAFFO to existing facilities Require evidence of beneficial use of manures/slurries Licensing pesticide use Quotas Cross-compliance Requirement to prepare codes and guidance
Economic instruments	Examples: Agri-environment schemes under Pillar II of CAP Capital grants Deposit/refund schemes Taxes on inputs Tradable quotas Charges and levies Charges on excess nutrients

Figures

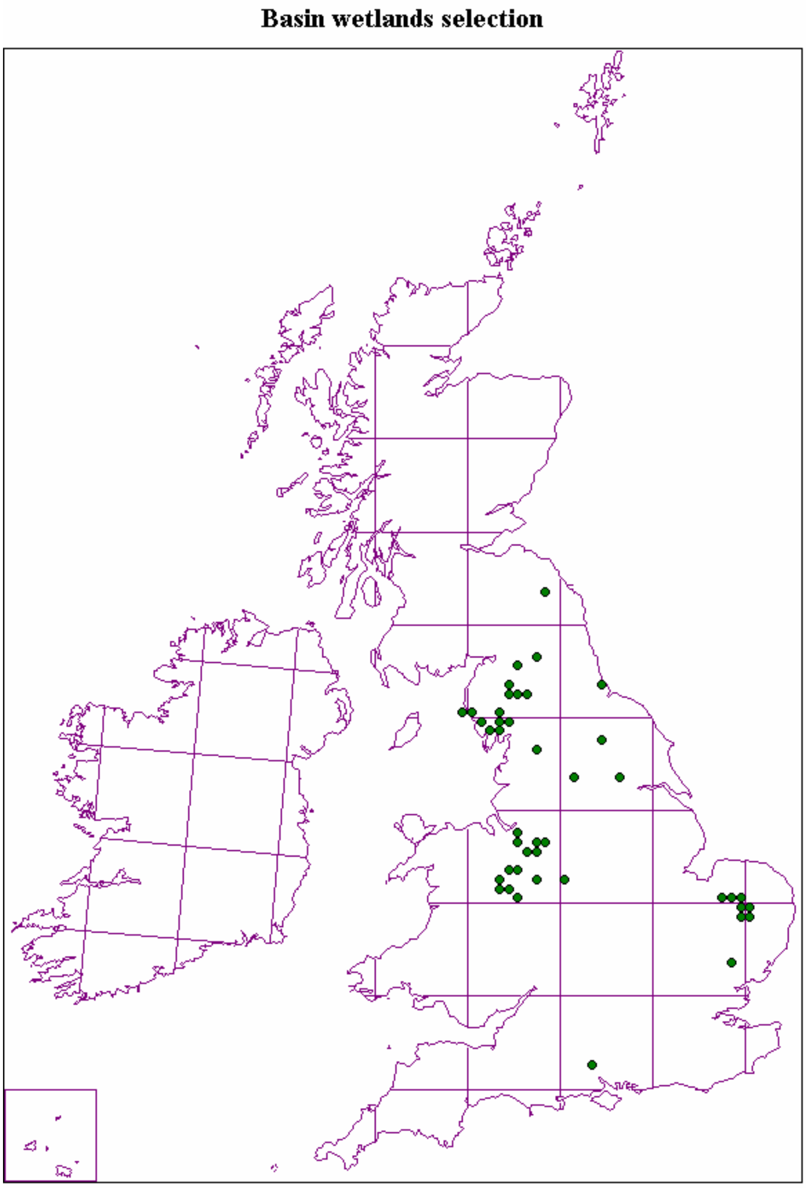

Figure 4.1. Distribution of the basin fen sites included in the current review.

