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CENTRE FOR ECOLOGY AND HYDROLOGY

(NATURAL ENVIRONMENT RESEARCH COUNCIL)
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Final Report to the Great Fen Project Steering Group

WILDLIFE HABITATS and THEIR REQUIREMENTS WITHIN the GREAT FEN PROJECT

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APPENDICES

EXECUTIVE SUMMARY

I. The last two millennia have witnessed a process of wholesale wetland drainage and agricultural intensification within the Fenland basin of Cambridgeshire, Lincolnshire and Norfolk. Within that time, there have been particular periods of concentrated activity *e.g.* the seventeenth century and the years since the Industrial Revolution. The net result of these changes was the reduction of (semi-) natural "wild" fenland to <0.1% of its extent in 1600.

II. Nature conservation in the UK has gone through three phases. At first, naturalists sought simply to preserve on nature reserves a relic of the former wildlife. This phase was followed by recognition that active management (conservation) was needed to maintain the biodiversity value of these reserves. The third phase has comprised an attempt to restore natural habitats where they once occurred, and to rehabilitate surviving fragments. In the Fenland basin, the move to wetland <u>restoration</u> has led to three very important schemes being conceived that, between them, would constitute the largest piece of habitat restoration in modern Britain.

III. One of these schemes comprises the *Great Fen Project*, focussing on the area around and between the National Nature Reserves (NNRs) at Holme and Woodwalton Fens. Its goal is to bring about a wetland nature reserve of some 3000ha on land that is now largely arable farmland. The scheme is managed through a Steering Group by a consortium of the Wildlife Trusts, English Nature and the Environment Agency. The Steering Group commissioned the NERC Centre for Ecology and Hydrology (CEH) to perform a further phase in a series of feasibility studies. The particular objectives of this phase of the research were to:

- Assess the present biodiversity value of the area, and the Biodiversity Action Plan targets to which restoration of the Great Fen might contribute.
- Assess the ecological needs of wetland species and habitats, and examine how far these could be provided for in the Great Fen Core Area.
- Provide a menu of habitats for future restoration on the Great Fen.

CEH undertook to perform this research at the "Broad Habitats" scale (*i.e.* fen, marsh and swamp; bog; standing water; neutral grassland and broadleaved woodland *etc*).

IV. Wetland restoration requires water - in the right amount and of the right quality for the target wetland type. This axiom meant that the first component of the research was to understand the water-budget of the proposed Core Area for restoration - how much water was there, where did it come from, how was it used and managed, where did it go and what was its quality. Section 2.1.2 provides a description of the water resources within the Core Area. Information was marshalled from the Lower Nene and the Middle Level, and the amount abstracted under licence for irrigation in the Core Area was calculated. Inputs to and outputs from the Core Area were measured: i) rainfall, ii) evapo-transpiration, iii) runoff of water from the adjacent higher ground into the Core Area; iv) pumping and outflow; and v) inflow diverted from the R. Nene.

V. The results of these calculations revealed that water was in excess during the winter, but that in summer existing entitlements for water use exceeded actual availability *e.g.* 140Mm^3 (million cubic metres) for water-supply, 7.4Mm^3 for environmental purposes and 28.7Mm^3 for irrigation and navigation. Licensed abstraction amounted to 0.67Mm^3 in summer and 0.64Mm^3 in winter. The resultant water budget suggests that the inputs include a rainfall total (555mm per year) of 20.8Mm^3, upland runoff of 8.1Mm^3 and potential diversion from the Nene of some 12Mm^3. On the output side of the equation are 20Mm^3 due to evapo-transpiration and >20.4Mm^3 lost to the Core Area through gravity drainage and pumping from Bevill's Leam pumping station.

VI. Information on water quality is available from five monitoring points around the Core Area. Using the standard General Quality Assessment, water varied from "fairly good" to "poor", with particular concerns in terms of high nitrogen levels and low oxygen availability. Work is in hand to improve this quality. The water pH was ≥ 8.0 (alkaline).

VII. The second stage was to assess what habitats and species of conservation importance existed within and adjacent to the Core Area. The relevant portion of the *Land Cover Map 2000* (derived from very recent satellite imagery) was abstracted, confirming that arable agriculture covered *ca* 80% of the Core Area, but that there were fragments of non-cultivated habitats outwith the two NNRs. The areas of these habitats in the Core Area were calculated and compared with the resource known to exist on sites designated for nature conservation both within the wider Fenland, and in other adjacent Natural Areas. The importance of the two NNRs for wet woodland, fen and lowland grassland was amply demonstrated.

VIII. Habitats mapped as present are not the only source of material for wetland restoration. It is believed that where the component species ("building blocks") of a habitat exist in close proximity, there is potential to restore that habitat. CEH therefore mapped the overlap in distribution of the key species of the Broad Habitats, and identified what restoration potential existed and where there was the highest "co-occurrence "of wetland species. The Core Area was shown to possess most of the elements of the target habitats, though it was acknowledged that some of these might be confined to the two NNRs.

IX. The project also made an inventory of all protected and designated areas within and near the Core Area, assessing them in terms of their Broad Habitats. Finally the goals set by the Biodiversity Action Plans (BAP), both national and county, were investigated for both habitats and species, to set a context within which planning the Great Fen restoration could take place.

X. Section 3 of the report comprised a literature review of the known physiological requirements of those wetland species and habitats relevant to the Great Fen Project. It was apparent that though the broad relationship between water (amount/quality) and wildlife was well understood, there was a dearth of quantitative information that might be used to set rigorous prescriptions for restoration. The best available material used the Sum Exceedence Value (SEV) approach to quantify for how long and by how much a habitat could be stressed by drought or waterlogging before it was damaged. Other measures were used for individual sites and studies.

XI. The report assessed the use of evapo-transpiration to characterise how much water a habitat required and consumed. Use of this variable allowed direct comparison of the water-regime needs of arable crops and restored wetland habitats. The approach used a standard irrigation approach to identify how much water plants require to minimise stress and maximise yield. The evapo-transpiration (ETc) of the crop or wetland vegetation was compared with that of a short grass reference crop (ETo), with a "crop coefficient" (Kc) that integrates the effects of transpiration and evaporation and which is specific to that vegetation.

XII. The interaction between water-level and nutrient status of the water for restoration was considered. The fen peats in the arable Core Area are now quite acidic, and it was concluded that addition of nutrient rich surface water to acidic fen soils may cause problems. There was some concern that the pH of surface water may even be too high for fen restoration, although some possibility existed of dilution by more acidic rainfall. Generally waters would not be well buffered because groundwater inflow in the Core Area was very low indeed.

XIII. Constraints to successful ecological restoration were summarised together with the means whereby these might be overcome. Constraints were both abiotic (soil and water) and biological (notably lack of propagules and altered soil microbial communities). Methods for reducing soil fertility were listed, and means of accelerating the colonisation of desirable species on the restored wetland.

XIV. The last part of section 3 outlined some case studies on wetland restoration, both small-scale and those more comparable with the Great Fen Project *e.g.* Lauwersmeer and the Oostvaardersplassen in the Netherlands. Some very preliminary ideas at costing the Great Fen scheme were described, with special attention to the likely costs for successful restoration identified within the UK and Cambridgeshire BAPs. Ease of restoration was ranked for different habitats.

XV. Section 4 comprised the key focus of the report, where the requirements of the target habitats were compared with the practicality and likelihood that these conditions could be provided in the Core Area. There is a summer water deficit for wetland vegetation, with insufficient water to meet full evaporative demand (average shortfall for reedswamp *ca* 3.3Mm^3). In order to allow wetland restoration over the bulk of the Core Area, some water storage appears necessary. A soil moisture accounting model (see XIX-XXI below) was used to assess the implications of different volumes of storage plus the duration/severity of any stress period (drought *etc*).

XVI. The relationship between amount of water storage and area of wetland that could be supported was portrayed. Without any water storage the present area of NNR wetland (*ca* 4.9km^2) could be increased to 10km^2. With *ca* 3.3Mm^3 of storage, the total area of wetland could be increased to 17km^2. Such calculations do assume that it will be possible to move water around within the Core Area to where it is required, and that there is no requirement for agricultural irrigation within the Core Area. The projected areas of wetland are those that could be maintained assuming that soil moisture remains above the Permanent Wilting Point in four years out of five.

XVII. Sufficient water for the restoration is available to the Great Fen in 84% of years, assuming that winter discharge (loss from the Core Area) at Bevill's Leam pump can be greatly reduced. In the remaining years some diversion from the Nene might be possible to meet the shortfall. The Environment Agency are at present content to permit winter storage for use in summer abstraction.

XVIII. Such calculations assume current climate conditions. However, the evidence is persuasive that the climate is changing with resulting potential impacts on water available to the Great Fen scheme. Amongst the various possible scenarios, one (the UKCIP98 Medium-high forecast) was tested for its possible impact on the Project. Although winter inputs increase to the Core Area, summer inputs are reduced, implying a need for more storage capacity or a reduced area of restored wetland. A thorough study of the range of possible impacts of climate change is required.

XIX. Modelling the hydrology with the Core Area estimated a) the water balance; b) the area of wetland habitat that could be supported; c) the between-year variation in water-balance; and d) the potential stress on the target habitats. It was assumed that the restored Great Fen would consist of a mosaic of dry grassland, wet grassland and a fen/reed/open water complex. Each habitat was modelled separately but linked by water-fluxes, with two external resources: summer irrigation of wet grassland and topping up of the fen complex in the winter. Rainfall, transpiration and drainage were also factors in each model, which comprised three compartments: a root zone, subsoil and a geological layer.

XX. The models predicted soil-moisture deficit, evapo-transpiration rates and average annual runoff. Runoff was graphed against rainfall for the whole year and for the winter period, and a predicted annual runoff for each habitat type was produced. In the dry grassland model, it is predicted that most runoff would occur in the spring, and that the temporal pattern in soil-moisture deficit is as expected. The drainage flux in the model was very sensitive to both the groundwater flux and the amount of water that can be stored in the root zone. Output from the same climate change scenario were applied to the model, and showed that dry grassland would then be parched for most of the summer, but that there would be more winter water available to top up the fen complex.

XXI. The wet grassland model was rather more complex, involving flooding of surface water and groundwater from the fen complex, as well as the possibility of irrigation. Within the "fen-pond complex" model, the irrigation factor was replaced by the potential to top the ponds up during the winter, and a "weir" control was introduced to control the maximum water-levels that could be achieved. The sensitivity was tested of this model to the area contributing to its existence ("catchment"), its target depth and availability of winter topping-up. These tests revealed that unless water could be diverted to the site in winter, open-water ponds would be transient vernal features. More optimistically, climate change is predicted to have no marked impact on the water level in the fen-pond complex, though without winter topping-up, the ponds are very unreliable.

XXII. The manner in which sensible targets could be adopted was discussed. Attention was paid to those BAP targets already set, to the landscape and habitats prior to the last major phase of drainage (mid-19th century draining of the meres) and to a pragmatic and broader perspective. Following discussion with the Steering Group, the focus of the scenario construction was on rapid restoration of low-maintenance habitats that might subsequently develop into more highly valued fen communities. Hence the initial focus of the modelling and the scenarios was a mosaic of dry grassland, wet grassland and a fen complex (including reedbeds and open water). Amongst the possibilities for the freer-draining higher (>1m AOD) ground were calcicolous and calcifuge swards related to those of Breckland, as well as boulder-clay grassland on the Core Area margins.

XXIII. The scenarios were integrated through a Geographical Information System (GIS), using output from the models and micro-topographic information derived from *LIDAR* imagery. The approach assumed a winter take-off of $3Mm^3$ for reed and open water, and a potential summer take of up to $1.8Mm^3$. This system would possibly fail one year in five, the dry grassland would be stressed during the summer and assumes up to a 500mm fluctuation in the level of the ponds. The habitat types were distributed on the basis of elevation. Up to $7.2km^2$ of fen (water-levels allowed to fall naturally through the summer) and $5.0km^2$ of wet grassland (requiring summer irrigation) could be restored, provided there is winter storage of $3Mm^3$ of upland runoff. The remainder of the site would initially be restored to dry grassland.

XXIV. Maps portraying the distribution of Broad Habitats identified the zone immediately north of Holme Fen as having the main area of fen and open water. The maps have no external storage *i.e.* supply is from upland runoff and Nene transfer, with water held in the reedbeds *etc* of the restored fen. Further scenario maps were subsequently incorporated as Appendix 4, with the conditions for restoration set such that summer abstractions would not exceed the average of what is presently taken, and that there would also be no winter diversion into storage.

XXV. A key conclusion of the work is the desirability of $3Mm^3$ of storage to maintain flexibility in the restoration, and maximise the area of potential wetland. This should be achievable through reduced discharge down Bevill's Leam. Further calculations on the area of fen and wet grassland were made on the basis of whether additional storage would be possible or not (section 6.2). These calculations were compared with the target areas for restoration in the national and Cambridgeshire BAPs. Even without storage of winter water for summer use, the Great Fen scheme would meet or exceed most of the local targets and make a major contribution to the national targets. Given the flexibility afforded by storage, the Great Fen (together with other schemes under way in Fenland) would provide the single biggest contribution to wetland restoration in the UK.

XXVI. The need for further research was reviewed, with greatest stress on increased hydrological information in the Core Area *e.g.* actual discharge, runoff from the uplands, proportion of inflow from the Nene that is available to the Core Area, volumes of water pumped and actual evapo-transpiration from the local wetlands. A detailed hydrological model for the Core Area should be developed, and ideally augmented with ecological models to produce an integrated whole. Such eco-hydrological approaches need rigorous and quantitative information on the water-regime requirements of the full range of plants and animals that comprise fen habitats. Further research on climate change and its impact on the Great Fen are clearly required. Some attention to the need for within-site water-control and engineering is required to provide an estimation of the costs of site management and flexibility. Finally improved data on the distribution of biota in the Great Fen area are needed, especially with regard to invertebrates.

XXVII. The report includes a body of supporting and illustrative or background information included in a series of appendices. These include i) definition of the Broad Habitats and their relation to the National Vegetation Classification; ii) results of co-occurrence mapping; iii) lists of protected areas; iv) a summary of all relevant BAP (local and national); v) tabulation of the habitat requirements of key species and communities; vi) explanation of the SEV approach; and vii) an illustration of the types of model and prescription used in other wetland restoration schemes.