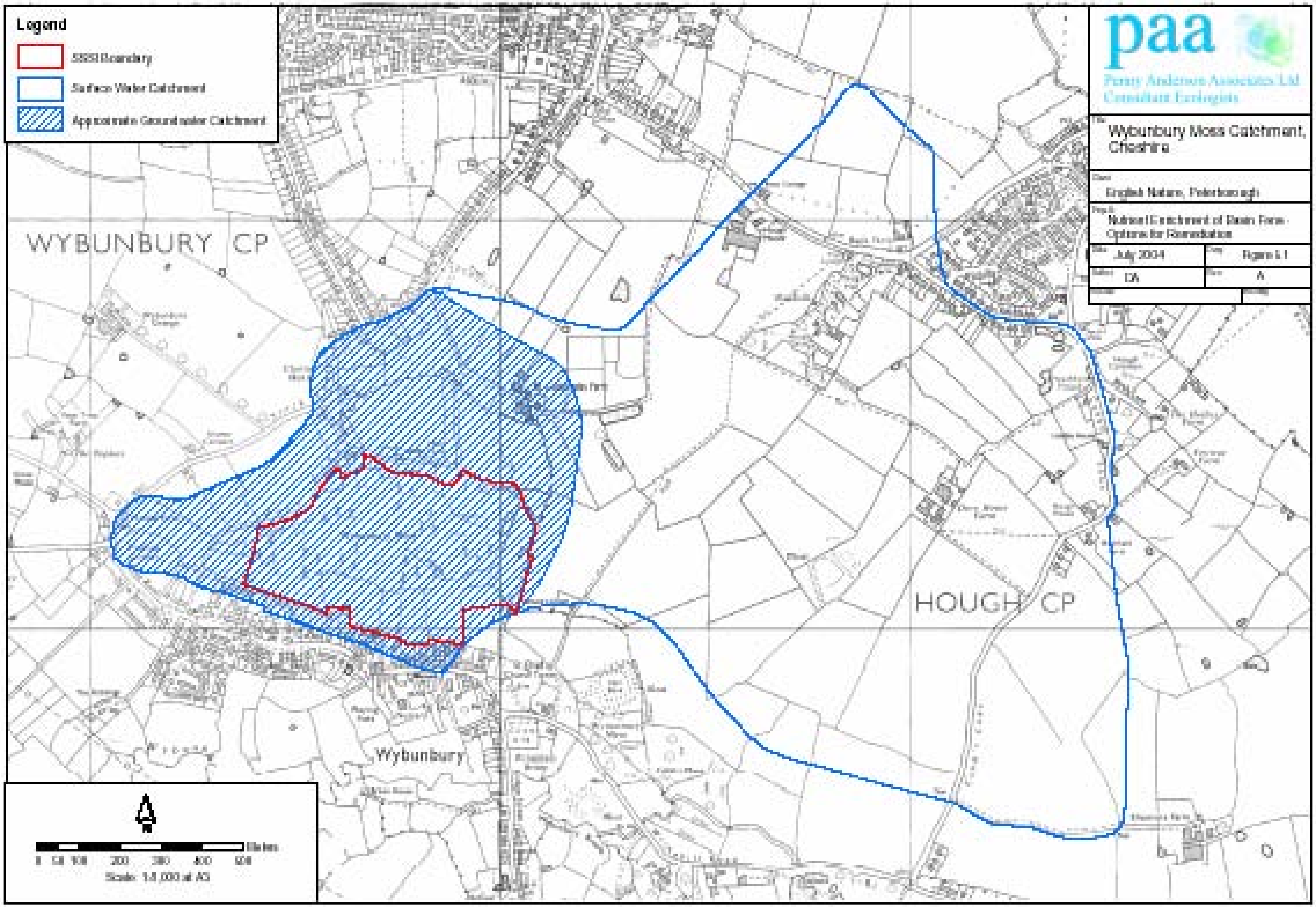

Figure 5.1 Wybunbury Moss Catchment, Cheshire

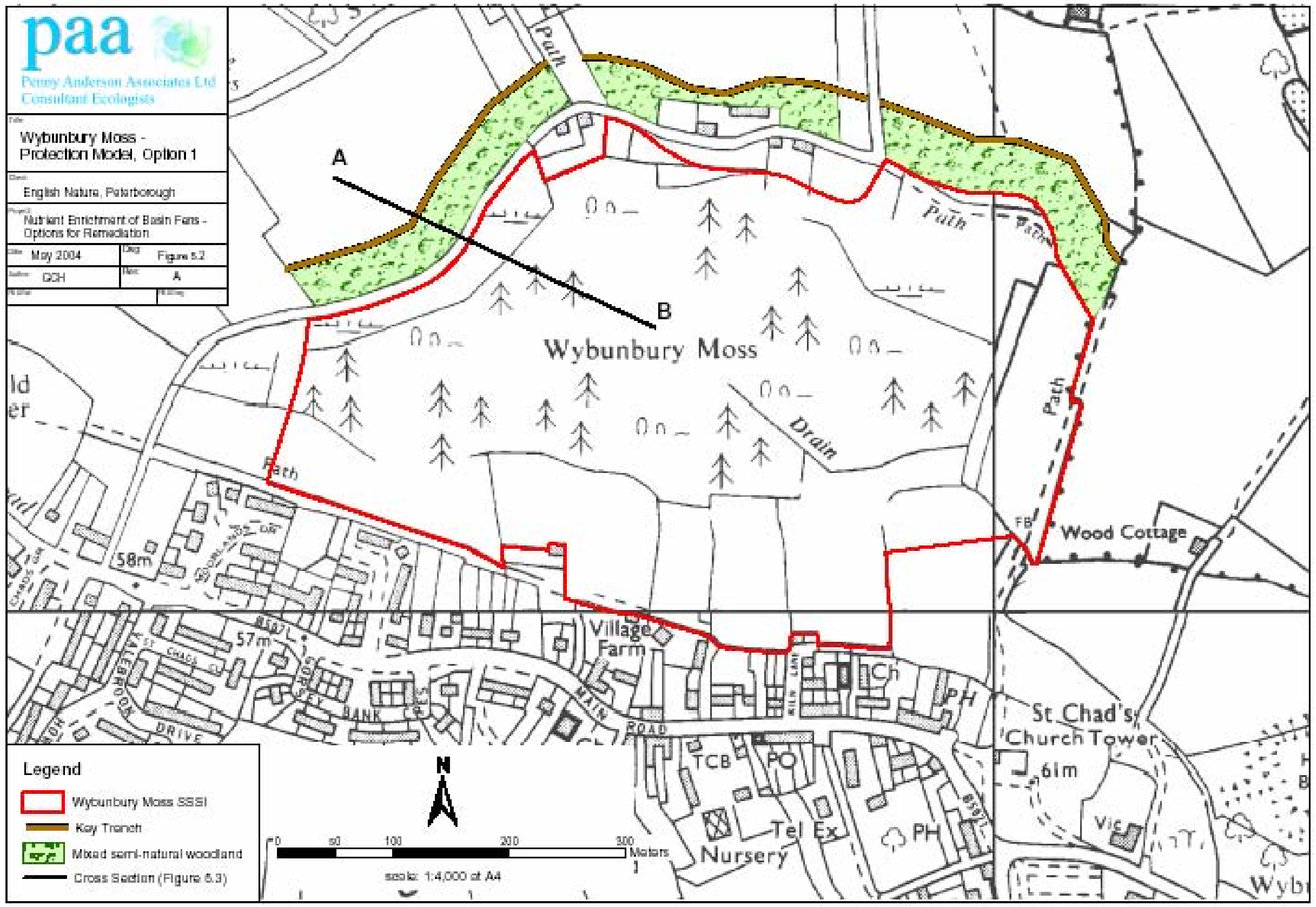

Figure 5.2 Wybunbury Moss – Protection Model, Option 1

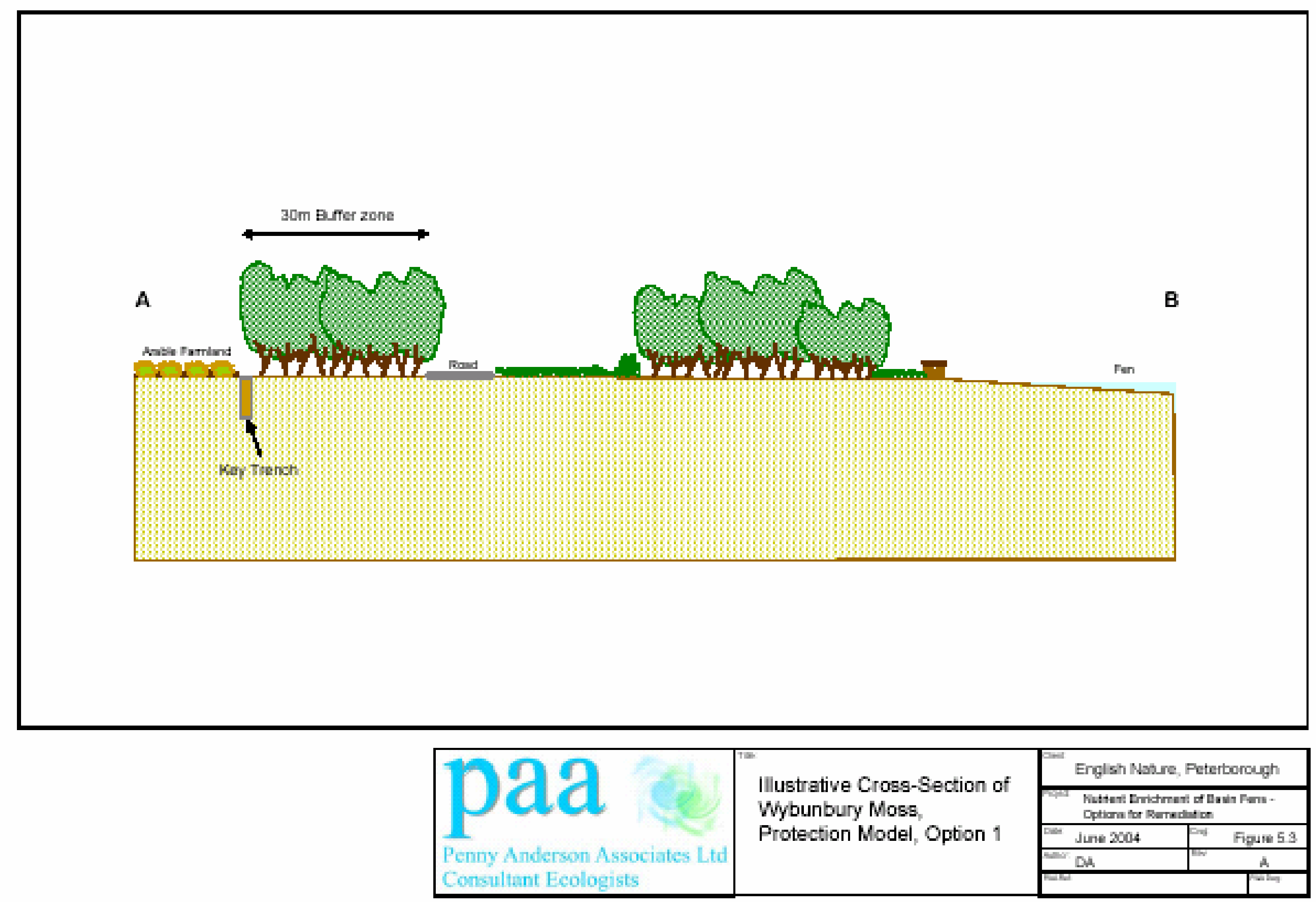

Figure 5.3. Illustrative cross-section of Wybunbury Moss, Protection Model, Option 1.

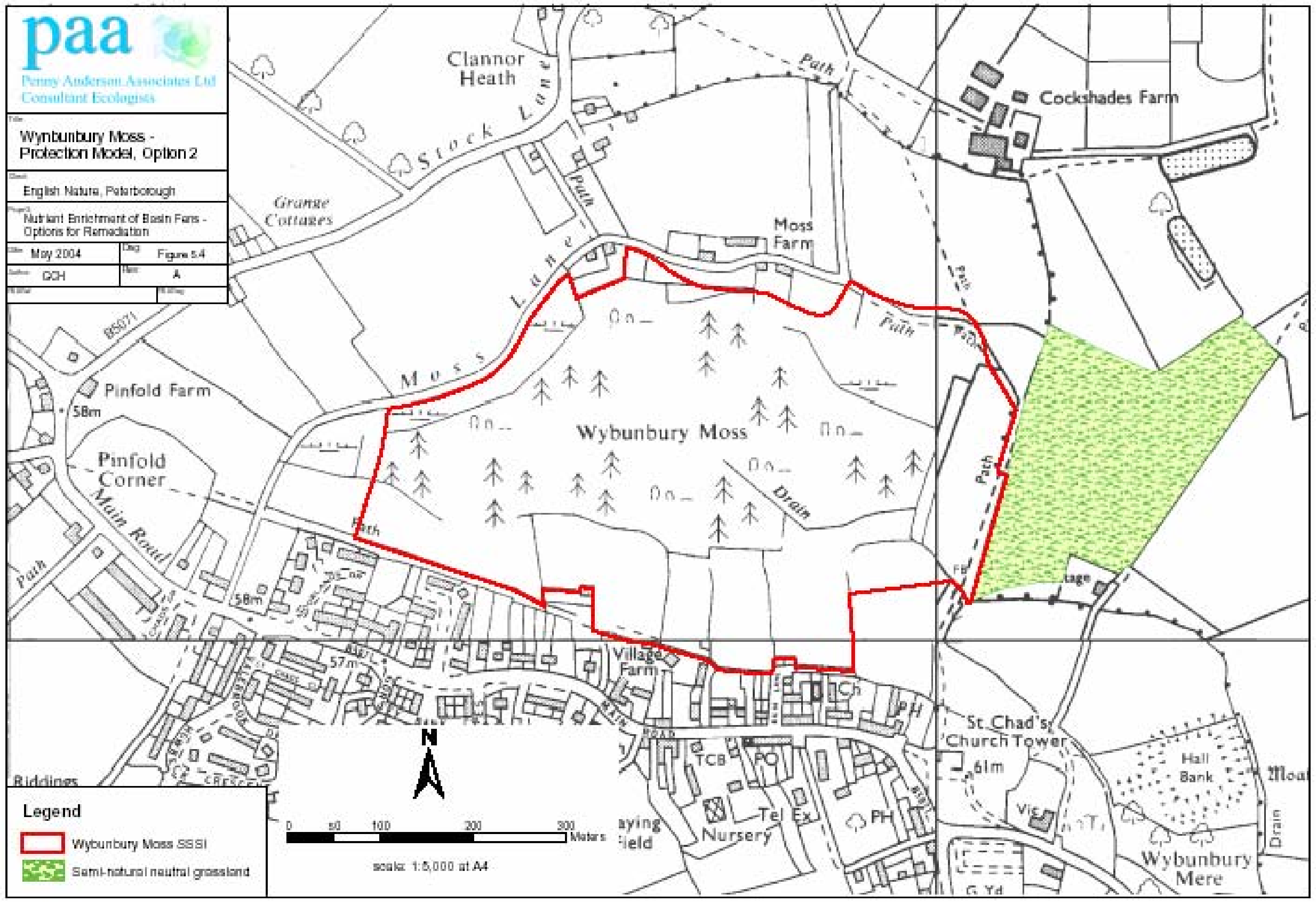

Figure 5.4 Wybunbury Mos – Protection Model, Option 2

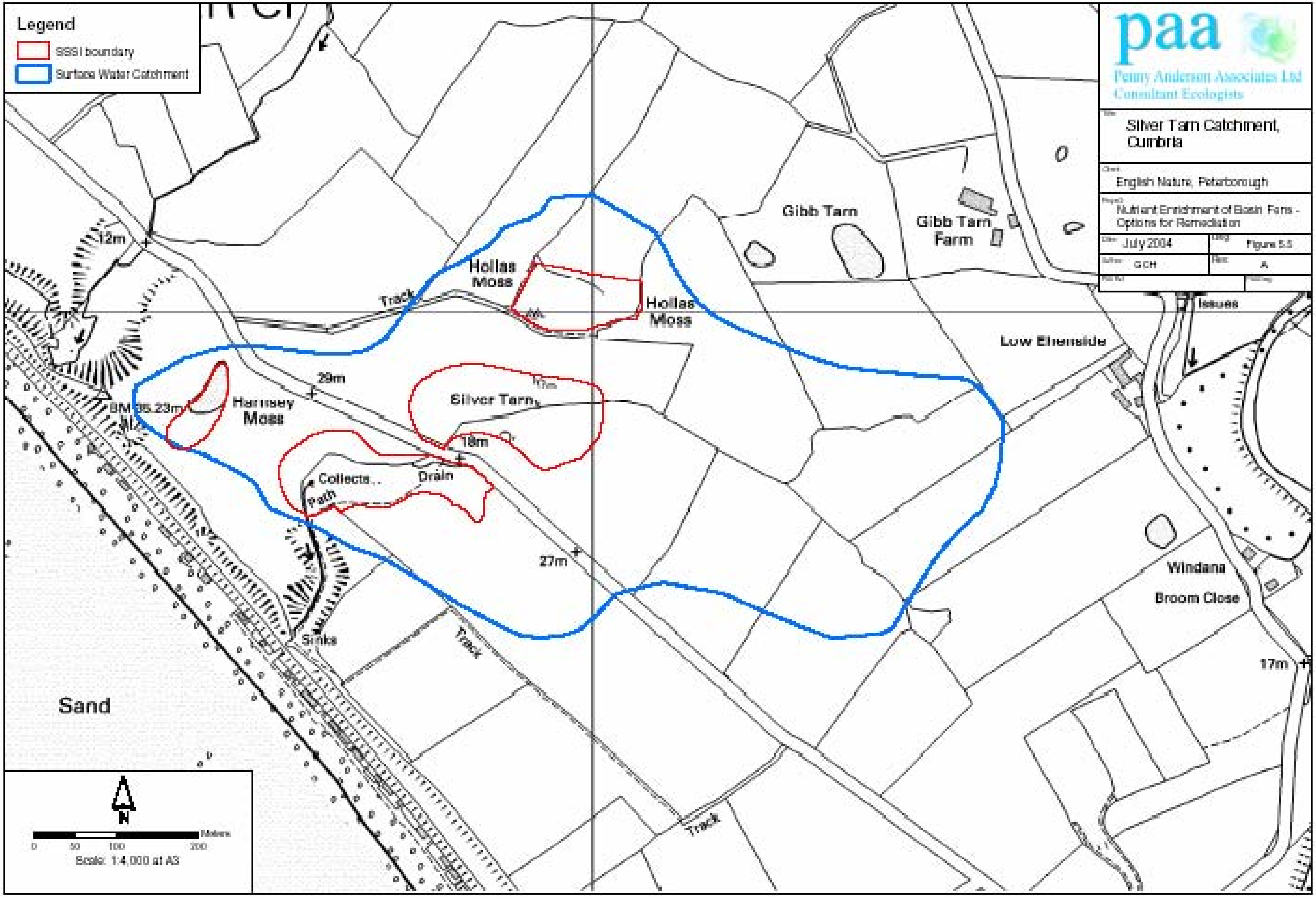

Figure 5.5 Silver Tarn catchment, Cumbria

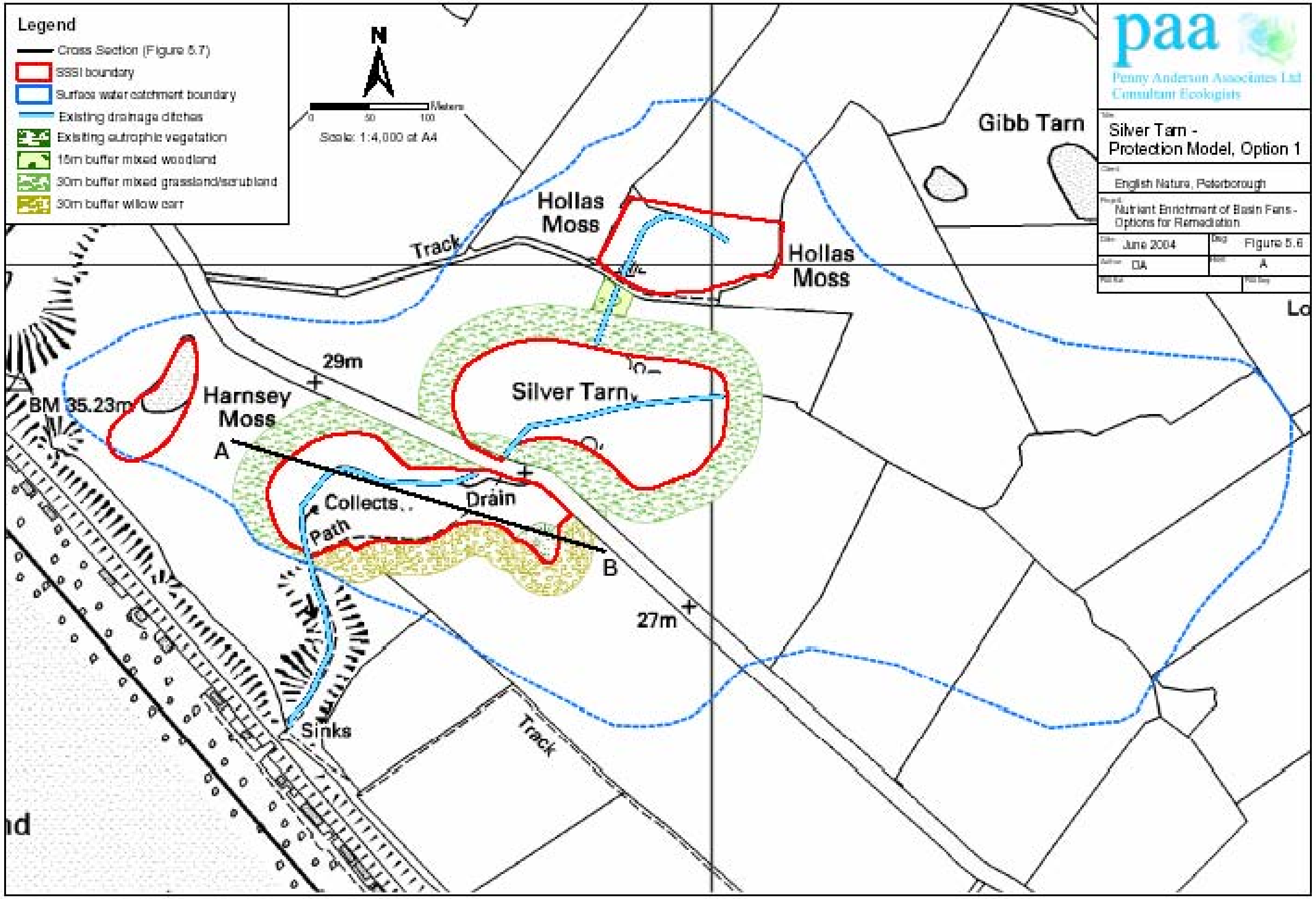

Figure 5.6 Silver Tarn – Protection Model, Option 1

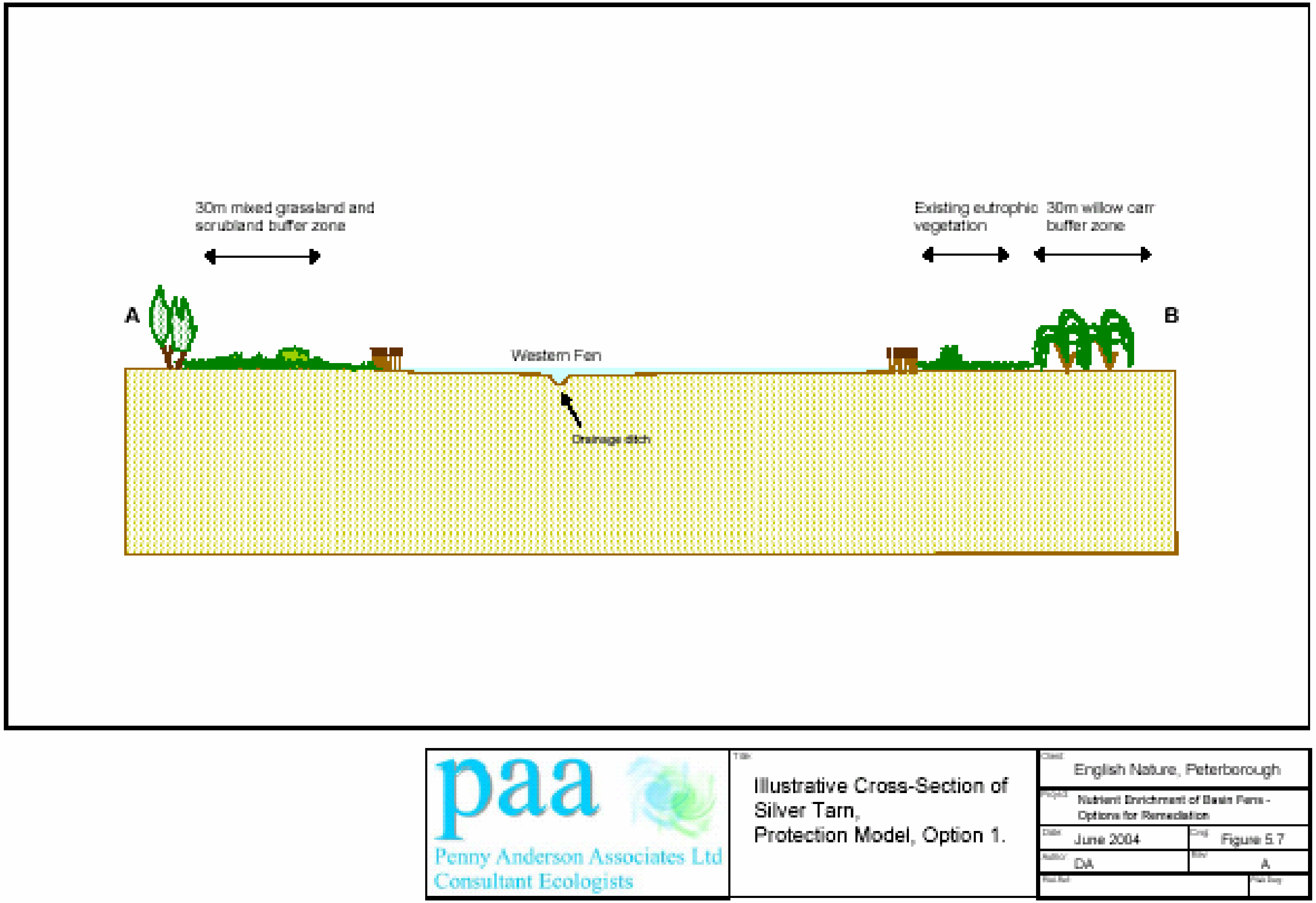

Figure 5.7 Illustrative cross-section of Silver Tarn, Protection Model, Option 1

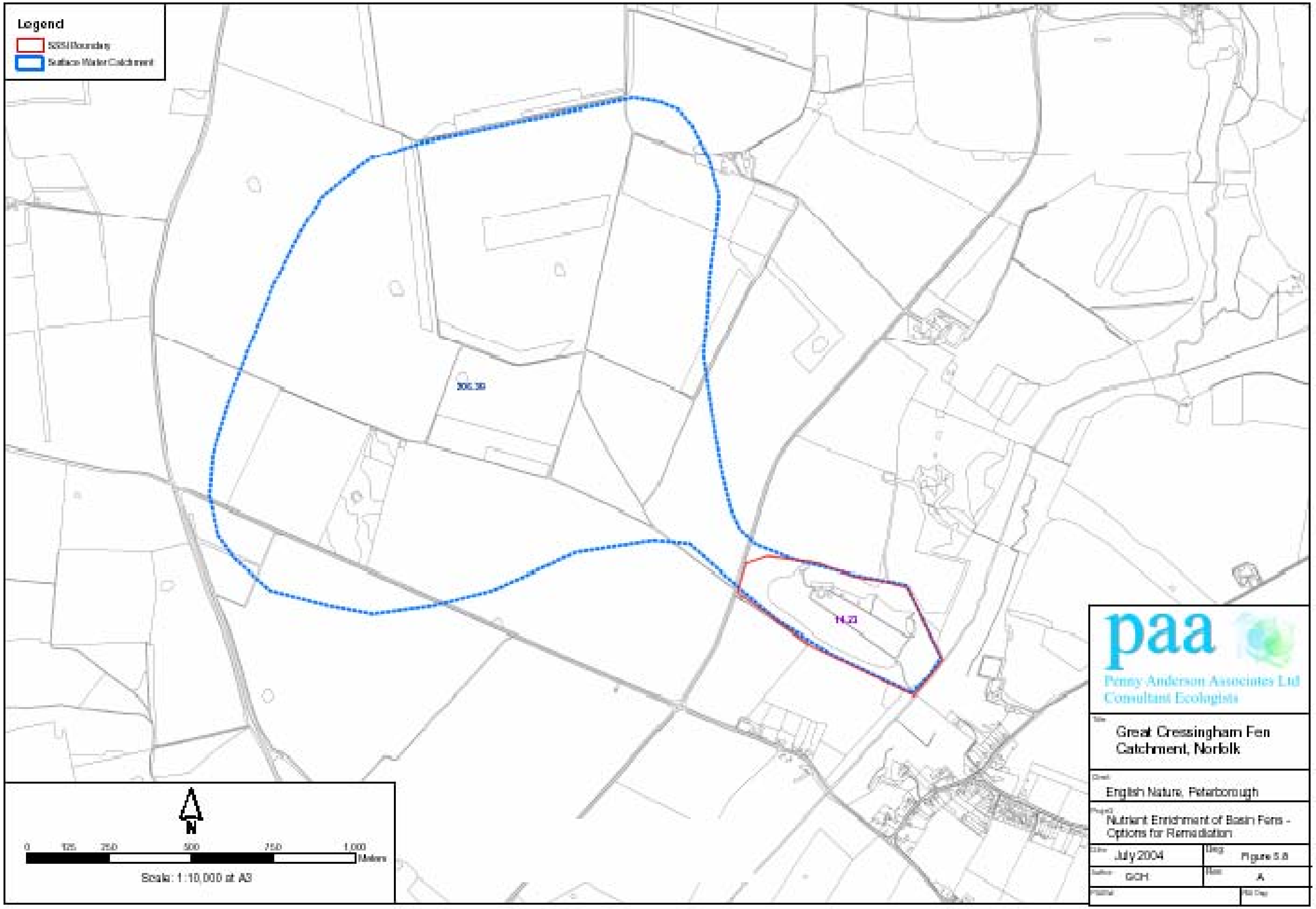

Figure 5.8 Great Cressingham Fen Catchment, Norfolk

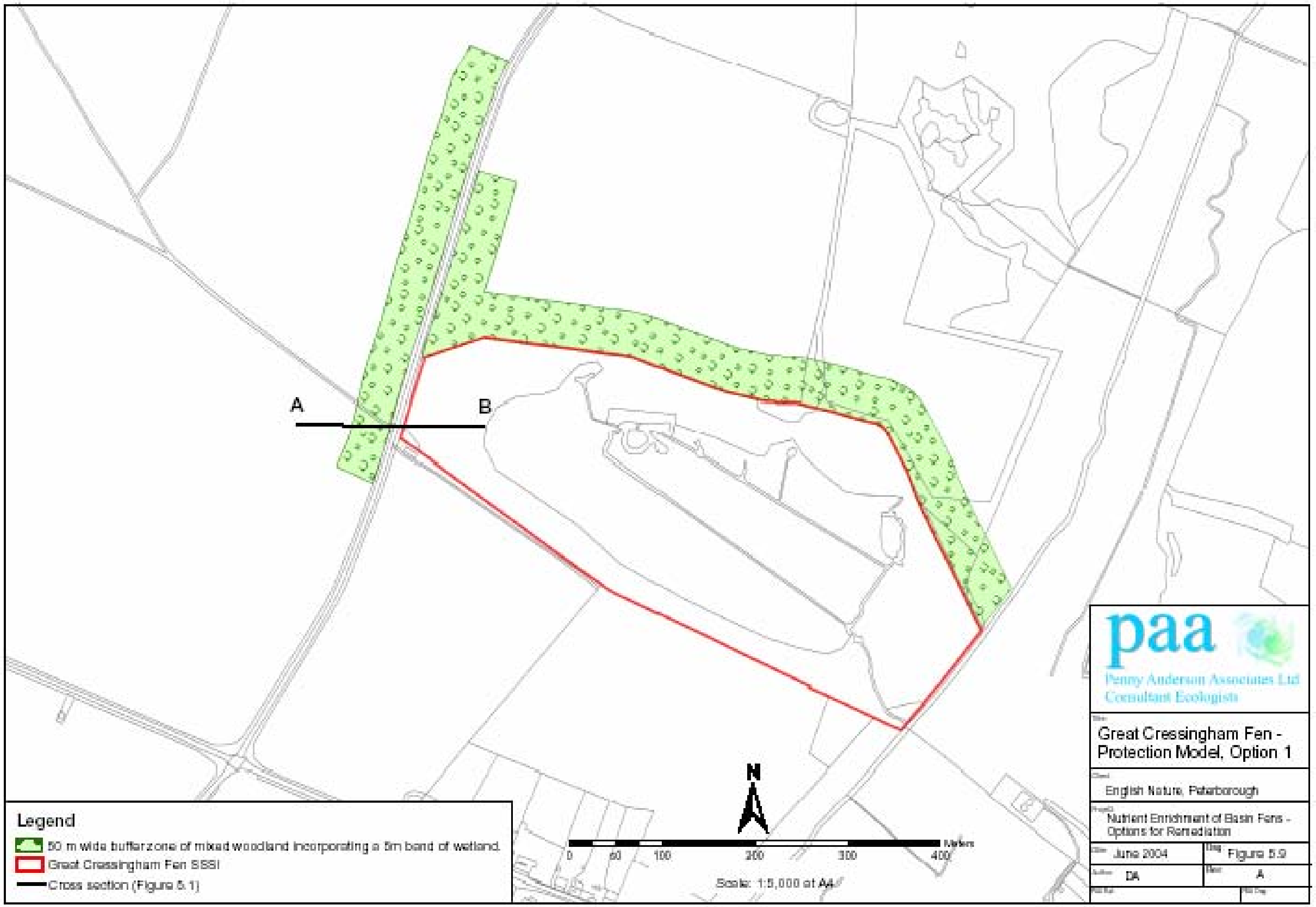

Figure 5.9 Great Cressingham Fen – Protection Model, Option 1

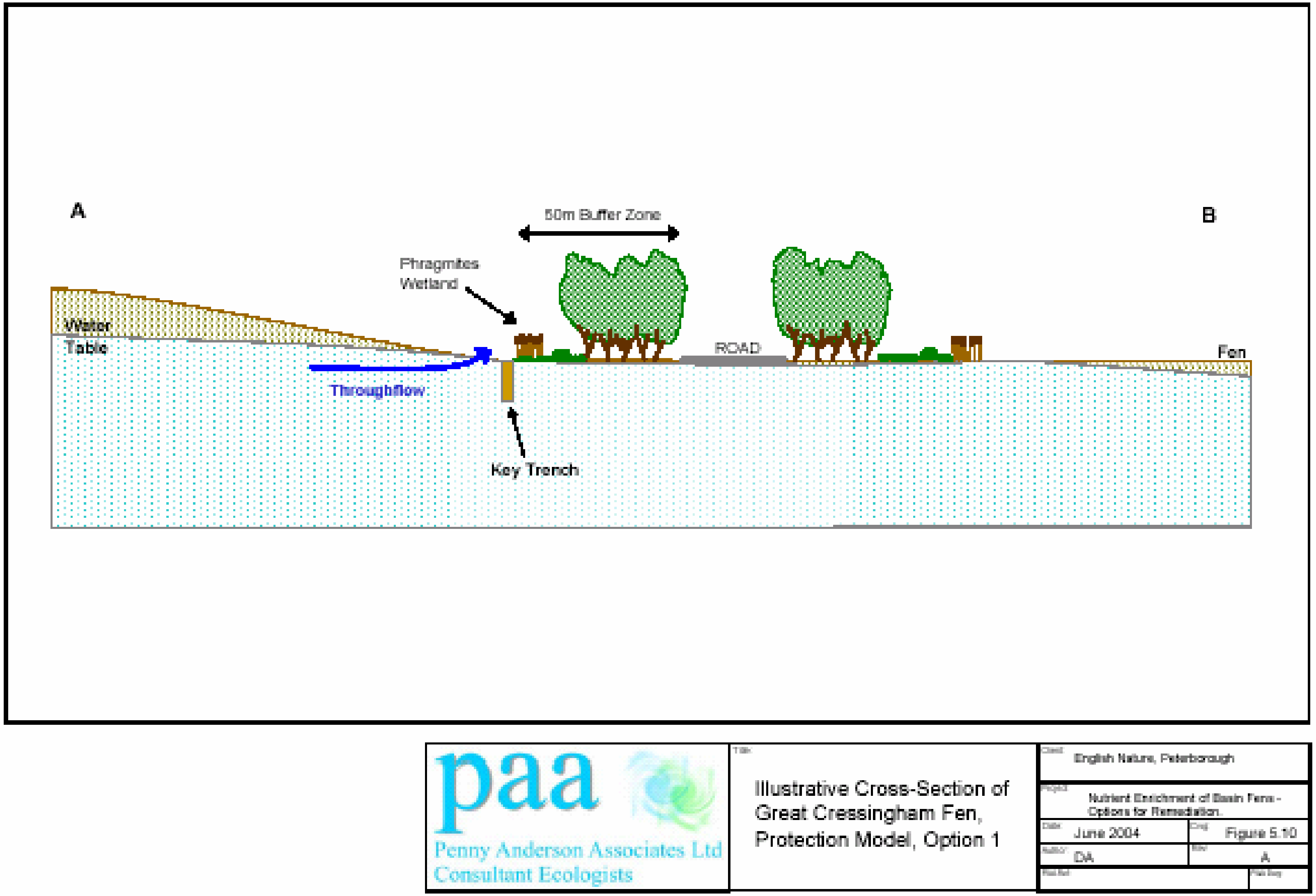

Figure 5.10 Illustrative cross-section of Great Cressingham Fen, Protection Model, Option 1

Figure 5.11 Great Cressingham Fen – Protection Model, Option 2

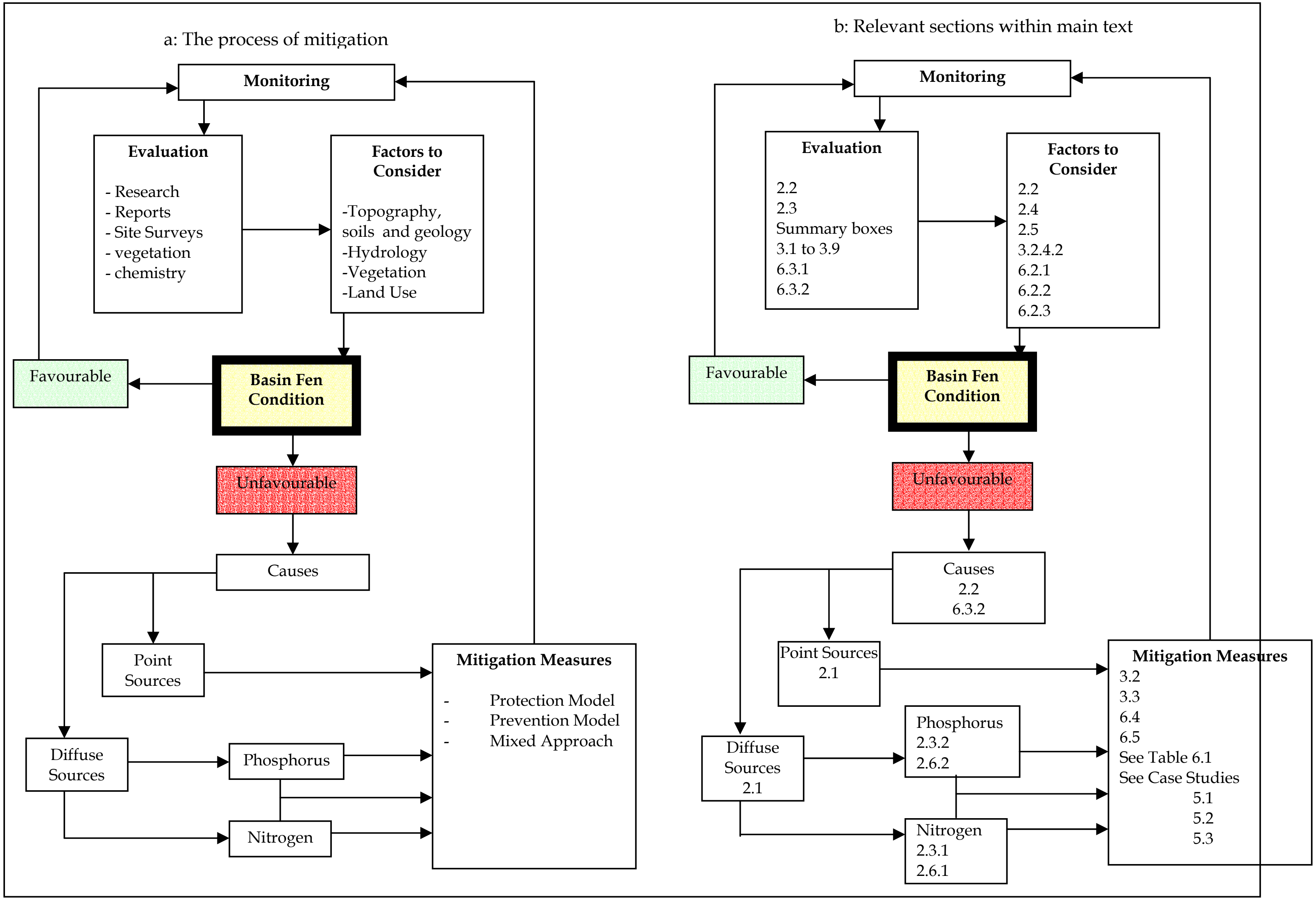

Figure 6.1 Process in preparing mitigation measures to counter nutrient enrichment of basin fens

Appendices

Appendix I. The concept of basin mire

Introduction

The term 'basin mire' is used widely by some ecologists and conservationists, frequently as an informal unit without a clear definition of its compass. Here the concept of 'basin mire' will be explored, with a view to enhancing the clarity of its definition. The aim is to identify a coherent and consistent 'type' of wetland and, subject to that constraint, one that corresponds as closely as possible to what seems to be meant by 'basin mire' in much common usage.

Basin mires and other mire types – a background

The term 'basin mire' has been used in various hydrotopographical classifications of British wetlands (Goode, 1972; Ratcliffe, 1977), to refer to mires contained within 'basins'. Whilst apparently straightforward, a recursive problem is that other units of the same rank identified in the same classifications (*eg* 'open water transition mires' and 'soligenous mires') frequently occur