1 INTRODUCTION: APPROACH and RATIONALE

1.1 From preservation through conservation to targeted restoration

At its beginning around the turn of the 19th and 20th centuries, the movement to protect wild nature in Britain focused on preserving those highly-valued fragments that survived, whilst rather little attention was given to the "wider countryside". Indeed, the names of some of the early NGOs to advance the cause of nature reflect this underlying philosophy of preservation and protection *e.g.* the *Society for the Promotion of Nature Reserves* and the *Royal Society for the Protection of Birds*. Effort focussed on purchasing the "best bits" and guaranteeing their survival for the future use of naturalists and collectors. However, it was not long before this approach was questioned by the promoters of the growing discipline of ecology. For example, at Wicken Fen (declared a nature reserve in 1899), although Wallis (1904) described the fen as appearing "*.... during most seasons of the year as a brown waste dotted with bushes......*", just 25 years later Harry Godwin (1929) observed that "*In all parts of the fen the sedge and litter may be seen in various stages of colonisation by bushes, and as the density of these increase...(typical species of rich fen)... are killed out.......*" Any rigid attempt to preserve the fen "in its natural state" by excluding all human influence, the ecologists argued, would soon eliminate most of the species it was desired to conserve (Godwin and Tansley 1929).

Thus the middle and latter parts of the 20th century became the era of nature conservation and the management of communities for conservation. Tansley (1945) contended that wildlife had to be preserved from damaging forms of land-use, but that this required more than a museum, more than placing a fence around the site of value and leaving it to look after itself. Some divergence of conservation philosophy could be observed between on the one hand, Western Europe, and on the other, Eastern Europe and North America. This debate was recognised by Westhoff (1971): "*Until a quarter of a century ago, nature preservation implied that man must be kept out. Human influence was considered an undesirable disturbance; nature should be left to look after itself. In the western European countries this viewpoint is nowadays considered to be an outdated idea*". To a great extent, one can relate these contrasting viewpoints to the status of wildlife in the two regions. In western Europe, valued habitats were semi-natural, frequently of very small extent and maintained by some traditional management regime. In North America and Eastern Europe, the concept of wilderness was much more valid, with extensive areas that had never been permanently occupied by humans or subjected to their intensive use. Such areas existed in a (nearly) natural state, and nature protection areas could be selected for their ecological wholeness.

Whatever their perspective, by the 1960s nature conservationists were expressing disquiet about the long-term sustainability of conservation strategies. Speaking in 1981, Derek Ratcliffe felt that there was "*... a danger of winning some minor battles whilst steadily losing the war*" (Ratcliffe 1981). Though saving key sites and protecting species through the scientific management of nature reserves was vital, the insidious isolation and deterioration of such sites could only be countered by a broad approach to nature conservation in the countryside with the re-creation of biotopes as a key tool (Sheail *et al.* 1997). The science of ecological restoration was under way.

1.2 Ecological restoration

Cairns (1988) defined ecological restoration as the "*.....the return of an ecosystem to an approximation of its structural and functional condition before damage occurred*". Much earlier, this goal had been implicitly recognised by Westhoff (1971): "*.....nature conservation has to maintain and <u>increase</u> environmental variety*". Such statements require qualification however - what needs restoring, where should it be restored and how does the nature conservation manager know that ecological restoration has achieved its objectives?

Success in both ecological restoration and habitat management requires planning in a clear framework of objectives and measurable outcomes (Gilbert *et al.* 1996; Treweek *et al.* 1993). The approach to setting restoration objectives that the CEH team promulgated *begins* with an estimation of the past and present distribution (and geographical variation) of the resource *i.e.* species, communities and/or habitats. This stage if *followed* by a review of current management practices and trends *i.e.* what is declining (needing restoration) and under what conditions does it presently survive? This knowledge can then be *combined* with practical information on restoration techniques to assess the scope for restoration. Finally, schemes can be targeted to where losses have been most pronounced and/or implementation is surest of success (*e.g.* Mountford *et. al.* 1997, 1999).

Assessing success in ecological restoration may use a number of pragmatic or process-based measures. It is rather superficial to simply look to establishing the correct dominant species within a habitat with the right general physiognomy. It is much preferable to apply the following tests:

- ***Sustainability*** - does the restored habitat maintain itself with minimal intervention?
- ***Invasibility*** – does it resist invasions by new species?
- ***Productivity*** – Is net ecosystem productivity similar to the target habitat?
- ***Nutrient retention*** – if the restored habitat loses greater amounts of nutrients than the original, the community may be considered a "defective imitation".
- ***Biotic interactions*** – the right plants may be in place, but can this also be said of the <u>full</u> range of animals and indeed microbes? Can the habitat be said to have functional integrity?

1.3 The Great Fen Project and its research needs

At first British ecological restoration largely comprised relatively small-scale schemes *e.g.* sowing of wildflower mixtures on marginal land, creation of farm woodlands and rehabilitation of ponds (Treweek *et al.* 1991, 1993). However, in the past decade, much more ambitious programmes of restoration have been planned and begun, notably in the Netherlands (*e.g.* the Oostvaarderplassen: Kampf 2000). In Britain, the Fenland basin became a centre for this activity under the auspices of the *Wet Fens for the Future* programme. Phase I of this programme included a "strategic overview" of the scope for fen creation, bringing together and reviewing information on geology, ecology, hydrology, archaeology and land-use policy (Anon 1995). This feasibility study defined a study area of some 5000 km^2 within which it:

- Summarised the technical feasibility for creating three types of priority habitat: open water, swamp and wash grassland.
- Derived objective criteria to be employed in searching the landscape for suitable sites for fen restoration.
- Quantified the water-management constraints within which any fen restoration scheme would have to operate.
- Assessed how the needs for archaeological study, and the preservation of artefacts, might be served by and integrated within a programme of fen restoration.

Phase II of the *Wet Fens* Feasibility Study comprised assessment of a) the socio-economic issues and b) problems of peat wastage and soil acidification. By 2000, three important complementary schemes for fen restoration had been launched:

a) the Wicken Fen 100-year vision (Friday and Colston 1999)
b) an RSPB programme of reed-bed restoration in worked-out gravel pits; and
c) the Great Fen Project itself.

1.4 Objectives of the present research

As set out in the original Invitation to Tender (ITT), the work reported here must identify the types of wildlife habitat that it would be feasible to restore within the Great Fen Project area, taking into consideration a variety of factors including:

- Current habitats
- Soil types
- Topography
- Hydrological requirements

The proposed Great Fen work is intended to return an area of presently arable land around and between Holme and Woodwalton Fen National Nature Reserves back to near-natural wetland habitats typical of the Fenland. The overall vision is of a nature reserve of up to 3000 ha, which would not only extend the area of wetland habitat, but also secure the survival of those habitats represented within the NNRs. A new reserve of this size would allow a full range of fenland habitats to be restored, including reedbed, wet grassland and carr (wet woodland), as well as fen meadow and tall-herb rich fen in the longer term.

The present report continues a series of feasibility studies that have addressed questions of a) hydrology and water-supply (Cranfield University 1999), and b) soil types and agricultural capability (Duncan 2002). In addition, information on land tenure has been collated (Smiths Gore 2001). Taken together with the results of the CEH study, these reports provide an assessment of the physical constraints that determine which habitats may be practically restored.

The ITT set out a number of questions, grouped into four categories, and it is the objective of the present research to provide rigorously-grounded answers to these questions and guidance for the future implementation of the Great Fen Project:

Questions focussing on wildlife habitats:

- What are the typical wildlife habitats within the peatlands of the Fens Natural Area?
- Which wildlife habitats are found within the Great Fen Project area?
- What are the areas of these habitats?
- Which of these habitats have a National or Local *Biodiversity Action Plan* (*BAP*)?
- What are the targets and timescales for these habitats within national and local plans?

Questions focussing on habitat requirements:

- Summarise the current thinking regarding the physiological requirements of these habitats, giving references for all sourced material.
- Give examples (local, national and international) where these habitats have been created, preferably with costs included.

Questions focussing on Great Fen habitats:

- Matching theory to actual conditions, which habitats can be created within the project area?
- Which habitats can be created given realistic site modification work?
- With a stated tolerance, what areas of each habitat can be created?
- How will these areas be affected by managing water-levels?
- Provide a map indicating the distribution of each habitat in the project area.
- Given all of the above, which habitats and what areas should the Great Fen Project aim for?

Questions focussing on species:

- List the key species that will benefit from the creation of these habitats.
- Of these species, which require specific management prescriptions, beyond "typical habitat management good practice"?

1.5 Research approach and rationale

The NERC *Centre for Ecology and Hydrology* proposed the following framework for the research, answering the requirements of the ITT in logical order. Throughout the report, CEH has used the *Biodiversity Broad Habitats Classification* (Jackson 2000; UK Biodiversity Group 1998; UK Biodiversity Steering Group 1995), and discussed the implementation of the Great Fen Project at that level. CEH has developed Jackson's work further, enabling subdivided Broad Habitats to be cross-referenced against *National Vegetation Classification* (*NVC* Rodwell 1991-2000) communities (Appendix 1). Hence, within these Broad Habitats, some reference to example plant communities described in the *NVC*: is made where this is possible and/or relevant.

- Description and, where possible mapping, of the Broad Habitats for wildlife present in the Great Fen Project area (and Fens Natural Area), together with their areas and a summary of their importance in terms of Biodiversity Action Plans (local and National) .... **Section 2**
- Having supplied a Broad Habitats context, a summary of those BAP priority species and habitat dominants that may benefit from the Great Fen restoration is provided, indicating those for which targeted intervention or management may be required. .... **Section 2**
- A brief literature review is presented, outlining the physiological needs of the Broad Habitats, and putting particular stress on their water-regime requirements. Examples of relevant restoration schemes are given where target habitats for the Great Fen Project have been created, and where possible provide an indication of the cost of the schemes. .... **Section 3**
- In the Great Fen area the "restorability" of these Broad Habitats is outlined in terms of a) present environmental conditions (drawing on earlier feasibility studies); and b) possible site modification (especially through water-management).. **Section 4**
- Results are provided partly in the form of maps indicating areas of potential habitat. Comparison of what is practical with what is desirable in a local and national context, a prioritised list of Broad Habitats to be restored and their approximate areas is given. .... **Section 5**
- Following a summary set of conclusions for the future implementation of the Great Fen Project, the likely research requirements for the future successful development of this and complementary schemes in the region are briefly summarised. .... **Section 6**

2. THE GREAT FEN: THE EXISTING RESOURCE

The objectives for successful ecological restoration should be determined by the suitability of the local environmental conditions for the scheme, together with the availability of the appropriate species-pool to achieve the target habitats (Mountford *et al.* 1997, 1999). These criteria set both the abiotic and biotic constraints within which restoration schemes must function. Site preparation and management may be able to make considerable progress in alleviating these constraints, thus allowing a wider range of habitats to be restored (Walker *et al.* 2001). However, the more ambitious the activity required in order to overcome the constraints at the site, the less likely is the scheme to successfully meet its objectives. The first theme of the present report is therefore to set out what the starting conditions are, what habitats are present and under what abiotic conditions.

2.1 Abiotic aspects: hydrology and soils

2.1.1 *Introduction*

The primary aim of the Great Fen Project is the restoration of a range of wetland habitats over a Core Area of 37.5 km^2 in the vicinity of Woodwalton Fen and Holme Fen (Figure 2.1). Both Woodwalton Fen (2.30 km^2) and Holme Fen (2.62 km^2) are National Nature Reserves and important sites of semi-natural fenland habitat.

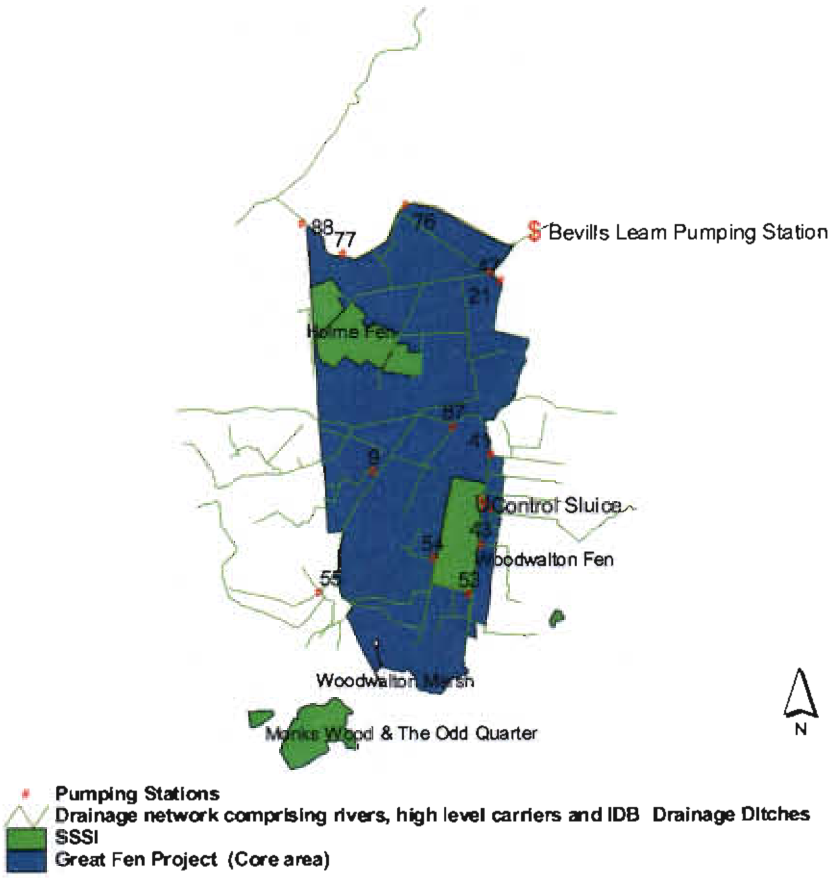


Figure 2.1: *Map of the Core Area and existing nature reserves*

A clear understanding of the hydrology of the area is essential in order to predict the effects of changing land-use, to confirm the long-term viability of the proposed wetlands and to improve management to increase the habitat value. The Great Fen project area is located within the Middle Level, part of the extensive low-lying fenland region of Eastern England. The Middle Level lies between the River Nene and the River Ouse (*i.e.* the Old Bedford River). The Great Fen area is bounded to the east by the Ouse Washes, to the south and west by low clay hills and by marine silts to the north. The Middle Level has an area of 705 km^2, of which 485 km^2 lies below mean sea level. Soft clays originating from marine and fluvial processes underlie most of the area (EA 1997).

2.1.2 *Water Resources*

2.1.2.1 Lower Nene

The two water resource concerns in the Lower Nene focus on a) abstraction to Rutland Water immediately upstream of Wansford gauging station and b) water quality through Wisbech. Figure 2.2 illustrates the main summer allocations in the Lower Nene. Overall demands exceed availability, including those necessary to maintain a target flow of 15 Mld^{-1} (a summer total of 2.75 Mm^3) into Moreton's Leam, which in turn supplies the Nene Washes. The summer demands from the Lower Nene are also summarised in Table 2.1.

Table 2.1: *Major summer water resource demands for the Lower Nene*

(Note: Data from Entec 2001)

Location	Purpose	Demand	
		Mld^{-1}	Mm^3
Nene to Rutland Reservoir	Support public water supply	764	139.8

Nene to the Middle Level - transfer at Stanground Lock	Support irrigation abstractions. Maintain 1) Navigation and river levels 2) Environmental requirements of region (including NNRs)	135	24.7
Nene to North Level – transfer at Dog-in-a-Doublet Sluice	Support irrigation abstractions Maintain river levels	10	1.83
Nene to Moreton's Leam flow at Stanground Sluice	Support Nene Washes	15	2.75
Nene Tidal Flow at Dog-in-a-Doublet Sluice	Maintain water quality in tidal Nene Allow fish pass operation	25	4.58

Riparian losses between Orton and Dog-in-a-Doublet Sluice	Uncontrolled seepage and evaporation losses	25	4.58
TOTAL		**974**	**178.2**

Transfers to the North and Middle Levels are both non-licensed abstractions, being deemed exempt for "land drainage" purposes under the *Water Resources Act 1991*. The Middle Levels transfer also has additional navigation related exemption. Total summer demands from the Lower Nene equate to 974 Mld^{-1} (a summer total of about 178.2 Mm^3). In recent years there has been an embargo on any new abstraction licences permitting summer abstractions from the Nene (Entec 2001). When low flows occur in the Nene, as in the early-mid 1990s, a management strategy is introduced to control abstractions on the Lower Nene. The present strategy was developed in the mid-1990s (Environment Agency 1996). Essentially the policy seeks to preserve the allocation of water resources to:

- meet losses on the Nene (*i.e.* between Orton and Dog-in-a-Doublet);
- maintain the 15 Mld^{-1} into Moreton's Leam for the Nene Washes; and
- maintain the 25 Mld^{-1} to the tidal Nene.

The other abstractions are managed according to a set of hydrometric criteria that reflect water resource availability/state, including Nene flows at Orton and drain levels in the Middle Level at Bodsey Bridge (National Grid Ref. TL294878). As water resources become increasingly scarce measures include:

- Restriction of spray irrigation licensed abstractions in the Middle Levels in accordance with licence conditions
- Co-operation from the *Middle Level Commissioners* (*MLC*) and North Level IDB to minimise transfer quantities
- Cessation of abstractions at Wansford

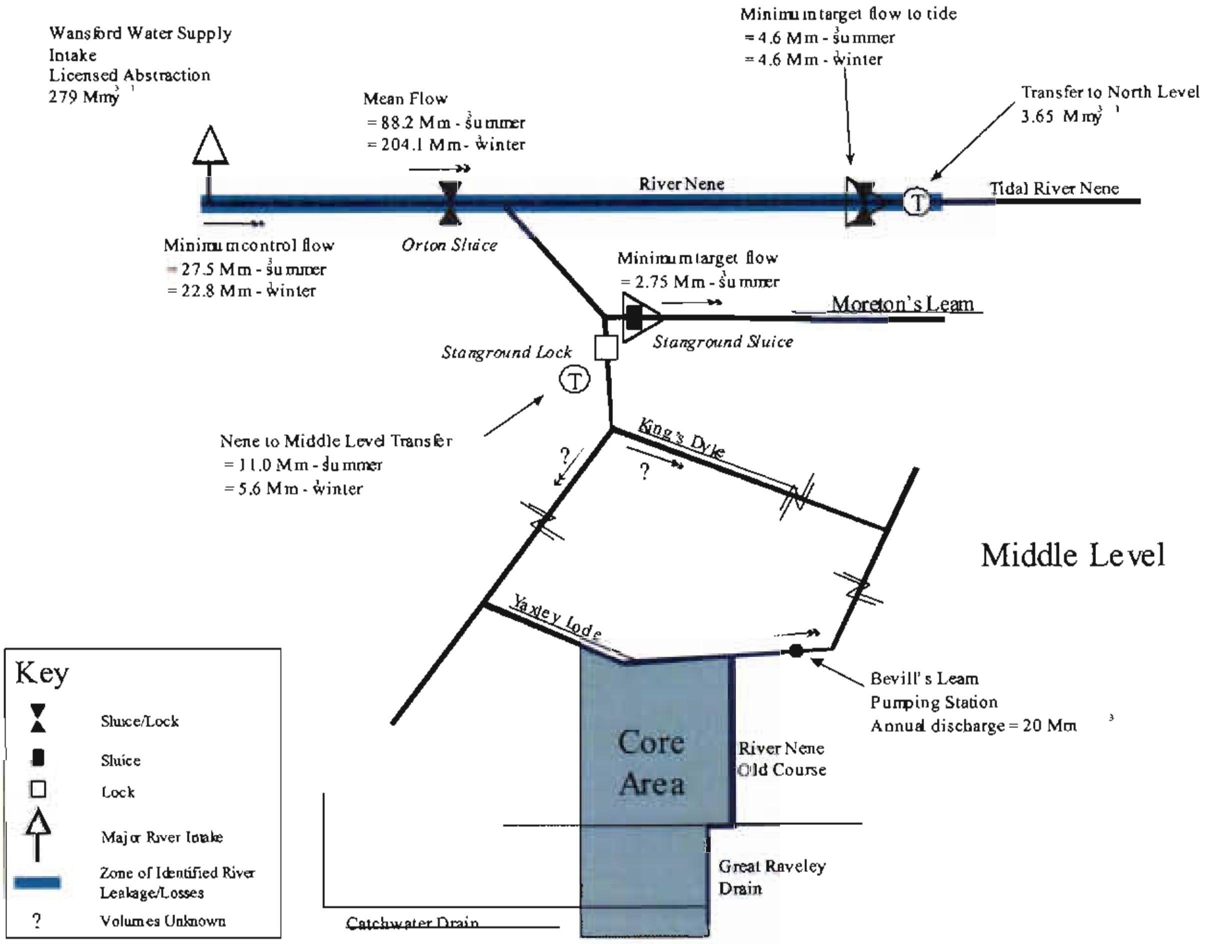


Figure 2.2: *Schematic showing major abstractions from the Lower Nene*

2.1.2.2 The Middle Level

In the 17th century, the Middle Level was developed for agriculture, by construction of a complex drainage network. Today the area is subdivided into 39 Internal Drainage Districts from which water is pumped into the main arterial drainage system via 78 pumping stations. The water from these is discharged into the tidal Ouse via the Middle Level Main Drain and the St. Germans pumping station. The *Middle Level Commission* (*MLC*) administers the area.

At present the water resources of the area are managed primarily for agriculture and navigation. About 92% of the Middle Level is used for arable cropping, predominantly cereals, sugar beet, potatoes and vegetables. Considerable volumes of water are pumped and moved around within the system in order to reduce flooding in the winter and to maintain water-levels for summer irrigation and navigation. Resources for irrigation (spray and sub-irrigation) are taken from internal storage within the watercourse system of the Middle Level with additional resources made available by diversion from the River Nene (at Stanground Lock).

The Core Area of the Great Fen project (Figures 2.1-2.2) has an upland catchment of 82.8 km^2 that drains into the area from the south and west. A number of main drains distribute water into, through and around the Core Area, with all flow leaving the area via the pumping station at Bevill's Leam.

I. To the south the Middle Level Catchwater Drain diverts water into the Great Raveley Drain.
II. Water in the Great Raveley Drain flows to the northeast of Woodwalton Fen.
III. Monks Lode and New Dyke channels flow to the south of Holme Fen.
IV. The confluence of the New Dyke and Great Raveley Drain is at the Old Nene channel.
V. Yaxley Lode/New Cut joins the Old Nene to the north of Holme Fen.

2.1.2.3 Irrigation in the Great Fen project area

At present the Environment Agency have licensed abstractions that incorporate the Core Area of about 1.28 Mm^3y^{-1}. Of this approximately 0.76 $Mm^3\ y^{-1}$ are for winter abstraction to fill reservoirs. This water is released into the drainage network in the summer for re-abstraction for irrigation. Total licensed summer abstractions, excluding re-abstraction of winter water released from reservoirs, equals 0.52 $Mm^3\ y^{-1}$ (Table 2.2). However, the picture is complicated because some of the licences are for "multi-point" abstractions that include locations outside the Core Area (*i.e.* the licensee can decide to take only a proportion of the licensed abstraction from the Core Area).

Table 2.2: *Licensed annual abstractions in the Core Area*

Licence Type	Volume of abstraction (Mm^3)
Winter abstraction for storage in the Core Area[1]	0.3632
Winter abstraction for storage outside the Core Area[2]	0.3940
Summer abstraction for land entirely outside the Core Area[2]	0.0296
Summer abstraction solely for land in the Core Area	0.2087
Multi-point summer abstraction that include the Core Area[2]	0.2839
TOTAL	1.2794

Notes: [1] it is estimated that, at present, *ca* **0.2932 Mm³** is for use entirely within the Core Area.
[2] None of this water has to be used within the Core Area.

Since 1991 the actual annual abstractions in the Core Area have been considerably less than the total licensed amount (Figure 2.3). This difference occurs for two reasons. Firstly, in wet years farmers are not taking their full allocation. Secondly, in very dry years (*e.g.* 1995) the amount abstracted is constrained by Environment Agency restrictions to save the limited resource. Since 1995, the only new abstraction licences that have been permitted are for winter abstractions.

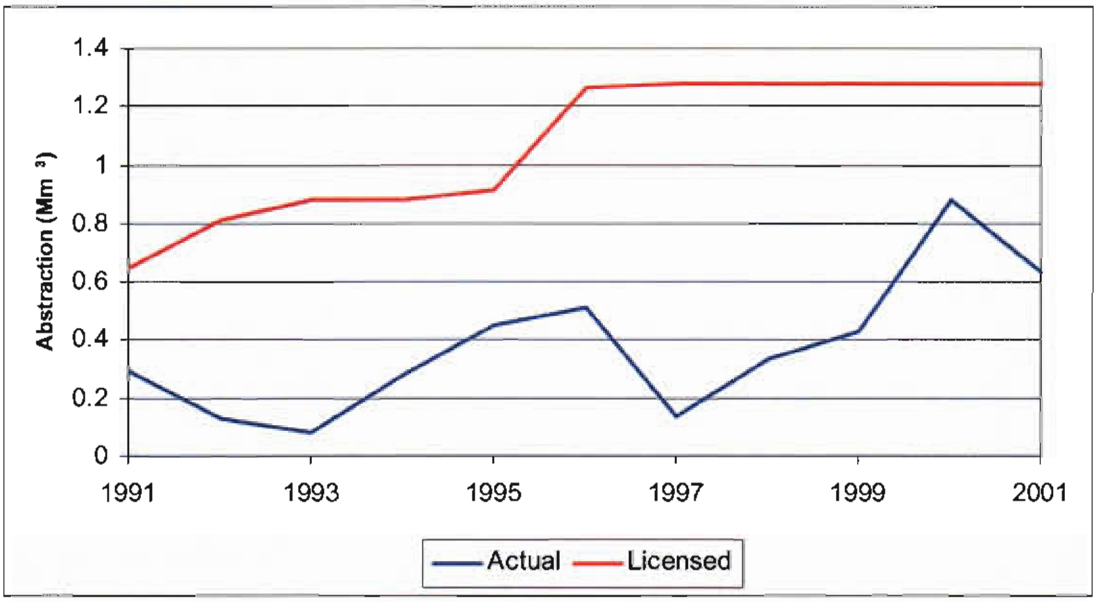


Figure 2.3: *Actual and Licensed Abstraction within the Great Fen Core Area*
Note: Data provided by the Environment Agency

When land is purchased the abstraction entitlements are not necessarily transferred with the land. The only licensed abstractions that can be guaranteed to the Great Fen Project (subject to EA agreement) are those that are available solely for abstractions and land within the Core Area. This amount equates to 0.2087 Mm^3 for summer abstraction and 0.2932 Mm^3 for winter storage and re-release in the summer. Given that in future EA restrictions are likely to continue to apply, it is possible that total (*i.e.* actual + re-releases) summer (*i.e.* April to September) abstractions will not exceed the average of those that have occurred to date. Analyses of the monthly abstraction data indicate that between 1991 and 2000 this total summer abstraction equalled 0.33 Mm^3.

2.1.3 *Hydrological Fluxes*

2.1.3.1 Rainfall

Rainfall is recorded at several gauges variously situated in or close to the Core Area (Table 2.3).

Table 2.3: *Rainfall data for the Great Fen Core Area and neighbourhood*

Rain gauge	Grid Reference	Period of record	Mean Annual Rainfall (mm)
Wyton Met Office	5284 2745	1954 – 1995	540
Woodwalton Fen	5239 2848	1955 -	548

Whittlesey Mere	5237 2904	1872 – 1973	592
Lutton Grange Farm	5110 2880	1996 -	562
Luddington in the Brook	5108 2831	1994 -	569
Abbot's Ripton Hall	5240 2777	1946 -	566
Bury	5283 2842	1992 -	549
Monks Wood	5201 2796	1963 -	549
Tebbitts Bridge	5248 2914	1983 -	516
Overall Mean			**555**

Data for these gauges were obtained from the *National Water Archive* (held at the Centre for Ecology and Hydrology, Wallingford). It is clear that there is very little variation in rainfall across the region. Average annual rainfall, derived by computing the arithmetic mean of rainfall from those gauges with greater than 30 years of record, is 560 mm. The average annual rainfall (1961-2001) derived from the *MORECS*[1] grid square in which the Great Fen project area is located (*i.e.* no. 128) is 570 mm. On average, rainfall is spread fairly evenly through the year (Figure 2.4). Average rainfall is 299 mm for the summer (April to September) and 271 mm winter (October to March) months.

2.1.3.2 Evapotranspiration

Average annual potential evaporation computed using the Penman-Monteith formula for the *MORECS* grid square 128 is 640 mm. Potential evapotranspiration exceeds rainfall in the months April to September. Average summer potential evapotranspiration is 492 mm. Figure 2.4 indicates how, without irrigation, estimated actual evapotranspiration declines below potential evapotranspiration between May and October.

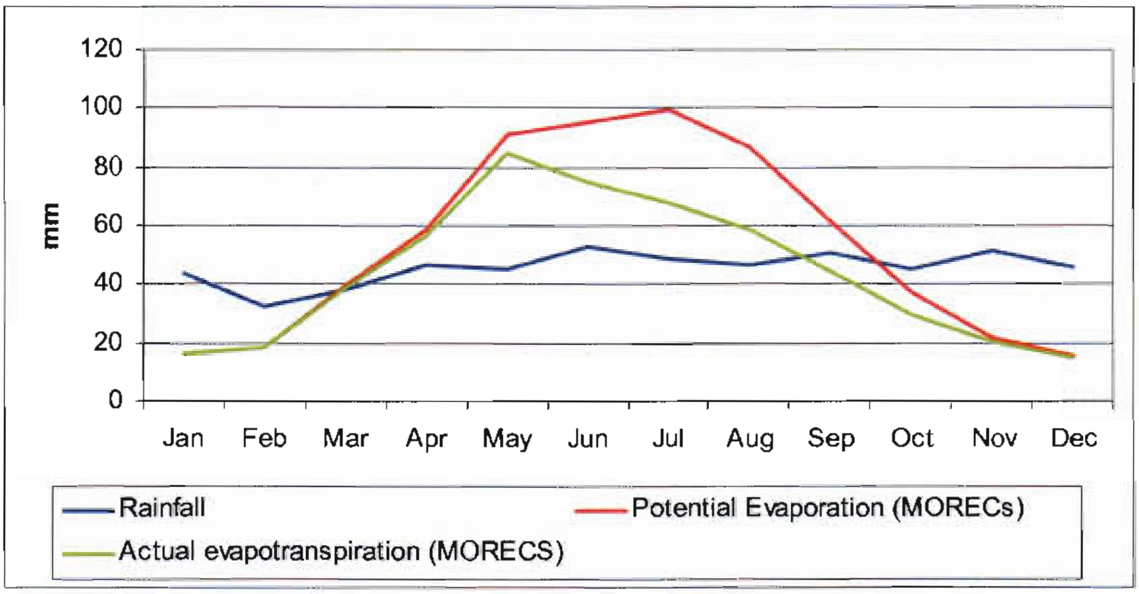


Figure 2.4: *Mean monthly rainfall (Woodwalton Fen) and potential evapotranspiration*

[1] *Meteorological Office Rainfall and Evaporation Calculating System (MORECS)* has been designed to provide estimates of rainfall and evapotranspiration in the form of averages over 40 x 40 km grid squares for the UK.