within putative 'basin mires', creating obvious difficulties of hierarchy and definition (Wheeler & Shaw, 1995). Likewise, Lloyd and others. (1993), in an informal hydromorphological classification of East Anglian wetlands, distinguished (at the same rank) '*schwingmoor*' from '*basin fen*' without recognising that '*schwingmoor*' (in the sense shown by these authors) can be a development *within* many basin fens. There is a clear need to disambiguate such typologies if they are to have consistent or clear usage, especially if they are intended to form non-overlapping units of resource.

Wheeler & Shaw (1995) recognised that, despite their limitations, hydromorphological units such as 'basin mire' were potentially useful, broad descriptive units. They suggested that the problem of units occurring within other units could be dealt with by recognising two independent layers of units: *situation types* and *hydrotopographical elements.* The situation types (which include 'basin wetlands' (Table 1)) represent the broad landscape situation in which wetlands occur. They were seen as broad and informal categories which are as variable as the landscape and which represent the first approximation for a wetland classification. The *hydrotopographical elements* were seen as units with distinctive water supply mechanisms and, sometimes, distinctive topographies in response to this. Many *situation-types* can contain a number of *hydrotopographical elements* and the same element may occur in wetlands belonging to different *situation-types* (Table 1). Since these proposals, the suggested *hydrotopographic elements* have become refined and subsumed into *WETMECs* (Wetland Water Supply Mechanisms) (Wheeler & Shaw, 2001). However, whilst solving some of the problems, Wheeler & Shaw (1995) did not critically address the definition and compass of the main 'situation types', including 'basin mires'.

Table 1. Wetland 'Situation Types' and Component 'Hydrotopographical Elements (*Taken from Wheeler & Shaw (2001).*

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

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

Basins

The relevant parts of the *Oxford English Dictionary* definition of 'basin' are:

II. A hollow depression, natural or artificial.

12. Phys. Geog. The tract of country drained by a river and its tributaries, or which drains into a particular lake or sea.
13. gen. A circular or oval valley or hollow.

The term 'basin mire' is used specifically with regard to the second of these categories, but this broad category contains a lot of topographical variation.

Size and shape

Although not essential for membership of the category, basin mires are mostly fairly small. The largest example in England appears to be Chartley Moss (SSSI area: 106.25ha). Wybunbury Moss, one of the next largest, is only 23 ha and many are much smaller than this (eg Sweat Mere: 2 ha). This size restriction is probably primarily because discrete 'basins' in the landscape are mostly small, but there may also be a perceptual element to it, *viz.* basins may not appear to be discrete when it is not possible readily to see the entire site and the constraining features which make it into a 'basin'.

At the smaller end of the scale, tiny discrete basins (eg < 0.1 ha) tend not to be called 'basin mires', though it is not very clear why not. For examples, the pingo fields of East Walton Common and Thompson Common (Norfolk) tend to be regarded as 'valleyhead mires' with small basins rather than as a complex of basin mires, even though many of the basins are discrete and in most other respects satisfy the criteria required of a 'basin mire'. This is doubtless partly a manifestation of the tricky question of what constitutes a wetland ‘site’, and the primary unit to be classified.

Perhaps the classic concept of a ‘basin mire’ is that of an roughly isodiametric unit, and many are indeed of this character (eg Abbots Moss, Cheshire), though elongate depressions are also quite frequent (eg Middle Harling Fen, Norfolk). Irregular shapes also occur: for example, Chartley Moss is roughly ‘L’-shaped, as also was Loynton Moss before the western portion was converted into farmland. In some cases apparently irregular shapes may occur where roughly isodiametric basins are adjoined by other wetland units.

Ecohydrological character

‘Basin mires’ can contain a variety of ecohydrological mire types (Table 1. Wetland 'Situation Types' and Component 'Hydrotopographical Elements), but these are not of equal importance in regard to their status as ‘basin mires’. For example, open basins which consist mainly of soligenous mire on the slopes are not normally considered to be basin mires. Rather, the essence of sites normally called ‘basin mires’ is that they have a prominent topogenous component, *ie* that water is retained in the bottom of the basin by topographical constraints on drainage, most usually provided by the rim of the basin, and this provides a basis for mire development. However, in many such sites, especially minerotrophic examples, the topogenous bottom of the basin may be fed in part by soligenous inflows from the adjoining slopes.

The character of the topogenous surface may vary considerably from solid peat to semi-floating mats of vegetation, from water regimes dominated by strongly fluctuating water tables to more stable systems with pronounced lateral water flow, and from minerotrophic (‘topogenous’ *sensu stricto*) to ombrotrophic (ombrogenous) surfaces. The water environment is essentially lentic and in consequence the topogenous infills are often mainly of lake muds or peats rather than of inwashed mineral material. Nonetheless, mineral inwashes do occur, particularly around the margins, sometimes in response to disturbance of the basin slopes (eg by ploughing, forestry operations). Inwash of mineral material into basin mires is often considered to be undesirable, especially if it enhances the trophic status of (parts of) the site and leads to species loss.

In basin mires, topogenous surfaces are generally fairly ‘flat’ although, except in some particularly wet, floating examples, or in some completely closed basins, there is normally some overall degree of slope. Where sites have been drained, there is often a quite pronounced lateral slope from the margins to the drainage axis, but such systems are still normally considered to be basin mires. However, where sites have a pronounced slope down the longitudinal axis of the mire, these are less obviously ‘basin mires’, even though they have originated in basins. Thus, the numerous, small, gently-sloping mires in rocky basins and troughs on Subberthwaite Common (Cumbria) are not generally considered to be ‘basin mires’[5]. However, in some more complex sites, such as the Eycott Hill mires (Cumbria), there are clear topogenous basins connected by sloping soakways and surfaces.

[5] These mires are perhaps best considered to be ‘valley-head basins’

Proportion of topogenous wetland

A feature common to most of the sites which are normally called ‘basin mires’ is that the topogenous component is large in proportion to other mire types in the basin. This helps to distinguish ‘basin mires’ from other mire types (eg valleyhead mires) which may contain a local topogenous element in small depressions. Moreover, in many ‘basin mires’ all or most of the bottom of the basin is occupied by a topogenous peatland. In addition, basins in which much of the bottom of the basin is occupied by open water tend not to be regarded as ‘basin mires’, perhaps on the not-unreasonable basis that they are more open water than mire. Thus many of the meres of the West Midlands are generally not called ‘basin mires’, even though they may be surrounded some topogenous mire and in some cases their ‘basin’ structure may show little material topographical difference from that of some of the basin mires of the same region. Equally, some sites that *are* normally considered to be basin mires may have substantial areas of open water (eg Lily Pond, Delamere). It might perhaps be most rational to call all such basin sites ‘basin wetlands’, but this would violate a widely-held intuitive subdivision of sites into those that are considered to be primarily lakes and those considered to be primarily mires.

The issue of the status of open water sites as ‘basin mires’ is not just a matter of the proportion of topogenous wetland. Another is their potential for hydroseral expansion of fen, in the foreseeable future. For example, although Crosemere (Salop) – which is not normally considered to be a basin mire – is in a basin and has some peripheral topogenous fen, the latter shows little propensity for significant hydroseral colonisation of this deep and fairly large water body. By contrast, the nearby, smaller and recently terrestrialised Sweat Mere (Salop) is considered to be a basin mire. Hence, it may be suggested that the status of open water sites as ‘basin mires’ is probably likely to be a material conceptual problem only in those examples where the open water is fairly shallow and susceptible to potentially quite rapid terrestrialisation, ie in those which have the potential to become basin mires within the foreseeable future, or have recently done so. In some – perhaps many – of these cases it may well also be the case that the open water phase is itself a transient, and perhaps artificial, feature eg as created by peat digging. For example, Tallis (1973) has pointed to transient changes in the amount of open water in some of the Delamere basins. It is also relevant to note that where topogenous fen surrounds an area of open water in a hollow, it is very likely to belong to the same hydrotopographical element (or WETMEC) irrespective of whether the site as a whole is called a Basin Wetland or a Lakeside Wetland. Thus WETMECs are less ambiguous, and more generic, descriptive units than are Situation Types.

Open and closed basins

Perhaps the biggest difficulty in categorising basin mires relates to their degree of ‘open-ness’, ie the degree to which they have surface water inflows and outflows. Only a very small number of basin mires in England appear to be truly closed, ie have no obvious surface water inflows or outflows (eg Lin Can Moss (Salop) and some of the ground-ice depressions on permeable strata in Eastern England), and these are exceptional.
Many basin mires occupy visually coherent depressions. In some cases the mire occupies a depression within more-or-less flat ground (eg Pilmoor, North Yorks), but in many examples not only is the mire itself in a hollow, it is also completely, or almost completely, surrounded by slopes that rise well above the mire surface around much or all of the periphery (eg Flaxmere, Cheshire). However, some ‘basins’ are much less obviously basins. For example, Wybunbury Moss (Cheshire) and Great Cressingham Fen (Norfolk) are both valleyhead

troughs rather than visually-obvious basins, apparently open along their downstream sides. In fact both of these examples do have a slight topographical barrier to surface water outflow across the downstream side, but it is much less tall and prominent than the slopes around the rest of the mire and is breached by an outflow ditch. The Wybunbury and Great Cressingham sites both also occupy a well-developed basin below the level of the mire surface (and outflow barrier), but it is questionable if this feature *by itself* is sufficient to confer 'basin mire' status. For example, a deep open-ended basin may function ecohydrologically more as a trough or flood-plain system than as a 'basin' (eg Biglands Bog, Cumbria).

Surface water outflows

Most basins have at least an intermittent surface water outflow, although in many cases these are clearly artificial. In some sites elaborate drainage measures have been imposed, including deep channels, pipes or culverts through solid rock (eg Attermire (North Yorkshire), Silver Tarn (Cumbria), Black Firs Reserve (Staffs)) and it is often difficult to be sure of the nature of any natural outfalls. Nonetheless, in most instances it seems likely that there was some surface water outflow out of the basins, through a low point in the basin wall. A corollary of this is that in some basins the natural water level, and peat surface, may once have been several metres higher than is currently the case.

Many basin mires have but a single outflow, but this is not always the case: in a number of sites the wall of the basin has been breached (naturally or artificially) in more than one place (eg Chartley Moss, Loynton Moss). This particularly occurs where the mires occupy hollows on an interfluve between local or regional catchments.

The nature, particularly the permanence, of the outflow from basins can provide useful insights into the water supply mechanisms of the mire. Persistent outflows require substantial water inflow and in the drier regions of England they can provide proxy indication of significant groundwater inflow into the basins (eg Great Cressingham Fen, Norfolk). Conversely, sites without normal summer outflows are less likely to receive substantial groundwater inflow (eg Cranberry Bog (Staffs), though they may still have some hydraulic connection with any aquifers. Examples with strongly fluctuating water tables are often primarily dependent upon inputs of rainfall, or rain-generated run-off. In some of these latter sites where the vegetation surface is semi-floating or buoyant, fluctuations in the water table are not necessarily reflected in large variations in surface hydration of the vegetation mat.

Water inflows

Many basin mires have no obvious water inflows at all, other than from rainfall and perhaps rain-generated run-off (eg Abbots Moss) and in others surface inflows appear to be largely from artificial drains. However, others undoubtedly have telluric inflows from various sources, and in some instances several basins are concatenated into a linked down-valley series of mires (eg Candlestick valley, Cumbria).

Groundwater inflows

A number of basin mires have obvious springs and seepages around the margin of the topogenous section, or higher on the basin slopes (eg Wybunbury Moss). In some cases (eg Great Cressingham Fen), peripheral springs may occur partly because groundwater flow is constrained by low permeability deposits (marl, gyttja) that have filled much of the basin.

Strong upwellings appear to occur into the bottoms of some shallow basins (eg one of the pingos at East Walton Common), but are generally not as pronounced in English examples as are the upwelling 'well-eyes' that are a distinctive feature of some basin mires in the Scottish Borders. Sub-surface groundwater flow undoubtedly occurs into many basins, but in the absence of visible surface evidence it can be difficult to detect or demonstrate. A number of basins are believed to be groundwater fed, at least in part (eg Foulden Common, Norfolk; Emer Bog, Hampshire), in some instances partly just because there is no other obvious water source. The behaviour of the water table in such depressions is strongly dependent upon the nature of the aquifer and, in the case of sites fed from small, probably 'slow', local aquifers (eg Emer Bog) or those subject to considerable fluctuation of the groundwater table in the vicinity of the basins (eg Foulden Common), the basins can regularly experience considerable fluctuations in water level.

Surface water inflows

Many basin mires have little evidence for significant surface water inflows, though some rain-generated run-off is likely to be a feature of many sites. In some cases, particularly the larger sites, the outer parts of the basins have been drained and a network of ditches feed into the residual mire (though in other cases drainage of peripheral areas is away from the mire remnant).

Some basins are also fed by relatively short streams and ditches, originating from sources higher on the basin slopes, but within the broad limit of the basin (eg Flaxmere, Cheshire). Some such streams represent surface drainage from the immediate catchment of the basin; others are sourced by springs and seepages.

Because of their essentially 'closed' character, rather few sites that are normally considered to be basin mires are fed by surface water inflows that have originated some considerable distance from the basin. Loynton Moss (Staffs) is one of the few good examples of this: the north-east corner of this basin was formerly fed by a stream which drained a considerable area of land east of the site, and which continued to do so, *via* a brick aqueduct, after the Shropshire Union canal was dug around the eastern side of the basin in the 1830s. Recent concerns about the quality of this water, and of water damage to the aqueduct, have resulted in the re-routing of this supply, apparently contributing to drying of the basin. Despite this site having once been fed from a source well outside the basin, there seems little reason to think of it as other than a 'basin mire'.