2.1.3.3 Upslope runoff into the core area

There is no measurement of flow from the upslope catchment into the Core Area. Based on the methodology of the *Low Flows Report* (Gustard *et al.*, 1992), average annual runoff into the area is estimated to be between 40 mm and 142 mm (Cranfield University, 1999). In the current study, *Low Flows 2000* software was used to generate estimates of catchment characteristics at two points; one on the Great Raveley Drain (Grid Reference: TL 234 843) and one on the New Dyke (Grid Reference: TL 228 870). These locations were chosen arbitrarily as points representative of the drainage network in the Core Area and having a total catchment area approximately equal to the upland area. The estimates of mean annual runoff and Baseflow Index (*i.e.* the proportion of the flow that is groundwater) are indices of the estimated natural flow regime at these points (Table 2.4).

Table 2.4: *Estimates of natural flow characteristics derived using Low Flows 2000 for two locations in the Core Area of the Great Fen Project*

Location	Grid ref	Catchment Area (km^2)	Mean annual rainfall (mm)	Mean annual runoff (mm)	BFI
Raveley Drain	TL 234 843	28.5	549	90	0.38
New Dyke	TL 228 870	54.8	555	97	0.41

The Alconbury Brook at Brampton is the nearest flow gauging station to the site both with a reasonably long record (1963-1999) and without too many gaps in the time series. Although the Alconbury Brook drains into the Bedford Ouse rather than the Nene, it is an arable catchment that was felt to be sufficiently similar to the upland catchment to serve as an analogue. Comparison of the *Low Flows 2000* estimates derived for this catchment with those derived from the available data, give confidence that the *Low Flows 2000* estimates in this region are reasonable (Table 2.5). Furthermore, the similarity in BFI estimates for this catchment with those estimated for the locations in the Core Area (Table 2.3) justifies the assumption that the processes influencing streamflow in this catchment are the same, and operate in a similar manner, as those governing flow from the upslope catchment into the Core Area. Hence, the use of the Alconbury Brook as an analogue catchment is reasonable.

Table 2.5: *Details of the flow gauging station: Alconbury Brook at Brampton*

Gauging station no. $^{\Phi}$	Grid ref	Catchment Area (km^2)	Mean annual rainfall* (mm)	Mean annual runoff + (mm)	BFI
33020	TL 208 717	201.5	589 (1963-1998)	117 (1963-1999)	0.29
Low Flows 2000 estimate			563	115	0.32

Notes: $^{\Phi}$ Station number and name as given in the Hydrometric Register of the National Water Archive
* Mean annual rainfall – number in brackets is the years over which the average was derived
\+ Mean annual runoff - number in brackets is the years over which the average was derived

Mean annual runoff of the Alconbury Brook at Brampton is 117 mm, but is seasonal and generally has very low summer flows (Figure 2.5). Seasonality of the flow is reflected in the baseflow index for the station, which indicates that the catchment is predominantly impervious and only 29% of total flow is contributed from groundwater. Runoff can be very low (0-1 mm) in any month of the year.

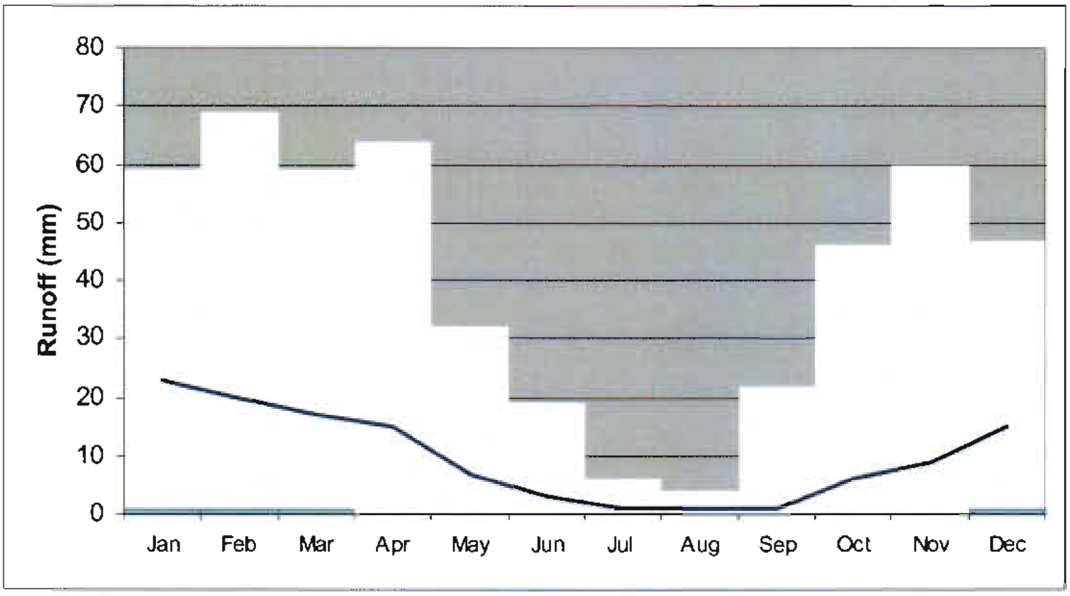


Figure 2.5: *Alconbury Brook at Brampton: Monthly mean and maximum and minimum flows from 1963 to 1999*

The flow data at Alconbury Brook were used to estimate a time series of runoff from the upland area. This was done by multiplying the observed flow series with the ratio of *Low Flows 2000* mean annual runoff estimates derived for the upland region (*i.e.* 95) and that derived for the Brook (*i.e.*115). Thus upland runoff was assumed to be 0.83 of the Alconbury Brook runoff. This provided a time series of runoff from October 1963 to December 2001, although with data missing in a few years, most notably 1993-1995 (Figure 2.6). For hydrological years[2] with complete data, runoff varies from 5.6 mm (HY1975) to 320mm (HY2000). Average annual runoff is 98 mm with an average summer and winter runoff of 23 mm and 75 mm respectively. This temporal pattern of runoff is very different to that predicted by the *WaSim* modelling, which indicated very little difference in winter and summer runoff volumes (Cranfield University 1999: Table 5). The Cranfield University analyses indicated that in 7 out of 28 years upland winter runoff would be <1.7 mm. The analyses conducted in the current study, using the Alconbury Brook as a surrogate, indicate

[2] Hydrological years extend from October 1st to September 30th. In this report the standard convention of naming the hydrological year after the year in which the month of October occurs has been adopted. Thus, the hydrological year 1965 (*i.e.* HY1965) extends from 01/10/65 to 30/09/66.

that the minimum in hydrological years 1963-2000 was 3.6 mm (HY1975) and in all other years winter runoff exceeded 10.0 mm.

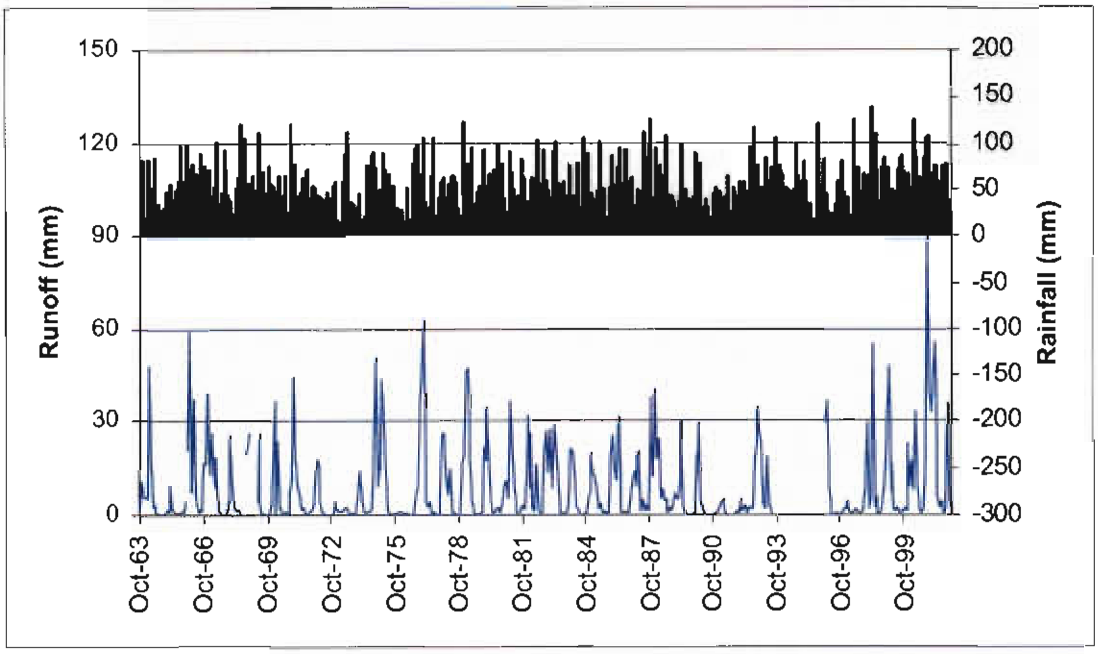


Figure 2.6: *Monthly runoff from the " upland" catchment, derived from the measured flow at Alconbury Brook*

2.1.3.4 Pumping/Outflow

In the Core Area there are a number of pumping stations (Figure 2.1), used primarily to pump water from the low-lying drains into the high level carriers of the Middle Level Commissioners' system. Most pumping occurs in the winter to remove water from agricultural land (David Phillips *pers comm.*). Although the duty point pump capacities are known (Table 2.6), no data are available on the number of hours of operation or the actual volumes of water pumped from these stations. There is a control sluice on the Great Raveley Drain on the eastern boundary of Woodwalton Fen. This sluice is raised during very high flow events to reduce flow to the Bevill's Leam pumping station, but only when the station cannot cope with inflows. The embankment on the west side of the Great Raveley Drain is lower than that on the east side, so raising of the sluice causes backing up and leads to controlled inundation of the Woodwalton Fen NNR (David Phillips – *pers. comm.*).

Table 2.6: *IDB pumping stations in the vicinity of the Great Fen Project core area*

Pumping station	**MLC ref**	**IDB name**	**Pump capacity at duty point (ls^{-1})**	**Discharge to**
Whittlesey Mere	21	Holmewood and Stilton	3000	Bevill's Leam
Daintree	47	Ramsey Fourth (Middlemoor)	510	River Nene
Yaxley Fen	88	Yaxley (private)	800	Yaxley Lode
Lords Farm	77	Whittlesey	450	Yaxley Lode
Conquest Lode	76	Whittlesey	850	Black Ham
Speechly's	87	Wood Walton (private)	424	New Dyke

Conington	9	Conington and Holme	714	Monks Lode
Sawtrys Roughs	55	Sawtry	500	Catchwater Drain
Castlehill (Manor) Farm	54	Sawtry	340	Catchwater Drain
Moat Farm	53	Sawtry	300	Great Raveley Drain
Upwood Common	43	Ramsey, Upwood and Great Raveley	570	Great Raveley Drain
Green Dyke	41	Ramsey, Upwood and Great Raveley	763	Great Raveley Drain

Surface flow from the Core Area ultimately leaves via the Bevill's Leam pumping station (Figure 2.1) or through Lode's End Lock located on the High Lode north of Ramsey. Lode's End Lock allows gravity drainage when levels to the west are higher than to the east. There are no data on flows through the lock. When pumping from Bevill's Leam pumping station, the lock prevents water entering the Great Fen region from the east. The *MLC* provided monthly pumping hours for the Bevill's Leam pump for the period April 1992 to March 2002. The capacity of the station at its duty point is 10,800 m^3h^{-1} (38,880 ls^{-1}) (Cranfield University, 1999). When the pump is in operation its efficiency is dependent on the difference in water level between the upstream and downstream side of the station (the greater the difference in head, the lower the discharge). Furthermore, the station performance is likely to have changed as the pump has aged. A pump performance curve and information on the head difference at the pumping station are held by the *MLC*, but were not available for the present study and it was thus not possible to determine actual volumes pumped. Consequently, as a first approximation, it was assumed that on average the station operated at duty capacity. There is some gravity drainage via a sluice at the station, but there are no records of gravity discharge from the catchment and this was assumed to be negligible in comparison to volumes removed by pumping.