By contrast there are a number of other sites in basins which are not only sourced by streams originating well outside the basin but which also have quite strong surface water throughflows. Examples include Biglands Bog, Finglandrigg Moss, (Cumbria) and Hockham Mere (Cranberry Rough) (Norfolk). Water flow through some of these basins has been promoted by the excavation of water channels, both within the sites and through the outfall, thereby removing some of the topographical constraints which may once have helped retain water in the basins. Biglands Bog is a particularly good example of this as, although it occupies a distinct and deep basin, it functions more as a deep trough than as a basin and is in many respects more comparable to a small flood-plain mire than to many 'basin mires'. It is difficult to provide a rule of thumb with which to categorise these sites, but at the very least it seems reasonable to propose that those basins which have a ± natural, strong stream flow through the site do not conform to the normal concept of a 'basin mire'. This criterion would exclude Biglands Bog from basin mire status along with a number of other 'basin' sites.

Some consequences of basin ontogenesis

Most mires are subject to ontogenic change and, because of their strongly hydroseral context, basin mires are perhaps particularly labile. Walker (1966) has described a series of successional pathways in small basin mires, identified from changes in their stratigraphy. Ontogenic changes in basins may be a product both of autogenic ('self-made') seral processes, mostly occasioned by the process of infilling with lake muds and peat, and allogenic ('other-made') events. The latter may be induced by, for example, increased water tables during parts of the post-glacial period as a consequence of climatic change, but without detailed stratigraphical and dating evidence it is often difficult to disentangle the autogenic and allogenic processes. At Flaxmere (Cheshire) Tallis (1973) was able to demonstrate that the peat surface and water table was fairly low in the basin (below the surface outfall) during the early part of the post-glacial and it was only later that the basin 'filled up', though it remains still recognisably a 'basin mire'. This is, however, not the case in all former basin sites, as ontogenic changes can convert basin mires into other mire types.

Accumulation of peat and other deposits within basins can have variable consequences, depending *inter alia* on the precise topographical, hydrological and climatic circumstances. In some instances several small basins have occupied a larger basin, and in this case increasing water tables led to the coalescence of the original basins into a larger basin, so that the system remains as a basin mire. The stratigraphical sections of Walker (1966) suggest that this may have occurred in some Cumbrian sites. However, in other cases changes have led to the obliteration of much, or all, of the original basin structure. For example, in areas of high precipitation, ombrogenous deposits have accumulated across basin ridges; in some cases the ombrogenous deposit still occupies a broad basin, but in others the original basin structure has been obscured. The terms 'ridge-raised' or 'intermediate' bogs have been applied to ombrogenous deposits that have grown out of their original basins, in contradistinction to 'raised bogs', which are considered not to have done this. However, as Wheeler & Shaw (1995) have observed, available sections indicate that the majority of sites that are usually called 'raised bogs' in Britain have developed over ridges of some sort, the main exceptions being those that have developed on extensive flood-plains without ridges, or in lake basins. Basins can also become overgrown and obliterated by minerotrophic deposits. For example, stratigraphical studies in the headwaters of the rivers Waveney and Little Ouse (East Anglia) have revealed the occurrence of several buried basins, mostly filled with late-Devensian sediments and covered by peat (Tallantire 1953, 1969). These systems can no longer be considered to be basin mires. The Redgrave and Lopham Fens are essentially soligenous / percolating systems fed primarily by marginal inputs of groundwater flowing across the original surface of the basins, whereas the Thelnetham Fens are (or, until fairly recently, were) fed both by groundwater flow from the margins and episodic flooding from the river. In these examples, not only have the former basins become overgrown, the water-supply mechanisms that sustain the fen surface have also changed. The recognition that this loss of basin mire status has occurred naturally perhaps makes it easier to accept that sites such as Biglands Bog also no longer really function as basin mires.

Another example of ontogenic changes can be found in some of the small rocky basins in south Lakeland (eg Subberthwaite Common). There can be little doubt that some of these were once true, topogenous basin systems, though with some degree of inflow and outflow. However, it appears that in some cases peat has accumulated up (and perhaps sometimes over) former basin slopes to form a sloping, soligenous mire upon former topogenous peat.

Where these systems have a clear slope and a well developed inflow-outflow system, they are clearly no longer basin mires, but the status of some of the flatter examples, or those which contain topogenous hollows embedded within part-sloping systems, can be more tricky to assess (see 1.9).

In some circumstances, mire basins may become deepened. Tallis (1973) has pointed out that some of the mires basins in Cheshire may have been created, or deepened, by subsidence caused by solution of the underlying saliferous rocks. This does not seem to apply to many of the 'best' basin mires in the Delamere Forest area, but there seems to be little doubt that both the Wybunbury and Chartley Moss basins have been considerably deepened by sudden subsidence and that this is responsible for the occurrence of a *schwingmoor*[6] structure. It can be argued that not only are these the largest *schwingmooren* known in England they are also amongst the very few deep-water (= true ?) *schwingmooren* that occur.

Basins in other mire situation-types

'Basin-mire habitats' are not restricted to 'Basin Mires'. Topogenous surfaces similar to those found in typical basin mires also occur in other mire types, in both natural and artificial contexts. The difference between these occurrences and 'basin mires' is (a) that the site does not occupy an overall 'basin'; and (b) that the 'basin-mire habitat' usually occupies only a limited proportion of the total mire area, rather than dominating it as might be expected in a 'true' basin mire. However, it will be appreciated that terms such as 'basin' and 'basin-mire habitat' are sufficiently ill-defined and variable sometimes to create uncertainties as to whether the habitat in question is part of a 'basin mire' or another mire situation-type.

Basin-like depressions frequently occur embedded in flood-plain wetlands and valleyhead wetlands. It is suggested that such small, shallow hollows within wetlands can be referred to generically as **sumps**. Some examples are natural hollows, sometimes of considerable antiquity (eg whole, partial or coalesced basins of former pingos), sometimes part of fluvial processes (eg terrestrialised ox-bow lakes), sometimes a consequence of various erosional and deposition processes (eg slumping) which may or may not be on-going. However, in lowland England, the main cause of such hollows in mire surfaces is past peat digging (sometimes marl digging). It is suggested that the name **turf pond** should be used for shallow, more-or-less closed hollows in mires created by peat digging and which have become reflooded, and where recolonisation has involved a component of terrestrialisation of free water. Where this is not the case, ie where peat digging has just created unflooded depressions within the mire surface, closed or open, it is suggested that the name **peat pit** should be used. Distinction between these two types is usually fairly easy: a turf pond often has a loose, buoyant or semi-floating infill whereas in a peat pit the vegetation is normally anchored onto a solid bottom. Of the two, turf ponds usually best mimic the 'basin mire habitat'. These shallow, artificial sumps can normally be distinguished from 'basin mires' on the basis that they occur within another wetland types and because they are usually accompanied by other less basin mire-like habitats. However, in some locations, such as parts of the Norfolk Broadland, turf ponds are both large and widespread and, because of this, it is possible to make the case that the largest representation of 'basin mire habitat' in England actually occurs in flood-plain mires rather than in 'basin mires'! Of course, turf ponds can also be located in true basin mires, and there can be little doubt that in some, perhaps many,

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[6] Floating vegetation raft

such examples past peat digging has largely created the current wet, quaking surfaces that are considered to be particularly ‘characteristic’ of basin mires.

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Appendix II. Summary of the main issues affecting basin wetlands in England

P = possible issue, Y = definite issue

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Southern England															
Emer Bog	SU396215	Unfavourable declining (2003)	Agriculture overgrazing			P Source of high nutrient levels is unknown.		P. Source of high nutrient levels is unknown. (Discharge consents are under review by EA)		Y (overgrazing is a problem on heath / scrub encroachment on the mire)	[No map] Rough grassland, heath and woodland, cereals and ley grasslands.]	Chemical, phytometric and vegetation evidence.	ENSIS only recognises the heath habitat		N
East Anglia															
Cornard Mere	TL888389	Unfavourable declining, or no change (1997 -2001)	Abstraction, flooding, drainage, siltation; woodland management	Y (diversion of surface input and drainage may have contributed to problem)	P (concerns regarding operation of an abstraction bore close to the site, but water levels high in 2001)	Y (arable) Runoff is nutrient rich and greatest during winter		Run off from the roads		Y (scrub)	(no map - presumed mainly agricultural, with some buildings / gardens etc.)	Desiccation and eutrophication are thought to have caused species richness to decline, with the possible loss of some species.			N
Cranberry Rough	TL936937	Unfavourable no change (1999-2000)	Undergrazing / inappropriate scrub control	Water level control is an issue						Y (Undergrazing / scrub control)	Forestry & some agricultural fields.	Presence of S26 around pond and in SE corner may indicate drying / enrichment / disturbance?			Y
East Harling Common	TM000880	Unfavourable recovering (2003)	X		P (11 groundwater abstractions within 3km of the site - monitoring in place)					(Scrub clearance has taken place. Low level of cattle grazing seems OK.)	Arable ploughing right up to edge of the site (but not individual pingoes)	None mentioned	System of wet pingoes		Y

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Foulden & Gooderstone Commons	TF7600	Unfavourable recovering / unfavourable no change (2001-2)	Inappropriate scrub control, undergrazing	Y (1998 water control structures installed in the inner dyke on Talents Fen to control outflows from the site and reduce drainage-induced drawdown in the fen)	P (monitoring in place)					Y (Issues regarding succession to oak/birch on drier pingos and ash/sallow on existing swamp/fen).	Catchment to individual pingoes mainly unimp. grassland / woodland. Catchment to site includes agricultural land - part is grazed under ESA	None mentioned			Y
Great Cressingham Fen	TF848022	Unfavourable - no change (2002)	Abstraction	P (link to river levels requires investigation)	P (concerns regarding operation of abstraction licences close to the site - monitoring in place)	P (agricultural run-off)			Some adverse change may be due to hydroseral succession	Y (scrub / grazing levels)	Mainly arable - small 'buffer' of rough grazing between arable fields and the seepage slopes / basin.	Some dense reed - possibly due to enrichment, but not proven.			Y
Middle Harling Fen	TL989853	Swamp & marsh: Unfavourable recovering (2003)	X		11 groundwater abstractions within 3km of the site - these are likely to have a significant impact on water levels in the site. [Monitoring in place]	P (agricultural run-off)				Scrub clearance has been undertaken; site grazed.	Presumed primarily agricultural + conifer plantation & farms.	P (some nettles & tall reed, but evidence inconclusive)	Wide fluctuations in water level prob. partly due to fluct. in aquifer		Y

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Old Buckenham Fen	TM0491	SU2, marshy grassland: unfavourable no change; SU3 & 5, Swamp/marshy grassland: Unfavourable recovering (2003)	SU2: drainage	Fen meadow considered too dry. [Water levels on part of site controlled by sluice]						(Managed)	A map from 1982 shows arable land adjacent to the fen in the north and improved pasture to the south.		Much of the southern area is pump-drained and supports relatively dry cattle grazed pasture, with some wet hollows.		N
Scoulton Mere	TF985014	2002: wet woodland on the island: Favourable; open water: unfavourable no change; swamp: unfavourable declining	Abstraction, siltation, inappropriate scrub control	Y (water levels controlled by sluice: management is a major issue)	P (concern raised regarding low water levels, but pump test suggested no evidence of impact)			Lake supports significant wintering wildfowl but is silted and may be enriched by previous gull roost.		Y (scrub invasion in the swamp)	Presumed to be mainly agricultural.				N
Thompson Common	TL9396	Many units, variously unfavourable recovering, favourable, unfavourable no change (2000-2003)	Inappropriate scrub control.		Concerns regarding impacts of abstraction are being investigated under RoC.					Y (scrub control / grazing etc. around pingoes)	SW catchment to individual pingoes is unimproved grassland / woodland. General surface catchment to site includes agricultural land.	None mentioned	System of wet pingoes within a valleyhead context. [The pingo 'wetlands' do not feature as a habitat category on ENSIS]		Y

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
West Midlands															
Abbots Moss (South Moss & Shemmy Moss)	SJ595688	Favourable (2000)	X		P (abstraction and quarrying; concerns being investigated under RoC)	P (forest nursery)		P (Road run-off)	Concerns regarding forestry in catchment, and disturbance from public recreation and moss gathering	Y (Scrub encroachment)	Mainly woodland and conifer plantation / nursery	None mentioned			Yes
Bagmere	SJ795643	Bog: favourable, Fen: unfavourable recovering, no change or declining. (2002-3)	Undergrazing, overgrazing, fertiliser, diffuse pollution, inappropriate cutting/mowing			P	P (sewage fungus found) [Past sewage & slurry problems have been addressed)	P (flooding of enriched water in drain from south)		Y (grazing levels / scrub)	Arable / improved grassland / roads / houses etc	Some nettle invasion at S end (outwith main basin)			Yes
Brookhouse Moss	SJ806618	Unfavourable recovering (2003)	X	Y (water levels in main ditch need control)				P (enriched water in new drains to W)		Y (scrub)	Improved pasture / arable	None mentioned	Sphagnum lawns in generally good condition		Yes
Brownheath Moss	SJ460300	Favourable (2000-2)	X			P (agricultural run-off at edges)	P (septic tank)			Mainly alder woodland - policy of minimum intervention.	Arable / semi-improved / roads / houses	None mentioned			Yes
Brown Moss	SJ562395	Unfavourable recovering (Basin mire) (2003)	X	P (drains)	P (abstraction)	P (agricultural run-off)		P (Nutrients from tree litter inputs)	Recreation (trampling)		Mostly improved grassland. Immediate Moss catchment is woodland.	No	Concerns regarding long-term fall in water levels.		Yes

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Chartley Moss	SK027283	Favourable / Unfavourable recovering (2003)	X	P (marginal drains)	Abstraction consents being investigated under RoC.	P (agricultural run-off/spray)		P (base-enriched aquifer; roosting corvids). Discharge consents being investigated under RoC		Y (pine, scrub & rhododendron)	Improved pasture / arable / buildings / woodland	Enrichment under trees; area of fen vegetation;	No reasons or comments given on ENSIS for current status (favourable / unfavourable-recovering)		Yes
Clarepool Moss	SJ435343	Unfavourable recovering (2003)	X			P (agricultural run-off/spray). Some land on the east side managed as buffer zone.	P (septic tanks)	P (road run-off)		Y (scrub, bracken)	Arable / semi-improved / woodland	None mentioned	Some land on the east side acts as buffer strip.		Yes
Cranberry Bog		Unfavourable no change (2003)	Inappropriate weed control			P (agricultural inputs to marginal drains, but doesn't appear to affect ombrogenous vegetation)	P (concerns regarding septic tank discharge into peripheral ditch)			Pine on bog surface, Himalayan balsam dominating lagg/peripheral ditch	Improved pasture / arable / housing	Loss of aquatics. Nettles around margins.			Yes
Flaxmere Moss	SJ556723	Main moss area is unfavourable recovering; 'buffer' area is favourable (2002)	X	Y (water levels need to be raised/controlled)		P (agricultural run-off/spray), but part of site acts as a buffer	Y (septic tanks). Partly addressed, but may still be an issue?	P (leaf litter inputs)	Small scale peat cutting	Y (scrub, bramble, aliens)	Improved pasture / arable / housing / conifers	None mentioned			Yes
Forest Camp (Abbotts Moss)	SJ598691	Favourable (2000)	X		P (concerns being investigated under RoC)		Past concerns have been addressed			Y (scrub control)	Woodland / conifer plantation + water from Abbots Moss	P (eg presence of Typha in Lily Pond, and Glyceria in other basins?)			Yes
Gleads Moss	SJ821685	Favourable (1999)	X			P (agricultural run-off/spray)				Y (scrub)	Mainly arable / (±semi-) improved grassland	None mentioned			Yes
Hencott Pool	SJ490160	Favourable (2001)	X	P (deep boundary drains)		P (agricultural run-off/spray)			Tipping; damage by Canada Geese	(Non-intervention policy)	Intensive agriculture (arable / pasture)	Not obvious			Yes

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Lin Can Moss	SJ375211	Favourable (2000)	X		P (considered vulnerable)	P (agricultural run-off/spray)				Y (scrub)	Almost entirely arable	None seen or mentioned			Yes
Linmer Moss	SJ547707	Unfavourable declining (2003)	Forestry; inappropriate ditch management; inappropriate scrub control	Y (drainage and flooding)				P (road limestone)		Y (scrub & conifers)					Yes
Loynton Moss	SJ788244	Unfavourable recovering (2003)	X	Y (drainage of surroundings - being addressed)						Y (scrub)	Mainly arable / grassland. Eastern catchment includes village & sewage works.	None seen or mentioned			Yes
Morton Pool and Pasture	SJ301239	Favourable	X	P				Y (factory, but problem sorted)		Woodland - not managed. Damp grassland is grazed.	Incl. arable, (semi-)impr. pasture, woodland, houses.	Pool appears to be eutrophic (reason unknown)			Yes
Oakhanger Moss	SJ767552	Unfavourable recovering	X	Y (sluice now installed on outfall ditch)				P (M6 road drainage)		Y (scrub)	Includes semi-natural, improved grassland, arable and built development				Yes
Shomere Pool	SJ505079	Unfavourable no change (1997)	Diffuse pollution, inappropriate scrub control				P (septic tank)			Y (Threat from encroaching alders - clearance needed).	Immediate catchment to the pool is woodland; catchment to the site includes arable.	None mentioned	It has not been established how much (if any) of the fen & woodland surrounding the pool is within the 'basin'		Yes

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Shrawardine Pool	SJ398162	Favourable	X	P	P	P (agricultural run-off/spray)		Y (farm drain)	Y (puddling of margins by livestock; dredging of pool; rubbish)	(Policy of non-intervention)	Intensive agriculture (arable / pasture)	Thick layer of duckweed in the Pool. Nettles.	Marked fluctuations in water levels but reasons not yet established		Yes
Sweat Mere	SJ438305	Favourable (2000)	X	P (outfall ditch)		P (agricultural run-off/spray)		P (supplementary feed for game birds)		Policy of limited/non-intervention.	Mainly agricultural	None mentioned			Yes
Wybunbury Moss	SJ696503	14 units: mainly favourable or unfavourable recovering (2000)	(SU8: Undergrazing)	Water levels are controlled by sluices	Being assessed under RoC	P (agricultural run-off/spray)	(Septic tank discharge problem has been addressed)	P (runoff from roads, houses etc.)		Y (scrub, pine)	Includes improved grassland, arable and built development	Yes - change in vegetation and degradation of peat. Water quality data (including microbiological)			Yes
North-east															
Barelees Pond	NT872384	Favourable (2002)	X			P (agricultural)			Concern over pool filling in.		The eastern field was a Lolium buffer. There is no buffer on the west side (barley right to edge) but the fertiliser is applied into the ground with a disc to minimise loss.	Some signs of algae at N end of the pool - possibly due to nutrient inputs.	EN seeking advice about CSS buffers.		N
Bingley South Bog	SE115386	Part destroyed (2002)	Planning permission	Y (control of water levels)		P?			New by-pass fly-over crosses the Bog.	Y (scrub)	Urban and some grazed fields	None mentioned			N

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Campfield Kettle Hole	NT862381	Favourable (2003)	X		P	P (agricultural)				Undergoing natural succession	No buffers - cereals at SE end, set-aside/pasture to North and SW.	No obvious adverse effects.	Concerns over falling water levels and loss of open water.		N
Caw Lough (Roman Wall Loughs)	NY770691	(No condition given for mire)	X	P (past drainage; current situation unknown)		P. (Possible enrichment from fields. Water quality in nearby loughs has declined, but Caw Lough has not been monitored)		(Run-off from cattle shed in the past)		Non-intervention. (Possibly lightly grazed from adjoining land)	Mainly unimproved hill grazing with areas of heather and mire vegetation with deergrass, purple moor grass and hare's-tail cotton grass. Some improvded fields.	Not known			N
Hart Bog	NZ452334	Favourable (2002)	X	N	N	P (agricultural)				Y (scrub)	A highly fertilised arable catchment - conifer plantations on 2 sides may help to provide a buffer.	No issue regarding enrichment noted by EN. Wheeler & Shaw found phtometric evidence of increased fertility at margin in 1987.	Scrub encroachment is considered the main issue.		N

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Hardacre Moss (Newby Moor)	SD717692	SU3, includes Hardacre Moss: Favourable (1999)	X			Y (close to intensively-farmed fields, although fertiliser not applied in lower parts of fields near Moss)		P (from slurry / fym applications)		Thought to be OK, but hasn't been assessed since 1999. Roads have discouraged commoners from putting on stock, so there is a general problem of undergrazing on the Common.		Visual assessment suggests some vegetation change - other species invading and fanning out in the Moss.	Citation for Newby Moor mentions several basin mires. Hardacre Moss is the most extensive and species-rich.		N
Pike Whin Bog	NZ415334	Unfavourable no change (25/9/2003)	Undergrazing	P (Concerns have been expressed about the bog drying out - possibly exacerbated by drains installed to intercept agricultural run-off.)		Y (agricultural)			Possible increased sediment inputs	Y (undergrazed)	"Arable desert"	Much Agrostis stolonifera & Juncus effusus. Margins rank and weedy. Wheeler & Shaw (1986) found evidence of increased substratum fertility			N
Pilmoor	SE460730	Unfav. Rec / unfav declining. (1997-2001)	Inappropriate scrub control	P (Concerns have been expressed about the bog drying out - but reasons unclear)						Y (scrub). (Presence of trees may contribute to the perceived drying of the site?)	Agricultural	Not known	ENSIS habitats/features are woodland and heath, not mire		N

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Skipwith Common	SE655373	Unfavourable recovering (2000/2003)	X	P (marginal drains; 1 internal ditch is dammed)	P	(On watershed - does not receive run-off inputs from surrounding land)				Y (scrub)		N	ENSIS habitat / feature is heath not mire		N
Cumbria															
Blelham Tarn and Bog	NY365005	SU5: Unfavourable declining (1998)	Diffuse pollution (but not mentioned in ENSIS comments)			Y	P (identified as a possible problem for the Tarn - not clear if it could affect the basin mires)			Y (may need light grazing & control of birch?)	Surrounding catchment appears well-fertilised.	Algae in the tarn	SSSI citation mentions 2 basin mires. No wetland habitat identified on ENSIS - the Broad habitat / feature description of SU5 (the NNR containing Blelham Bog) is listed as 'Earth Heritage' - Inland outcrops and stream sections.	Y awaiting comment from EN - why not basin mire?; any indication of pollution?	Y (scanned)
Brown Stone Moss (Claife)		Part of Claife Tarns & Mires									Conifers	None mentioned		Awaiting comment from EN.	
Burney Tarn Mire	SD254859	SU 10. Favourable (1998-2002)	X					Localised enrichment from duck feeding at Burney Tarn		P (Overgrazing?)	Rough grazing and some improved grazing	No			No

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Cliburn Moss	NY576256	Unfavourable declining (9/7/02)	Fertiliser use; inappropriate scrub control		Concerns raised, but no firm evidence yet	Y (agricultural run-off)				Y (scrub and pines)	Fertilised fields	Yes (soakway vegetation and nettles on margins). Wheeler & Shaw found evidence of increased fertility in the M9 in 1986. Some recent water chemistry results available.	Bioremediation (helophyte filters) being considered to help alleviate enrichment		N
Cropple How Mire	SD131975	Unfav. recovering. (10/12/1998)	X	Blocked drains causing flooding on neighbouring land. May need to be cleared out (but not deepened)		P (Inflowing streams from higher ground, where 1cwt/acre/year of compound fertiliser is applied and 2 cwt/acre lime and phosphate is applied every 2 years)				Y (birch scrub)		Oenanthe crocata and Urtica. Effects appear to be localised.	Considered in good condition		Y (scanned)
Great Candlestick Moss	SD400926	SU 8. favourable (2002)	X							(Grazed)	Semi-improved / Rough grazing (+road/track))	None mentioned	No problems identified		No
Great Ludderburn Moss	SD402920	SU 7: Favourable (2002)	X	Old drains with beneficial effects as the ditches support fairly interesting communities.						(Grazed)	Semi-improved / Rough grazing (+road)	None mentioned	No problems identified		No
Hallsenna Moor	NY066007	Open areas unfavourable no change or declining (2001)	Undergrazing	P (further study required)		P (Does get agricultural run-off but not known whether this is a problem)				Y (scrub / grazing / rhododendron)	Mostly dairy pasture / imp. grass.	Possibly - eg stands of tall herbs around margins.	Site possibly drying out - reason unknown. [There is a sand & gravel quarry nearby]		No