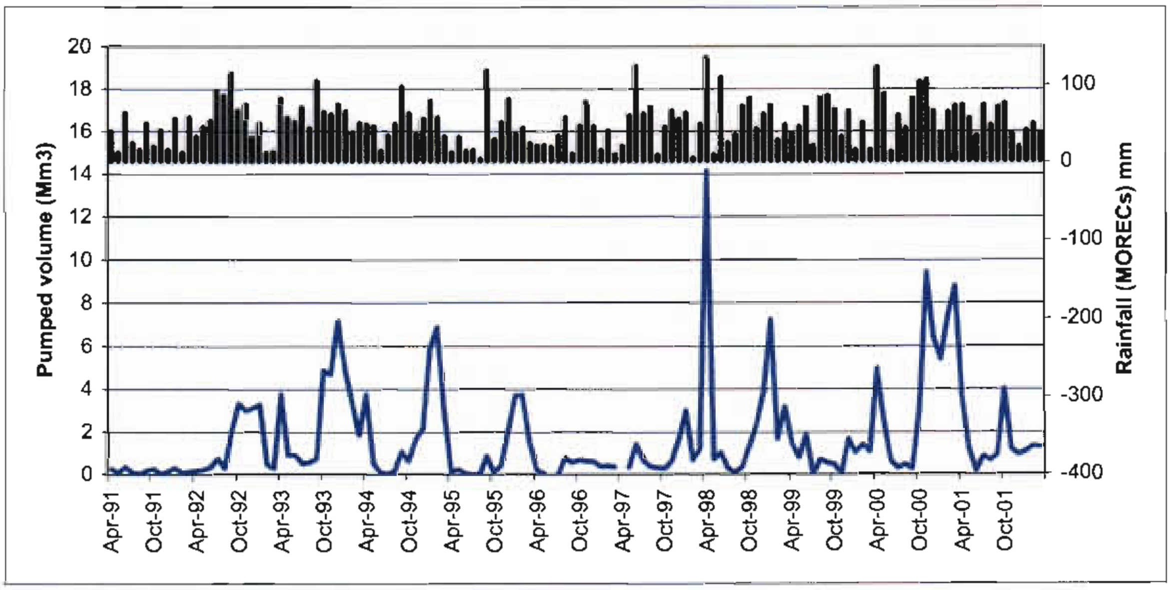
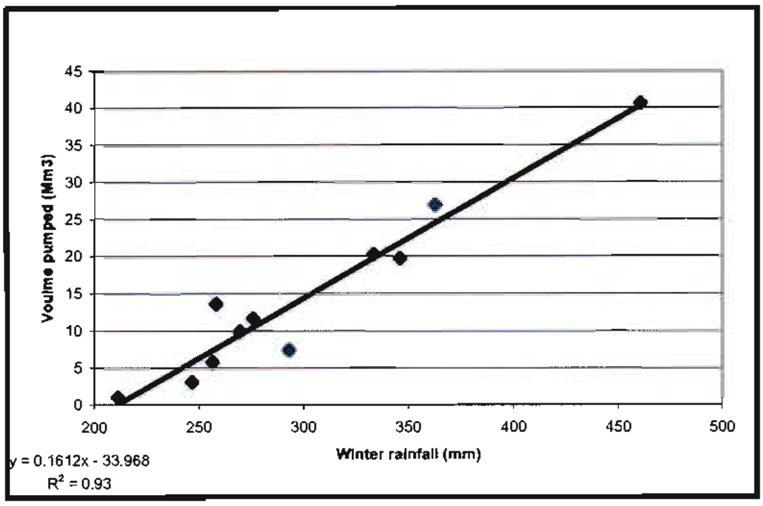


Figure 2.7: *Monthly rainfall and the volume pumped from Bevill's Leam pumping station*

Over the period of available data, there is considerable variation in the amount of water pumped from the catchment (Figure 2.7). On average annual pumped discharge was 20.35 Mm^3. The majority of pumping is in the winter months (on average 14.6 Mm^3) with much less in the summer (on average 5.8 Mm^3). The greatest pumped discharge was in April 1998 when monthly rainfall in excess of 130 mm resulted in pumped discharge of 14.2 Mm^3.

As would be expected the winter pumped discharge is highly correlated with the winter rainfall (R^2 = 0.93) (Figure 2.8a). Volumes discharged range from 40.6 Mm^3 in the winter of HY2000 to just 1.0 Mm^3 in the winter of HY1991. It seems that when winter rainfall is less than *ca* 210 mm, no water is pumped from the catchment. The *MORECS* data indicates that since 1963, there have only been 5 years (*i.e.* hydrological years 1964, 1972, 1973, 1975 and 1988) when winter rainfall did not exceed 210 mm. Volumes pumped each summer are much less correlated with rainfall; ranging from 16.7 Mm^3 in the summer of 1998 to 1.1 Mm^3 in the summer of 1991 ($R^2 = 0.41$) (Figure 2.8b).



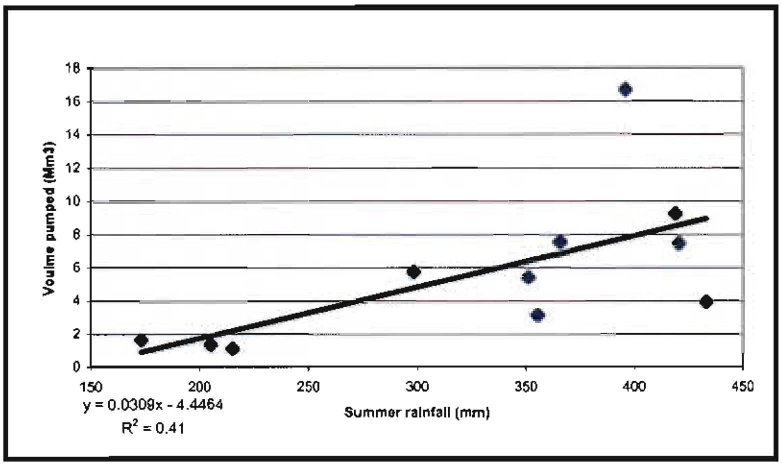


Figure 2.8: *Correlation between volumes pumped from the catchment and a) winter and (b) summer rainfall*

2.1.3.5 Water inflow diverted from the Nene

In summer, water is transferred into the Middle Level mainly for irrigation and to maintain navigation. Water is diverted into the Middle Level drainage system from the R. Nene via a sluice at Stanground (Figure 2.9), and is split between King's Dyke and the Pig Water. Water transferred into King's Dyke is conveyed into the system downstream of Bevill's Leam pumping station. However, that entering Pig Water is conveyed to the Yaxley Lode and enters upstream of Bevill's Leam pumping station. There is no information on the proportion of flow diverted via each of these routes.

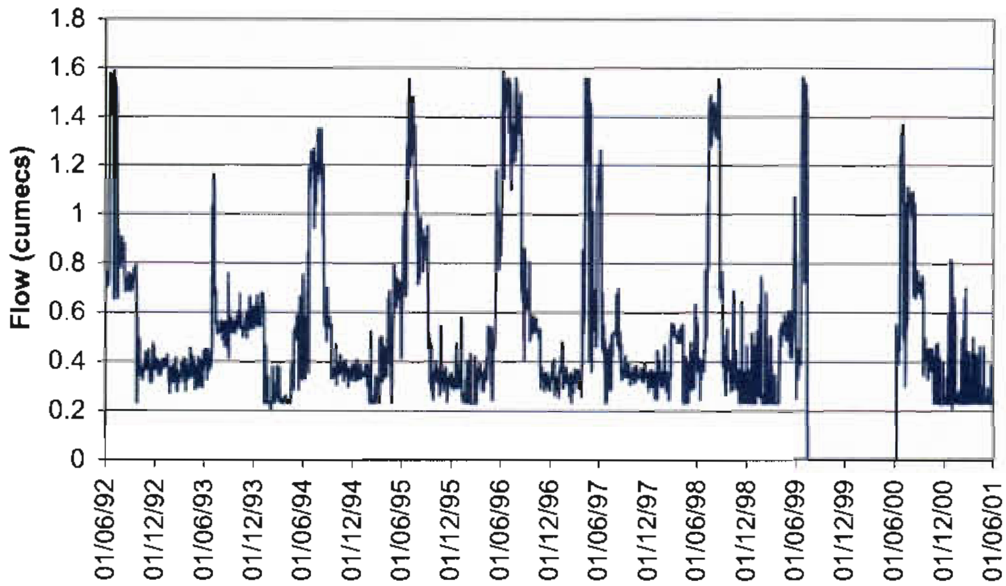


Figure 2.9: *Diversions from the Nene at Stanground into the Middle Level*

There are a complex set of operating rules that govern water transfers depending on flow conditions at Orton, the Dog-in-a-Doublet Sluice and water-levels within the Middle Level area at Bodsey Bridge (Environment Agency 1996). The maximum allowable diversion is 135 thousand cubic metres per day (*i.e.* 1.56 m^3s^{-1}). Flows through the sluice in the winter are predominantly leakage. Data are missing from July 1999 to June 2000. Table 2.7 shows summer volumes diverted and summer rainfall. As would be expected, since the water is being used largely for irrigation, the volumes diverted are inversely correlated with the summer rainfall (Figure 2.10).

Table 2.7: *Summer (April to September) diversions from the Nene at Stanground*

Year	Rainfall – from MORECs (mm)	Diversion (Mm^3)
1992		-
1993	421	7.62
1994	299	10.63
1995	205	12.40
1996	173	14.77
1997	356	10.01
1998	396	10.41

It is also important to note that irrigation was restricted in HY1995, because of a drought and it is likely that a diversion of *ca* 14.8 Mm^3 represents an upper limit on what could be diverted, whilst still maintaining downstream environmental requirements in the Nene. Winter volumes diverted at Stanground range from 4.96-6.82 Mm^3 with an average of 5.58 Mm^3.

The distribution of water diverted from the Nene within the Middle Level is not known. However, as indicated above (section 2.1.2.1) licensed annual abstractions equal 1.3 Mm^3y^{-1} of which 0.67 Mm^3 equates to a maximum summer entitlement. Although this is a relatively small component of the total water budget of the Core Area, it nevertheless represents additional water that can be utilised in dry summers. If this water were to be used for wetland conservation rather than agriculture, such an amount would represent a change of water-use rather than additional water requirement.

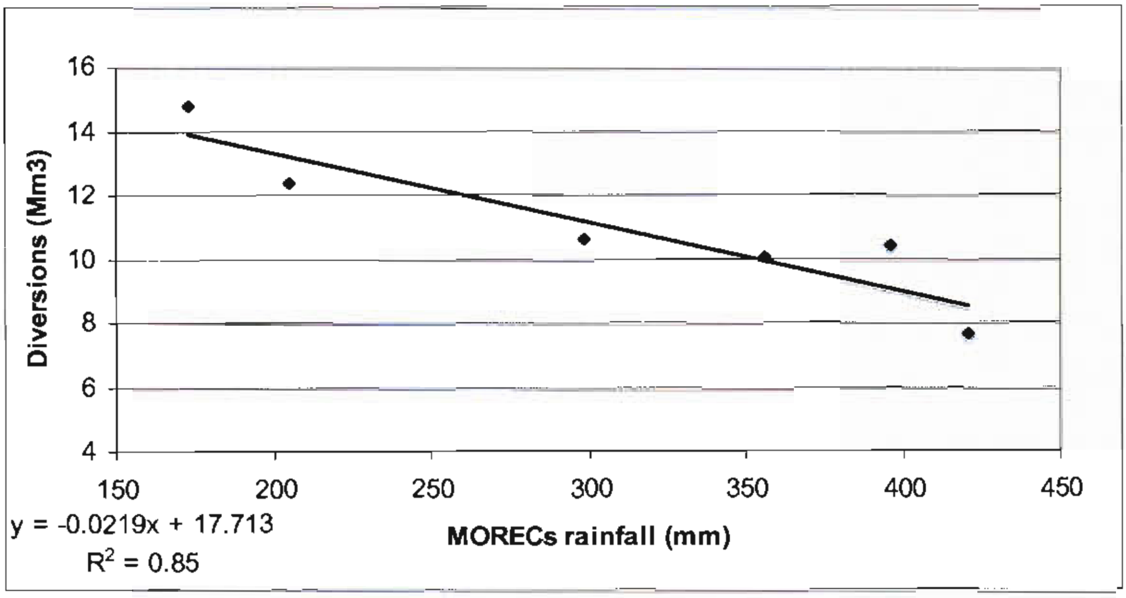


Figure 2.10: *Relationship between summer diversions from the Nene at Stanground and rainfall*

2.1.4 *Water quality*

Within the area of the Middle Level, water chemistry is greatly influenced by human activities. Agricultural activities (*e.g.* fertiliser application) and some of the sewage treatment works (STWs) have a significant impact on the chemical quality of the rivers. Drainage of the fenland has resulted in shrinkage of the peat soils and affects leaching of minerals, such as iron, which causes localised differences in background water quality (EA 1997).

Table 2.8: *General Quality Assessment (GQA) determined at locations in and around Core Area*

	Name	Location	GQA in 2000
53M19	Sawtry Fen Drain	On the Catchwater Drain	B
53M46	Great Raveley Drain	Close to the entrance to Wood Walton Fen	E
53M08	New Dyke		E
53M55	Yaxley Lode	Close to the confluence of the Pig Water and Yaxley Lode	C
53M07	Bevill's Leam	Close to Bevill's Leam pumping station	C

Legend: A = very good, B = good, C = Fairly Good, D= Fair, E= Poor and F = Bad

The Environment Agency regularly monitors at 5 locations in the immediate vicinity of the Core Area (Figure 2.11) and each year grade the water quality on a scale from A to F (Table 2.8). The quality grades indicate that, in general terms, poor water quality is found in both the Great Raveley Drain and New Dyke, but at other locations, including on Bevill's Leam the water quality is reasonable. The water chemistry of the Yaxley Lode (*i.e.* 53M55) and Bevill's Leam (*i.e.* 53M07) will be partially influenced by the quality of water diverted from the Nene via the Stanground sluice. The data indicate that in broad terms the water from the upland catchments is of reasonable quality (*i.e.* 53M19), but deteriorates as it moves through the drainage network surrounding the Core Area. The slightly improved water quality in the Yaxley Lode and Bevill's Leam may be a consequence of dilution of the drainage water with water diverted from the Nene.

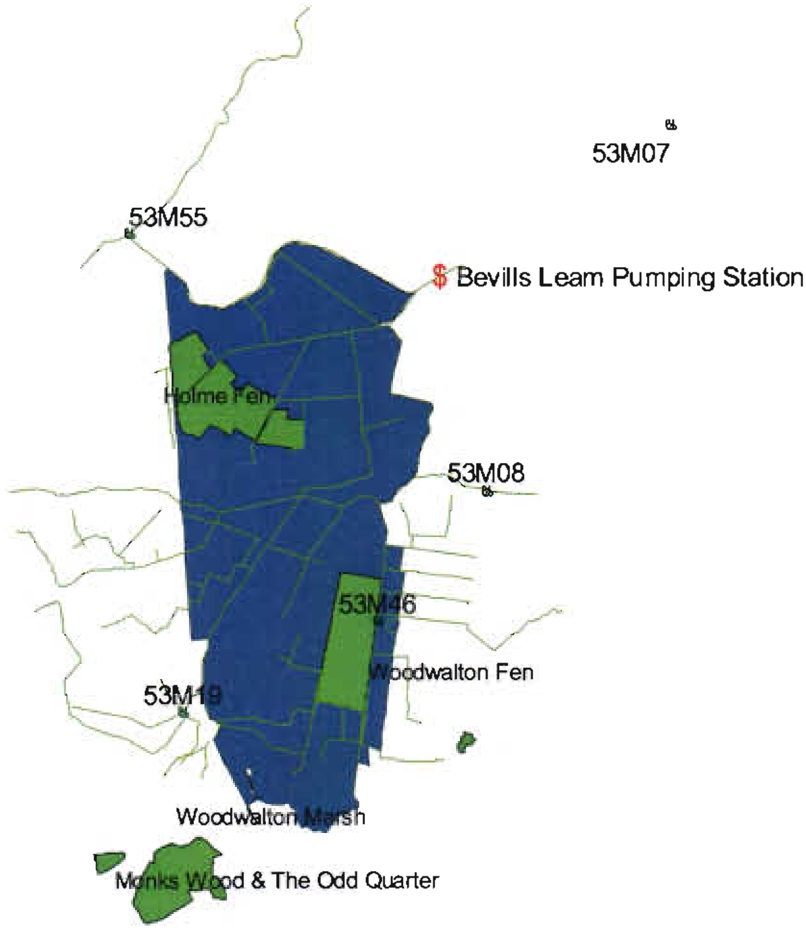


Figure 2.11: *Environment Agency sampling points for water quality*

Other legend as Figure 2.1

A summary of key determinants monitored at each location is presented in Table 2.9. These indicate that all the waters are generally alkaline with average pH $\geq$ 8.0. Nitrogen levels are high, probably reflecting the agricultural nature of the catchment. At all locations the highest concentrations have been measured in the winter and lowest in the summer months indicating the expected seasonal distribution with greater uptake of nitrogen by growing plants in the summer. High orthophosphate concentrations in the water of the Sawtry Fen (Catchwater) Drain and the Great Raveley Drain are believed to reflect phosphorous inputs from the Sawtry STW.

Improvements are presently being made to this STW to meet river quality objectives and help combat eutrophication problems at Woodwalton Fen (EA 2001). It is planned that this work, which it hoped will reduce average phosphate concentrations to <1 mgl^{-1}, will be completed by 31^{st} March 2003.

Table 2.9: *Summary statistics of determinants measured at each monitoring site over the period 1992 to 2002*

	53M19			53M46			53M08			53M55			53M07		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
PH	9.6	7.0	8.3	8.8	5.3	8.0	8.95	6.2	8.0	9.2	7.4	8.1	9.1	7.3	8.1
Temperature (°C)	27	0.5	12.9	23	1.0	5.8	24	1.0	12.5	23.4	0.5	12.3	25	0.0	11.9
Conductivity (uScm-1)	2560	528	1147	1830	697	236	3690	891	2033	2740	795	1145	2430	876	1508
Dissolved Oxygen (% sat)	309	3.1	115	222	18.7	35.4	316	10.6	35.3	166	29.8	94.2	154	28.3	88.5
Ammonia mgl^{-1}	0.72	0.03	0.11	0.84	0.03	0.14	9.1	0.03	1.45	4.7	0.03	0.19	3.29	0.03	0.50
N Oxidised (mgl^{-1})	36.4	0.20	9.29	30.6	0.20	7.97	30.4	0.20	8.05	18.7	0.5	6.79	31.8	0.2	8.6
Orthophosphate (mgl^{-1})	5.1	0.02	1.29	3.1	0.02	0.53	1.24	0.02	0.18	1.63	0.03	0.46	1.4	0.02	0.20
Alkalinity (mgl^{-1})	250	60	49.9	230	150	197	230	47	185	265	190	214	240	120	196
BOD-5day															

The availability of oxygen influences nearly all chemical and biological processes in aquatic ecosystems. Dissolved oxygen concentrations in slow moving water systems are determined by a number of factors including: the interplay between oxygen consumption (respiration) by animals, plants and aerobic microbes; photosynthetic oxygen production by submerged aquatic plants during daylight hours; losses and gains of oxygen from the overlying air; salinity, atmospheric pressure and temperature; and groundwater flow (which is often low in dissolved oxygen concentration). As a consequence of photosynthesis, oxygen levels typically increase to a peak during daylight and then decline to a minimum at night. It is likely that all the water samples collected by the Environment Agency for analyses were collected during the day and so give a somewhat misleading impression of the dissolved oxygen conditions in the ditches. Nonetheless, from the results presented it is clear that, even during the day, dissolved oxygen levels are very low on some occasions (*i.e.* < 10%), particularly in the Catchwater Drain, Great Raveley Drain and New Dyke. This observation may be a consequence of anthropogenic influences, in particular eutrophication, which tends to cause the growth of floating macrophytes that exchange gases with the air and so do not contribute to dissolved oxygen cycling. The low dissolved oxygen concentrations observed may be deleterious to aquatic life in the ditch network.

2.2 Biotic aspects: the present situation in the Fens Natural Area and the Great Fen

Description and mapping of the habitats and species that now occur within the Great Fen Project Area is strongly indicative of what might be successfully restored. It is acknowledged that the Great Fen Project might eventually aspire to holding biota representative of the whole Fenland basin, and to that end the inventory of species and habitats was extended to cover the whole of the Fens Natural Area.

2.2.1 *Broad Habitats*

2.2.1.1 Introduction and approach

Those Broad Habitats present in the Great Fen core are defined in Appendix 1, but special attention is given to those that should form the main components of a restored fenland landscape: **BH1** Broadleaved woodland, **BH6** Neutral grassland, **BH11** Fen, marsh and swamp, and **BH13** Standing water. Appendix 1 also provides a cross-reference between Broad Habitats and the communities of the *National Vegetation Classification* (*NVC*: Rodwell 1991-2000). A wide range of sources have been marshalled to identify and map the extent of these habitats, their location and extent, drawing on material held by CEH (notably within the *Biological Records Centre: BRC*) as well as the partners within the Great Fen Project. The *Land Cover Map 2000* (*LCM2000*: Centre for Ecology and

Hydrology 2001) provided an up-to-date account of land cover classes within the Fens Natural Area, and more narrowly within the Great Fen Project Area. Requests for information were made to *English Nature* local offices, the Wildlife Trusts and the RSPB. These data were compiled as they relate not only to SSSIs (including LNRs and NNRs) but also to non-statutory sites of nature conservation value and sites detailed in the *Invertebrate Site Register*. Results of Phase I/II habitat surveys were pursued from County Council ecologists and the Wildlife Trusts.

Some use was made of co-occurrence mapping of ecological species-groups defined as those typical of the *Broad Habitat* (Mountford *et al.* 1997). The approach used *BRC* databases to create a spatial framework for targeting habitat restoration, demonstrating which "building blocks" of named habitats do occur locally. Though co-occurrence mapping cannot be said to prove that a particular habitat is present, it does infer that restoration of that habitat should be practical, and allows appropriate species-pools to be identified. This species-based approach was later augmented with information on environmental factors, such as that gathered in the earlier phases of the Great Fen feasibility study (Cranfield University 1999; Duncan 2002). Hydrological information gathered by CEH Wallingford and outlined in section 2.1 was also incorporated to display the nature of the water-resource.

2.2.1.2 Land Cover in the Great Fen Project Area

The *Land Cover Map 2000* (CEH 2001) portrays the present land cover throughout the UK (including Northern Ireland). Replacing the earlier *Land Cover Map of GB* (1990), *LCM2000* is derived from a computer classification of (mainly *Landsat*) satellite scenes, and incorporates information derived from other datasets. *LCM2000* comprises a vector database for use within a GIS, and is registered to the OS National Grid, showing areas of land as polygons. To each polygon is attached a series of attributes and values *e.g.* land cover class, polygon area, length of polygon boundary, processing history, knowledge-based correction and identification of the original satellite scene. Figure 2.12 provides a somewhat simplified portion of *LCM2000* for the Core Area (*ca* 3754 ha). Using this map, areas of each land-cover type were calculated, together with their correspondence to *Broad Habitat* types (Table 2.10).

Examination of the map confirms certain expected patterns as well as suggesting some interesting and potentially useful features. The great majority of the Great Fen area (79%) is under arable or horticulture, with most of the other habitats confined to the two blocks of the National Nature Reserves. Land cover in the NNRs is overwhelmingly allocated to Broadleaved Woodland (**LCM 4.1-4.3**), Fen/marsh/swamp (**LCM 11.1**) and Improved Grassland (**LCM 5.1-5.2**). It is clear that unchecked reliance on results derived from satellite imagery is unwise, since there is some evident confusion between fen grassland (fen-meadows, rush-pastures, *Calamagrostis* stands *etc*) and improved grassland. This confusion appears to be most pronounced in areas where carr has been cleared in order to restore tall herbaceous fen communities (especially those where *Phragmites* is prominent). This disturbance resulting in a relatively uniform vegetation surface dominated by a single species may partially explain the apparent similarity using satellite imagery.

As well as the large blocks of Broadleaved Woodland (plantation and carr) in Holme and Woodwalton Fens, there are scattered fragments of such cover in the arable land between the Fens, as well as two patches (Riddy and Gamsey Woods) on the upland to the south (within the Project Area, but outwith the Fenland landscape). Polygons mapped as fen/marsh/swamp occur around Higney Grange, by the Middle Level Catchwater Drain, Brick Mere and, significantly, around the old pits in Great Raveley Fen (between the NNR and Brighty's Drain). Finally, the most important area of open water lies within Holme Fen NNR - the new mere at Woodwalton Fen NNR is not registered.

Figure 2.12: ***Land Cover within the Great Fen Study Area (LCM2000)***

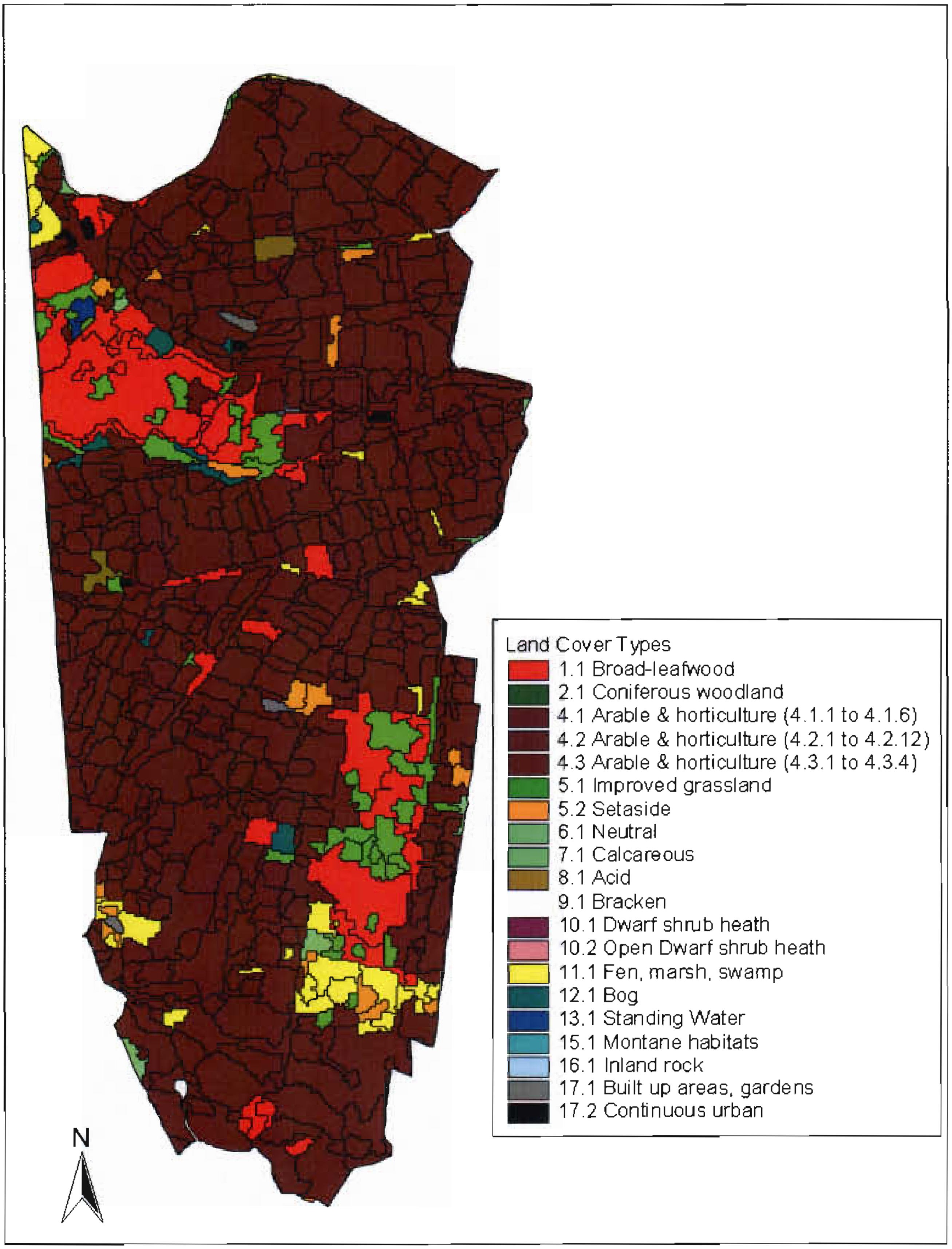


Table 2.10: *Areas (ha) of Land Cover Map 2000 categories within the Great Fen study area, with corresponding Broad Habitat types*

LCM code	Description	Hectares	Corresponding Broad Habitat Type
1.1	Broad-leaved/mixed woodland	407.27	1-Broadleaved, mixed & yew woodland
4.1	Arable and horticulture: a) Cereals	1245.48	4-Arable and horticultural
4.2	Arable and horticulture: b) Horticulture/ non-cereal or unknown	1678.49	4-Arable and horticultural
4.3	Arable and horticulture: c) Not annual crop	29.05	4-Arable and horticultural
5.1	Improved grassland	150.40	5-Improved grassland
5.2	Abandoned & derelict grasslands: a) Set-aside grass	51.32	5-Improved grassland
6.1	Abandoned & derelict grasslands: b) Rough grass	8.92	6-Neutral grassland
7.1	Calcareous grass	9.86	7-Calcareous grassland
8.1	Acid grass	15.69	8-Acid grassland
11.1	Fen, marsh, swamp	107.69	11-Fen, marsh and swamp
12.1	Bog	25.72	12-Bogs
13.1	Water (inland)	5.50	13-Standing open water and canals
17.1	Built up areas, gardens: a) Suburban/rural developed	10.64	17-Built-up areas and gardens
17.2	Built up areas, gardens: b) Continuous urban	7.93	17-Built-up areas and gardens

2.2.1.3 Broad Habitats in the Fens Natural Area and Great Fen Project Area

The *LCM2000* map (Figure 2.12) also provides an indication of the distribution and extent of *Broad Habitats* in the Great Fen Project Area. Other sources were brought to bear to extend the search to the whole Fens Natural Area. Results of the co-occurrence mapping approach are given below (section 2.2.1.4), and description here is confined to those sources provided by the partners within the Project Steering Group. The Wildlife Trusts provided information on Broad Habitats within both the Fens Natural Area and seven adjacent Natural Areas (Table 2.11). In contrast to those comprehensive estimates of Broad Habitat area given in Table 2.10, Table 2.11 covers only those areas within Sites of Special Scientific Interest (SSSIs) and County Wildlife Sites (CWSs). However, comparison of the two sources provides a valuable estimation of the contribution that the Great Fen Project area makes to the overall habitat resource in the Fens.