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Highs Moss (Claife)	SD375980	SU5. Favourable (2000)	X	Y (Water was seeping from outflow dam in 2002 - situation to be monitored)						Work has been done to maintain some open water habitat.	Basin is surrounded by conifers	No	Water level maintained by a dam		Y (Claife)
Hollas Moss	NX999070	Favourable (2001)	X			P (agricultural)					Agricultural	None found			Y (Silver Tarn)
Low Church Moss	NY016057	Part destroyed (22/6/1999) [Open water]	Agriculture (other)			P (Likely to receive some agricultural run-off and possible nutrient enrichment from drains)		Slurry, dead sheep, farmyard manure and silage; fly tipping		Y (scrub and grazing regime)	Part of surrounding land is in Countryside Stewardship	Enrichment could be cause of alder/willow die back observed in southern section of site?			N
Moorthwaite Moss	NY511511	Unfavourable declining (2000)	Tree management / inappropriate scrub control	Y (some drains have been dammed)		Y (agricultural)		Possibly silage effluent / slurry from farm?	Has been cut-over	Y (some clearance of scrub / pines has been undertaken; more needed)	Agricultural	Adverse effects on wetland vegetation along drains / peat cuttings (eg nettles, Holcus, Stellaria alsine)			Y (scanned)
Newton Reigny Moss	NY478309	Unfavourable declining (1998 -)	Diffuse pollution & inappropriate scrub control	Knowledge of hydrology poor, influence of ditches uncertain, site can be very wet but unaware of seasonal variation.		P (agricultural)		Localized enrichment problems. (Buried sheep carcases & dumped silage bales / slurry)	Problems of siltation and succession.	Y (limited herbaceous fen as site now mainly wooded)	Agricultural	Large area of nettles on E side.			N
Nor Moss (Claife)	SD377992	Favourable (1999)	X	P. (Water levels could be controlled in future by blocking or installing sluice in western boundary ditch if needed)						Y (encroaching pines)	Surrounded by conifers	None mentioned			Y (Claife)

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Outley Mosses	SD363819	SU 1, 2 (Bog) Unfavourable declining (2002). SU 3 (Flush), 4, 5 (Bog) Favourable	Overgrazing					Tipping on inflow; stock feeding on catchment		Y (grazing / cattle poaching problem)	Unimproved acid grassland / semi-improved pasture / conifer plantation	Presence of Typha	Evidently a complex wetland 'site', including topogenous and soligenous mires.		N
Peat Moss (Ludderburn/Candlestick Mires)	SD402921	Part of SU 6 Favourable (2002)	X							(Grazed)	Semi-improved / rough grazing (+road?)		No specific information		No
Silver Tarn	NX999068	Favourable (both basins) (1998/1999)	X			Y (agricultural)		Fly tipping on SE margin of W basin	Authorised moss collecting by local fishermen.	Y (scrub)	agricultural	Some floristic and phytometric evidence of nutrient enrichment, with an increased prominence of grasses and fen meadow species such as *Lotus uliginosus*.	Carr woodland at E end of E basin may be helping filter out some nutrients from catchment. Silver Tarn SW is thought to have deteriorated.		Y
Tarn Moss	NY400275	Favourable (2002)	X	P (marginal drains)		P (agriculture)		P (road & railway bed run-off)		Vegetation not actively managed, but few trees - probably kept open by deer grazing.	Agriculture, conifer plantation, rough grazing (fell), road	Siltation/spread of Juncus. Water chemistry monitoring started in 2002.	Potentially vulnerable to contamination from severe spillage on the A66.		N
Temple Sowerby Moss	NY616270	Unfavourable declining (1998)	Direct pollution & inappropriate scrub control	P		P (agriculture)		Tipping has occurred on south-eastern side, behind buildings. (this is into a ditch which used to have rare beetles in)	Possibly a cut-over raised mire	Y (now mostly dense woodland rather than herbaceous fen)	Agricultural	Some areas appeared enriched (especially NW edge which is below heavily improved field; dense nettles and lush grasses). Also algal growth.			N

Site Name	Grid Ref	ENSIS condition (date)	ENSIS adverse reasons	Land drainage	Abstraction etc	Diffuse pollution	Sewage discharge	Other nutrient/ pollutant sources	Other issues	Vegetation management	Land use in surface water catchment	Evidence for enrichment on site	Comments	Queries	Catchment map?
Unity Bog	NY529590	Favourable (15/2/1999)	X		N		(Sewage outfall mentioned on 1993 map)						Birch stunted, lots of Sphagnum, no apparent threats. Little clear evidence on which to base decision regarding wetland type. Citation calls it "valley / basin mire type" in a glacial hollow. Small "fluid schwingmoor" indicated on one map.		y (scanned)
Ustick Moss (Claife)	SD375980	SU8: Favourable (2000)	X							Y (birch scrub + larch/spruce). Site fenced in 1986.	Surrounded by heavily grazed pasture with J effusus.	None mentioned			N

Appendix III. Models used for calculating buffer zone widths

Simple Ratio Model

The buffer zone width is related to the size of the catchment. This approach has been used to determine riparian buffer zone widths in relation to the size of the river basin. It may be possible to use a similar, straight-forward relationship to advise on zone widths in fen catchments although this has not yet been attempted (Williams & Nicks, 1993).

Slope Relationship Models

These models introduce the additional element of slope as well as catchment size. Again, they have only been applied in the context of river basin catchments but there is a potential for adaptation.

Riparian Ecosystem Management Model (REMM)

REMM is a computer model used to simulate hydrology, nutrient dynamics and plant growth for land areas between the edge of fields and a water body. It is used to calculate riparian forest buffer zones.

NICOLAS : Nitrogen Control by Landscape Structures in Agricultural Environments

Born from concern about nitrate pollution impacts and used to identify the range of conditions (climate, geomorphology and farming system) under which riparian zones offer effective protection to freshwater ecosystems. It evaluates the N retention and transformation processes of morphologically similar riparian areas within representative agricultural drainage basins of Europe. The results obtained will be used to calibrate a European-based REMM. NICOLAS uses the procedures produced by the FAEWE project. It may help identify buffer zones situated away the fen that are serving to protect the fen or have the potential to do so (Blackwell and others*,* 1999; NICOLAS, 2003).

Functional Analysis of European Wetland Ecosystems (FAEWE)

The EU funded FAEWE Projects involve the development of procedures for evaluating the functional characteristics of wetland ecosystems. It adopts a hydrogeomorphic approach, based on HGMUs (a HGMU is an area of homogeneous geomorphology and hydrology/hydrogeology and homogeneous soil) to help in the interpretation of wetland functioning. This includes studies of N-mineralisation and plant production based on HGMUs, at sites where anthropogenic impacts affect changes in wetland functioning. The assessment procedure may help identify areas suitable for specific functions like N removal and assist in locating buffer zones. The approach has been designed for river marginal wetland ecosystems but may also be used in fen catchment studies (Maltby and others*.,* 2004).

Riparian Management Systems (RiMS)

A model devised at the Leopold Center for Sustainable Agriculture, Iowa State University. It consists of rows of trees and shrubs adjacent to the river with an additional filter of perennial grasses on the outside of the trees. The width of the buffer increases with size of the river and the catchment area. It is used particularly in the restoration of degraded river corridors (Iowa State University, 2004).

Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS and successor GLEAMS)

The prediction model is currently widely used in the USA. It estimates chemical pollution and sediment loss from agricultural sources and has been used to calculate buffer zone widths. It requires information on precipitation, radiation, temperature, land use, cultural practices, plant nutrients and pesticides and is described as not very user friendly (URL:<http://www3.bae.ncsu.edu/bae473/models/CREAMS.txt>).

Universal Soil Loss Equation (USLE and successor RUSLE – R=Revised)

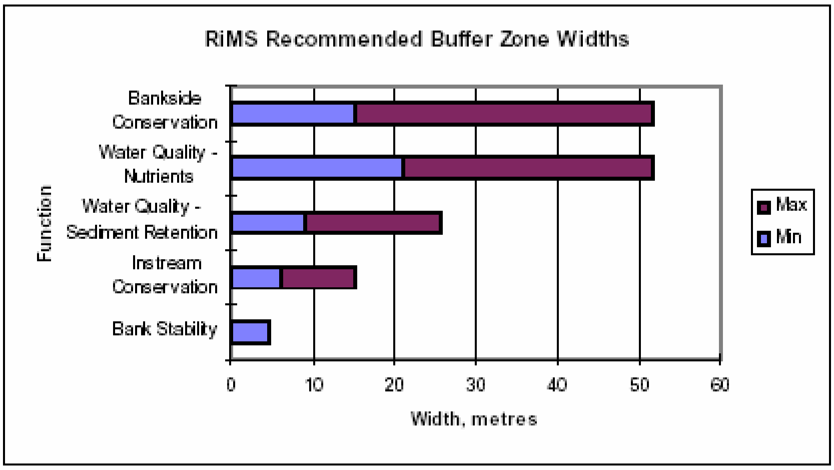
Not directly concerned buffer zone widths but soil loss is a significant environmental factor. USLE provides the best estimation of long-term average annual soil loss from arable land. The USLE has been used for over 50 years and computer aided successors like RUSLE2 are used to estimates rill and interrill erosion caused by rainfall and its associated overland flow (USDA, 2003).

Riparian Buffer Zone Delineation Equations (RBDEs)

RBDEs are a method for selecting suitable riparian buffer widths for water quality protection. It uses two formula for predicting the effectiveness of buffers in attenuating adsorbed pollutants delivered by overland flow, and dissolved pollutants transported primarily through subsurface flow. It makes use of Darcy's Law and Manning roughness coefficient equation. The results can be used in conjunction with GIS to indicate the effectiveness of a riparian buffer strip for a given area. It provides land managers with a way to objectively evaluate the need for establishing riparian buffer strips. The model results can be used as a guide for determining erosion susceptibility and pollution removal potential of riparian areas (URL:<http://www.grida.no/cgiar/awpack/water.htm>).

Water Erosion Prediction Project Model (WEPP)

WEPP is a complex computer program soil erosion model that describes the processes that lead to erosion. WEPP calculates the soil water content in multiple and plant growth and decomposition. The effects of tillage processes and soil consolidation are also modelled. This is available to download from the web (Elliot and Hall, 1997).



Recommended buffer widths for a variety of purposes.
(Source: UK-CHM <http://www.chm/org.uk/cats.asp?t=268)

PSYCHIC Model (Phosphorus and Sediment Yield CHaracterisation In Catchments)

This model does not directly concern the establishment of appropriate buffer zone widths but it represents an important UK initiative. Policy, regulatory and conservation bodies (Defra, Environment Agency and English Nature) have identified the need for a pragmatic decision support system to help implement pollution control measures in river catchments most at risk from diffuse agricultural pollution. PSYCHIC (Phosphorus and Sediment Yield CHaracterisation In Catchments) is a major new research project based on a GIS based decision support system for locating specific source areas of agricultural P pollution.

Two study catchments: Hampshire Avon and the Herefordshire Wye are being used to identify practical and cost-effective options for controlling P and particulate loss, as well as evaluating barriers to their uptake. The project also seeks to identify the data requirements and costs needed to operate such a decision. Control practices will then be chosen through informed process-based modelling approaches which can quantify the impact of changes in land management, and in P inputs, on particulates and P export at the field and catchment scale (Psychic Project, 2004).

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Front cover photographs:
Top left: Using a home-made moth trap.
Peter Wakely/English Nature 17,396
Middle left: Co_2 experiment at Roudsea Wood and Mosses NNR, Lancashire.
Peter Wakely/English Nature 21,792
Bottom left: Radio tracking a hare on Pawlett Hams, Somerset.
Paul Glendell/English Nature 23,020
Main: Identifying moths caught in a moth trap at Ham Wall NNR, Somerset.
Paul Glendell/English Nature 24,888