- Some 600 ha of Broadleaved woodland (including carr and wet woodland) occur in the SSSIs and CWSs of the Fens, and around two-thirds of this is present in the Core Area, notably within the two NNRs.
- The great majority of grassland in the Fens Natural Area is agriculturally improved (**LCM 5.1-5.2** and **BH5**), and such vegetation is much more extensive outwith the Core Area than within, notably on the Nene and Ouse Washes. As noted above, the estimate provided from *LCM2000* seems exaggerated following misclassification of disturbed herbaceous fen.
- Areas of calcareous and acid grassland (**LCM 7.1** and **8.1**) given in Table 2.10 (and Figure 2.12) largely refer to the upland fringe, and are not strictly within the Fens Natural Area. Vegetation related to these *Broad Habitats* does occur locally in the Fens, naturally in the

"heath" portions of the NNRs, but chiefly in anthropogenic habitats *e.g.* associated with railway lines (limestone ballast - hence calcareous) or sand/gravel pits (acid swards).

- The area of fen/marsh/swamp (*ca* 108 ha) given by *LCM2000* for the Core Area includes wet grassland (fen-meadow and rush-pasture) as well as habitats summarised in Table 2.11 as fen/mire, reed beds and marsh. The total area of all such wetland habitat in the Fens Natural Area is 1071 ha, with major blocks in the NNRs and LNRs (in addition to Woodwalton and Holme Fens: Wicken and Baston Fens, as well as the Cam/Nene/Ouse Washes).
- Important, if small, areas of such wetland habitats occur associated with old mineral workings and drainage channels throughout the Fens. Though open water (**LCM 13.1** or **BH13**) may comprise the most extensive cover in these sites, the fringing vegetation and banks provide an important refuge for wetland species. For example in National Grid TL29 (Whittlesey area), many fenland species have recently only been recorded in and by old clay-pits (Bassenhally Pit, Feldale area, the Lattersey Field complex, Stonald Road *etc*) or by major channels with established flood-banks (Blackbush Drain, Briggate River, Delph Dike, Moreton's Leam *etc*).
- A small proportion of arable land (17 ha) in the Fens Natural Area lies within SSSIs and CWSs. The biodiversity value of the great bulk of Fenland arable land appears low, though locally corn and beet fields harbour local weeds (*e.g. Galeopsis speciosa*) or provide food and roosting for wildfowl and waders.

Table 2.11 *Estimated Areas of Priority Habitats in the Fens Natural Areas (with data for adjacent Natural Areas for comparison)*

	Natural Area							
Priority Habitat	The Fens	Bedfordshire Greensand Ridge	Breckland	East Anglian Chalk	East Anglian Plain	Lincolnshire Limestone	Rockingham Forest	West Anglian Plain
Broadleaved Woodland	283	62	2	115	247	36	623	1008
Broadleaved Plantation	7	22	3	240	77	59	183	213
Coniferous Plantation	0.1		1.7	75	60	14.5	172	178
Pollard Trees	4.7					0.2		8
Scrub	198		1	133	10	6.3	31	123
Carr	91		7.5	39		11	4.5	83
Wet Woodland	17		1			1.5	1	32
Improved Grassland	3700	2	36	316	1	241	344	2255
Neutral Grassland	23	3.4	0.7	223	2.3	0.2	18	209
Calcareous Grassland	0.2		0.1	629	0.5		59	52
Acid Grassland	6	1.5	0.1			0.1	0.1	
Wet Grassland	782			7.5			8	210
Fen/Mire	104			34			2.5	3.5
Reedbed	65			25		0.5	1.7	15
Marsh	120			2	0.4	5	5.2	119
Standing Open Water	172	5.5	0.2	6		92	4	1172
Running Water	451		0.7	24	1.4	5.5	1.2	203
Lowland Heathland	0.1							
Inland Rocks and screes	21		19	2		5.5	8	156
Saltmarsh	2.5							
Arable	17		64	213		8	153	189
Industrial	60		2	10		24	1	86

Comparison of the Fens with adjacent Natural Areas suggests that certain habitats are appreciably either over- or under-represented in Fenland. Absolute areas of habitat can be misleading, since the Fens are noticeably larger than some neighbouring Natural Areas. Not surprisingly, Broadleaved Woodland and semi-natural grasslands (acid, calcareous, neutral) are relatively rare in the Fens. The Fens make their largest contribution regionally in terms of wet grassland (especially the washes), reedbed and, of course, fens themselves. Further information on the distribution of *Broad Habitats* can also be gleaned from the summary of protected areas within the Fens Natural Area, tabulated in *Appendix Tables 2.1* and *2.2* (see section 2.2.1.5).

2.2.1.3 Co-occurrence mapping of species pools: Broad Habitats and *NVC*

Co-occurrence mapping was conducted of BAP *Broad Habitat* types within the Fens Natural Area working at the 10 km square of the National Grid, used by the *Biological Records Centre* as the standard mapping unit. Most of the Core Area for the Great Fen project is contained within a single such square (TL28), with the Whittlesey Mere portion in TL29, and very much smaller strips in TL18 and TL19. Appendix Figures A1.1-A1.8 present some results of this co-occurrence exercise, with the outline of the Great Fen Core Area marked on each map. However, the presence of the mapped habitat cannot be unequivocally stated, for as discussed above, these maps indicate the potential occurrence of each *Broad Habitat*, based upon records of their constituent species.

The selection of habitats and communities for this exercise was largely based upon that used by *Humphries-Rowell Associates* and incorporated within the early feasibility studies for the *Wet Fens for the Future* programme (Anon 1995). This basic list was supplemented with *NVC* communities targeted for attention by the Great Fen Project Steering Group and from earlier work on targeting wetland restoration conducted by CEH (Mountford *et al.* 1999). All selected *NVC* communities were then assigned to their corresponding '*BAP Broad Habitat*'. Where appropriate, the constituent species of the separate communities, as given in the *NVC* constancy tables, were merged to produce a single list for each of the *Broad Habitats*. It should be noted that the *Broad Habitat* (as mapped) is not comprised of all the *NVC* communities that could be assigned to the *Broad Habitat* using Appendix 1, but includes only those communities of particular relevance to the study area.

The following Broad Habitats were mapped:

BH1 Broadleaved, mixed and yew woodland (Figure A1.1): Three *NVC* communities were merged to produce the *Broad Habitat* list: **W2, W4** and **W6** (Rodwell 1991a). The three communities are all found within sub-divided habitat '1d-Wet Wood'.

BH6 Neutral grassland: Three *NVC* Communities were included: **MG5, MG11** and **MG13** (Rodwell 1992), of which **MG11** and **MG13** fall within 6c-Inundation grass, and **MG5** within 6a-Lowland meadow.

BH11 Fen, Marsh and Swamp (Figure A1.2): Communities included: **S2, S4 (a-c), S5, S12 (a-d), S24b, S24c** and **S25** (all Rodwell 1995) and **M24a** (Rodwell 1991b). In terms of subdivided *Broad Habitats*, **S4a-c** fall within 11a-Reedbed; **S2, S5, S12a-d, S24b, S24c** and **S25** within 11b-Swamp and tall-herb fen; and **M24a** within 11d-Marsh, rush, wet grass.

BH14 Rivers and streams (Figure A1.6): Included communities **A11, A12** and **A16.**

BH13 Standing water and canals (Figure A1.7): Communities included: **A1, A2b, A3, A5b, A11, A12** and **A16.**

Two *NVC* communities of particular importance to the Great Fen Project were also treated individually to the co-occurrence mapping approach:

S24 *Phragmites australis-Peucedanum palustre* tall-herb fen (Rodwell 1995): all sub-communities were included and mapped in Figure A1.4.

M24a *Molinia caerulea-Cirsium dissectum* fen-meadow, *Eupatorium cannabinum* sub-community (Rodwell 1991) - mapped in Figure A1.5.

The total species lists for some of these *Broad Habitats* are long, and include occurrences at low constancy of some species that are hardly typical of the habitat. Thus, in an attempt to elicit a clearer picture, the *Broad Habitat* lists for **BH11** (Fen/marsh/swamp) and **BH13** (Standing water) were trimmed to include only those species with constancy IV and V (*i.e.* ≥61% constancy). The results of this co-occurrence mapping are presented in Figures A1.3 and A1.8 respectively.

BH1 Broadleaved woodland shows a clear, and expected pattern (Figure A1.1). The constituent species of the habitat are much better represented around the margin of the Fens Natural Area, especially in 10 km squares that straddle the Fenland/upland boundary. Within those squares that are entirely within the Fens, the representation of woodland species falls to ≤50% of the list for the wet woodland whole habitat (*NVC* **W2**, **W4** and **W6**). Woodland plants are apparently very well represented within the Core Area, partly because ancient clay woodlands on the upland fringe are included in the exercise, but also because the two NNRs themselves contribute extensive woodland habitat.

BH6 Neutral grassland is not mapped. The greater part of the species complement, especially those of high constancy, are almost uniformly distributed through the Fens Natural Area. Hence, restoration of neutral grassland anywhere in the Fens Natural area does not appear to be limited by local presence of the constituent plant species.

BH11 Fen/marsh/swamp shows a rather similar pattern to that for Broadleaved (wet) woodland whether examined using the full list (Figure A1.2) or with high-constancy species alone (Figure A1.3). Higher representation of fen species at the margins of the Fenland basin partly reflects the distribution of primeval fen habitat and hence peat soils, and partly the continued presence of related wetland vegetation in valley mires around the Fenland fringe. Fen plants are much more poorly represented on the silt "marshland" nearer the Wash, but the habitat shows low co-occurrence of constituent species in some squares close to the Core Area *e.g.* TL38 (Chatteris area) and TL49 (March area). TL38 and TL49 have no relict old fen and few of the worked-out clay-pits that provided some refuge for fen species during the late 19th and 20th centuries. The Great Fen Core Area is shown to possess many of the required constituents for fen restoration.

S24 *Peucedano-Phragmitetum australis* tall-herb fen is mapped by Rodwell (1991) for only a few 10 km squares in Fenland (TL28 Woodwalton and TL57 Wicken), though it should be borne in mind that these *NVC* maps simply depict samples of the original survey allocated to particular *NVC* types, and are not a definitive portrayal of the distribution of a particular community. Nonetheless, the very restricted distribution of tall-herb rich-fen appears genuine (Wheeler 1978). Figure A1.4 confirms the importance of Woodwalton (*i.e.* the Core Area) and Wicken Fens as *refugia* for fen species, though other parts of Fenland also support a high proportion of **S24** species. The eastern fringe of the Fens (including Boughton Fen, Lakenheath Poors Fen, Pashford Poors Fen and Wilde Street Meadow) have many of the "building blocks" of **S24**, as do those squares that include the West Norfolk valley Fens (Walton Common *etc*), which are actually outwith the Fens Natural Area.

M24a the *Eupatorium* sub-community of *Cirsio-Molinietum caeruleae* fen-meadow appeared to be especially typical of the Fenland basin (Rodwell 1991), where traditional management of "marsh hay" or "litter" maintained the vegetation, often on the margins of relic tall-herb fen, as at Wicken and Woodwalton. When the distributions of individual fen-meadow species are subjected to co-occurrence, the community appears to be potentially present in much the same parts of Fens Natural Area as **S24**, including the Great Fen Project Core Area (Figure A1.5).

BH14 Rivers and streams are mapped in Figure A1.6. The constituent species of the flowing water habitat are again best represented in the margins of the Fenland basin, especially in the southern and western parts *i.e.* Rivers Cam, Great Ouse, Welland and Witham. Those rivers feeding the eastern part of Fenland (Lark, Little Ouse and Wissey) appear somewhat poorer in aquatic species. The Project Core Area is not quite so rich in riverine species as, for example, the Ouse Washes and their environs.

BH13 Standing water *Broad Habitat* is depicted in Figures A1.7 and A1.8. The distribution of "ditch species" follows the general pattern of species-richness shown for other Broad Habitats, but there are some less-readily interpreted features. The Ouse Washes ditch network remains as the Fenland stronghold of aquatic vegetation, despite recent declines due to eutrophication (Cathcart 2002). The greatest diversity of macrophytes is found in the same areas as portrayed for BH14, with very poor representation on the silt south and west of the Wash. The drainage network of the Core Area is not quite so rich as the washes further east, but still supports a significant proportion of the typical macrophytes of this Broad Habitat, especially in the ditches of Woodwalton NNR.

2.2.1.4 Protected areas within the Great Fen and the Fens Natural Area

Information on protected areas is provided within the Appendix (Appendix Tables 2.1-2.2) and summarised as a map below (Figure 2.13). This map updates earlier attempts to document the occurrence of freshwater wetlands in relation to Natural Areas (Gardiner 1996). These data allow the present actual distribution of *Broad Habitats* to be assessed, and hence the likely sources of material for restoration of the Great Fen, either through natural colonisation or deliberate transplantation and introduction. If attention is focussed on those protected areas closest to the Core Area:

BH1: Appreciable areas of Broadleaved Woodland occur within the Core Area in the two NNRs, with many of the constituent species occurring on peat at Wicken and Chippenham, as well as in poorer scrubby carr of sallow and hawthorn at Bassenhally Pit *etc.* The clay woodlands around the fenland margin (*e.g.* Monks Wood NNR) are also potential sources.

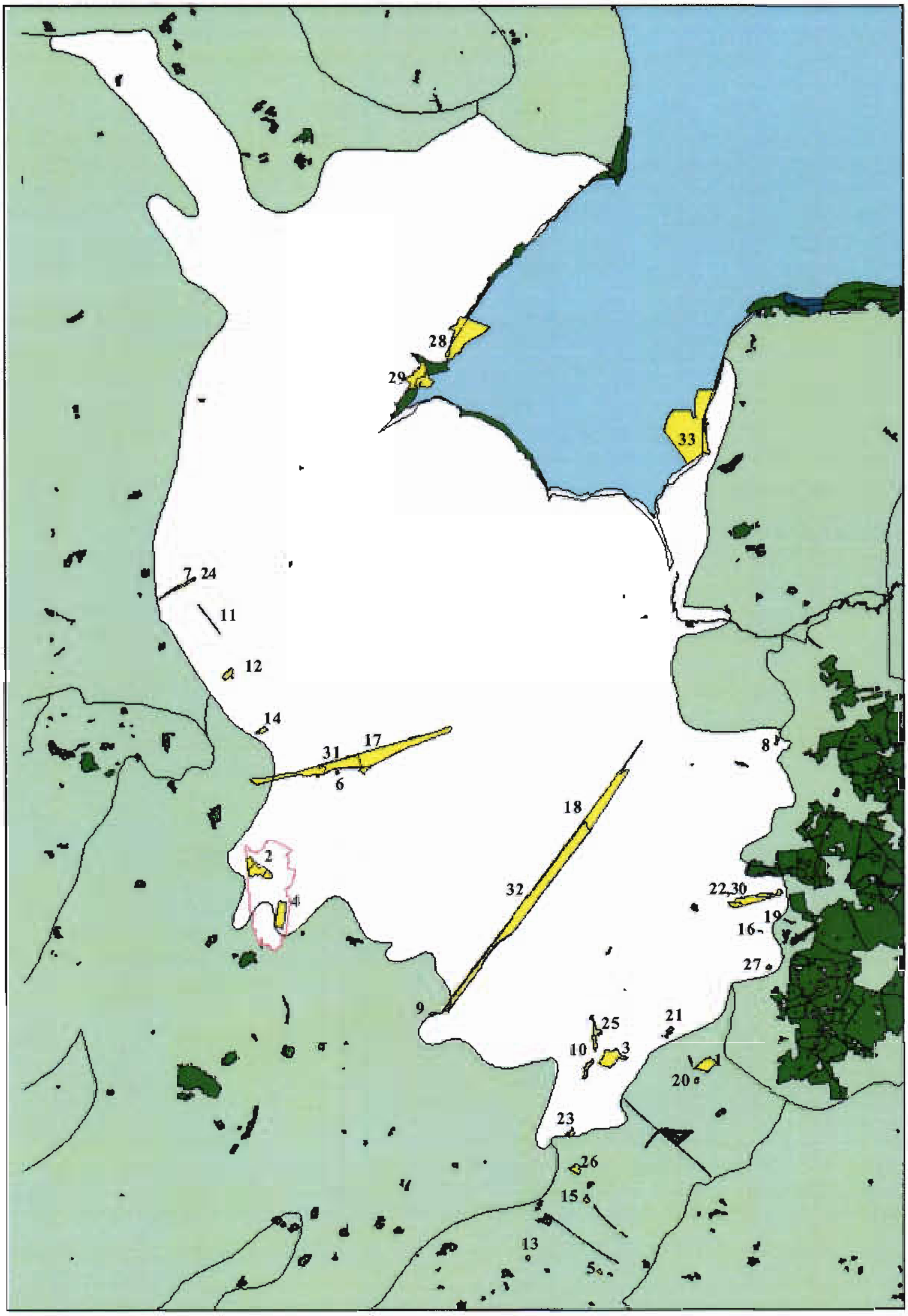
BH6: Within the Fens Natural Area, neutral grassland is most extensive on the Nene and Ouse Washes, with fragments within the habitat mosaic in many other peatland protected areas. Further afield, lowland moist-wet grassland is scattered in the nature reserves around the south and east margins of Fenland. As with the woodland habitat, the surrounding upland provides a potential source of many of the constituent species *e.g.* along the railway banks at and south from Woodwalton village.

LEGEND to Figure 2.13

1 Chippenham Fen	12 Deeping Gravel Pits	23 Stow-cum-Quy Fen SSSI
2 Holme Fen	13 Dernford Fen SSSI	24 Thurlby Fen Slipe
3 Wicken Fen	14 Dogsthorpe Star Pit	25 Upware North Pit
4 Woodwalton Fen	15 Fulbourn Fen LNR	26 Wilbraham Fen SSSI
5 Alder Carr SSSI	16 Lakenheath Poors Fen LNR	27 Wilde Street Meadow SSSI
6 Bassenhally Pit	17 Nene Washes SSSI	28 Freiston Shore (RSPB)
7 Baston Fen	18 Ouse Washes SSSI	29 Frampton Marsh (RSPB)
8 Boughton Fen	19 Pashford Poors Fen SSSI	30 Lakenheath Fen (RSPB)
9 Berry Fen	20 Snailwell Meadows SSSI	31 Nene Washes (RSPB)
10 Cam Washes	21 Soham Wet Horse Fen	32 Ouse Washes (RSPB)

Figure 2.13 *Protected areas (NNR, LNR, SSSI etc) in the Fenland Natural Area (on peat)*

Note: Great Fen Core Area indicated



BH11: Significant areas of the core wetland habitats (fen/marsh/swamp) occur in the two key NNRs within the Great Fen Project Area. Wet grassland communities linking neutral grassland to fen-meadow and rush-pasture are extensive on the Washes. Smaller, but potentially useful, patches of wetland are present in most of the protected areas in the Fens, varying from relatively extensive species-poor reedbed to scraps of vegetation that approach fen-meadow or even tall-herb fen in worked-out pits *etc* (*e.g.* Kingfisher Bridge and Upware North Pit). Several SSSIs in the valleys feeding the Fens have this Broad Habitat as an important component. Chippenham Fen NNR is the main such example, but the LNRs *etc* listed in the note to Appendix Table 2.1 may also comprise useful source sites.

BH13: Open standing water is the most uniformly distributed of all the *Broad Habitats* in the Fens Natural Area, due to the vital importance if the ditch/lode/leam/drain network in draining the fenland and conducting it through to the outfalls. Although almost ubiquitous when mapped at the 1 km square scale, this habitat is by no means uniform in quantity and quality. An important source site for the Core Area is provided by the Conington Fen Drains, in addition to the internal systems of Woodwalton Fen, and (to a lesser extent) Holme Fen.

A further category of designated area can be found in the *Invertebrate Site Register* (*ISR*) - a catalogue of important sites subdivided by habitat, but using categories that do not correspond exactly with those of the Broad Habitats system. Nonetheless, it is possible to separate lowland ponds and lakes (often derived from "quarries" *i.e.* gravel pits *etc*), streams and rivers and a complex of wetland habitats (Appendix Table A2.3)

Table 2.12 *Habitat Action Plans of relevance to Great Fen Project Area*

National	Cambridgeshire	Lincolnshire	Norfolk	Suffolk
Wet woodland	Wet woodland	Wet woodland	[needs action - no plan]	Wet woodlands
Lowland meadows	Meadows and pastures			Lowland hay meadows
Coastal and floodplain grazing marsh	Floodplain grazing marsh	Coastal and floodplain grazing marsh	Coastal and floodplain grazing marsh	Coastal and floodplain grazing marsh
Fens	Fens		Fens	Fens
Reedbeds	Reedbeds	Reedbeds	Reedbed	Reedbeds
Eutrophic standing waters	Lakes and irrigation reservoirs	Ponds, lakes and reservoirs		Eutrophic standing water
Rivers and streams	Rivers and streams	Rivers, canals and drains		
	Drainage ditches			

2.2.1.5 Biodiversity Action Plans (BAPs)

A series of BAPs for wetland habitats have been developed both nationally and county by county, summarised for the Great Fen Project area in Table 2.12. In particular, Cambridgeshire has a very detailed system of local BAPS, covering all major wetland habitats, and these are integrated within the National BAP framework. This system can provide a context within which the inventory of extant habitats in the Project Area can be examined, assessing to what degree these meet BAP targets for conservation or rehabilitation. Such a calculation then allows estimation of how far the various restoration scenarios outlined in subsequent sections can meet the appropriate BAP targets for restoration. A detailed summary of targets and milestones for national and local BAPs is provided in Appendix 2, within Tables A2.4-A2.10 covering the *Broad Habitats* central to the Great Fen project.

2.2.2 *Key species*

A similar approach can be taken to the statutory recognised need for nature conservation action with individual species. For three Fenland counties, Table 2.13 lists those individual species where BAPs are being, or have been, drafted. The great majority of these are potentially relevant to the Great Fen.

Following the construction of scenarios for the Great Fen project (Sections 5 and 6), it will be possible to make preliminary estimates of the likely extent of suitable habitat for each of these BAP species, together with an outline of the nature of any management required to introduce or maintain them within the Project Area. Such "key species" for biodiversity protection can be placed into one of three categories:

I. Species already present in the Great Fen area that may be expected to expand in range and population should suitable conditions be created.
II. Species (normally animals or plants with mobile propagules) likely to colonise the Great Fen area should suitable conditions exist.
III. Species that are likely to require action to ensure colonisation and establishment - often deliberate introduction followed by some maintenance management.

However, such "flagship" species do not comprise the essential building blocks of the Broad Habitats that the Great Fen Project seeks to restore. Rather they may represent the final indicators that a fully functioning and diverse fenland habitat has been achieved. In the shorter term (say, ≤5 decades), the successful progress of restoration can be recognised through production of sustainable communities with the correct dominants, biomass and nutrient retention. The criterion of low invasibility for measuring successful ecological restoration comes into play relatively late in the habitat development.

In the present scheme, where one is working with broadly defined habitats, the species for which priority should be given are the major dominants and constants (IV and V) of these habitats. Such species not only form the greater part of those tabulated in Appendix Tables A3.2 and A3.3, but also were central to the co-occurrence exercise reported in section 2.2.1.4 (notably in Figures A1.3 and A1.8). As discussed before, the co-occurrence maps essentially depict where key species for habitat restoration are present, and thus where restoration planning might profitably focus.

Table 2.13 *Extant Wetland Species Action Plans (by county).*
Note: All species of rivers and wetlands, except those marked (HP) *i.e.* heathland & peatland. Bittern (and Reed Bunting) are also expected to benefit from the Reedbed Action Plan

A. **Cambridgeshire**

Mammals	Water Vole	*Arvicola terrestris*
	Otter	*Lutra lutra*
Birds	Bittern	*Botaurus stellaris*
Butterflies	Large Copper Butterfly	*Lycaena dispar*
Crustaceans	Freshwater White-clawed Crayfish	*Austropotamobius pallipes*
Molluscs	Glutinous Snail	*Myxas glutinosa*
	Shining Ram's-horn Snail	*Segmentina nitida*
	Desmoulin's Whorl-snail	*Vertigo moulinisiana*
Vascular Plants	Ribbon-leaved Water-plantain	*Alisma gramineum*

B. **Lincolnshire**

Mammals	Water Vole	*Arvicola terrestris*
	Otter	*Lutra lutra*
Fish	Spined loach	*Cobitis taenia*
Coleoptera	Hazel Pot-beetle	*Cryptocephalus coryli* (HP)
	Mire Pill-beetle	*Curimopsis nigrita* (HP)
Crustaceans	Freshwater White-clawed Crayfish	*Austropotamobius pallipes*
Molluscs	Depressed River-mussel	*Pseudanodonta complanata*
	Witham Orb-mussel	*Sphaerium solidum*
Vascular Plants	Ribbon-leaved Water-plantain	*Alisma gramineum*
	Grass-wrack Pondweed	*Potamogeton compressus*
	Greater Water-parsnip	*Sium latifolium*

C. **Norfolk**

Mammals	Water Vole	*Arvicola terrestris*
	Otter	*Lutra lutra*
Birds	Bittern	*Botaurus stellaris*
Amphibians	Great Crested Newt	*Triturus cristatus*
Molluscs	Ram's-horn Snail	*Anisus vorticulus*
	Depressed River-mussel	*Pseudanodonta complanata*
	Narrow-mouthed Whorl-snail	*Vertigo angustior*
	Desmoulin's Whorl-snail	*Vertigo moulinisiana*
Worms	Medicinal Leech	*Hirudo medicinalis* (published)
Vascular Plants	Ribbon-leaved Water-plantain	*Alisma gramineum*
	Fen Orchid	*Liparis loeselii* (published)
	Floating Water-plantain	*Luronium natans*
	Holly-leaved Naiad	*Najas marina*
Liverworts	Norfolk Flapwort	*Lophozia rutheana* (published)

3 BROAD HABITATS: THEIR PHYSIOLOGICAL REQUIREMENTS

The aim of this section is to summarise what is known about the physiological requirements of the *Broad Habitats* and key species. CEH has taken this to mean a review of the information (published and unpublished) on the environmental conditions within which the target habitats (together with species and communities where appropriate) for the Great Fen project are known to exist in Britain and mainland Europe. Such a review differs somewhat from other major appraisals of habitat restoration schemes and techniques *e.g.* fens (Moorhouse 1999), grasslands (Walker *et al.* 2001), and wetlands in general (Treweek *et al.* 1991; Wheeler *et al.* 1995). However, material covered by these reviews frequently includes some reference to the target conditions for restoration. It should be borne in mind that in actual restoration projects, conditions for successful initiation of habitat restoration may differ from those that pertain to the eventual target habitat (Manchester 2002).

In addition to those sources cited below, which, in the main, address specific sites and projects, several major works attempt a more synoptic account of the habitat conditions within which wetland habitats and species occur *e.g.* Rodwell (1991-2000) and Wheeler and Shaw (1987). CEH has worked particularly to define the needs of plants, adapting and expanding the approaches developed on the mainland of Europe to rank the habitat requirements of plants (*e.g.* Ellenberg indicator values by Hill *et al.* 1999). The approach has been expanded to include animals and communities (Newbold and Mountford 1997). Such ranking approaches are based not only on the results of extensive fieldwork (*e.g.* Countryside Survey; Wierda *et al.* 1997), but also benefit from testing through autecological experiment (Barratt *et al.* 1999; Treweek *et al.* 1998; Walker 1999). Three tables have been prepared that summarise this largely qualitative information, and are incorporated in Appendix 3: Table A3.1 (*NVC* communities), Table A3.2 (aquatic plants) and Table A3.3 (terrestrial plants).

Such qualitative approaches and rankings allow species to be classified in groups that can suggest their likely responses to the creation of particular environmental conditions in a habitat restoration scheme, such as that for the Great Fen Project. However, ecology has attempted in recent years to move from a correlative and descriptive discipline toward a more mechanistic science. Despite this move toward a predictive science, most ecologists and practitioners accept that a degree of unpredictability has still to be accepted in restoration schemes (Klötzli and Grootjans 2001). Forty years of experience and research has not yet prevented schemes witnessing vegetation developments in an undesired or unexpected direction. For some groups (*e.g.* water birds), their autecology is sufficiently well understood for detailed management/restoration prescriptions to be coined for their survival and increase. For many of the ecologically most important groups, invertebrates, microbial communities, and even vascular plants, such quantitative information is sparse at best. The following discussion attempts to assess how far a quantitative description is possible for the target *Broad Habitats* (and specific plant communities) in the Great Fen Project, and to what extent a looser, qualitative approach remains necessary.

3.1 **Water Quantity: Eco-hydrology**

3.1.1 *Introduction and site studies*

The overwhelming influence of the amount, quality and seasonal distribution of water on the occurrence, composition and dynamics of wetland communities has long been realised, and a large body of qualitative and correlative research has studied the nature of these relationships (Keddy 2000). Keddy himself has been instrumental in attempting to achieve a more mechanistic and quantitative analysis of the processes that determine wetland function. However, at present there is still limited quantitative knowledge of the water requirements of different wetland habitats and their tolerance to water shortage and waterlogging (Gowing *et al.* 1994; Gowing 2000). Broad indications of preferred water requirements and upper and lower tolerances for drying and wetting of individual species are presented in Newbold and Mountford (1997) - see also Appendix Table A3.1.

Table 3.1: *Water requirements of four selected wetland habitats - NVC communities*

***NVC* vegetation type**	**Water-requirements**	**Flooding regime**
S4 Reedbed	Associated with open water, but many species can tolerate long periods with the water-table below ground level.	-
MG13 Mesotrophic Grassland	Soils damp and sometimes waterlogged	Regularly flooded by fresh-water, sometimes for long periods
M24 Litter and wet Culm grassland	From fairly moist to quite dry (especially in summer) with little fluctuation of the water-table throughout	Very seldom flooded
S24 Rich Sedge Fen	Mean water levels are low	Winter flooding

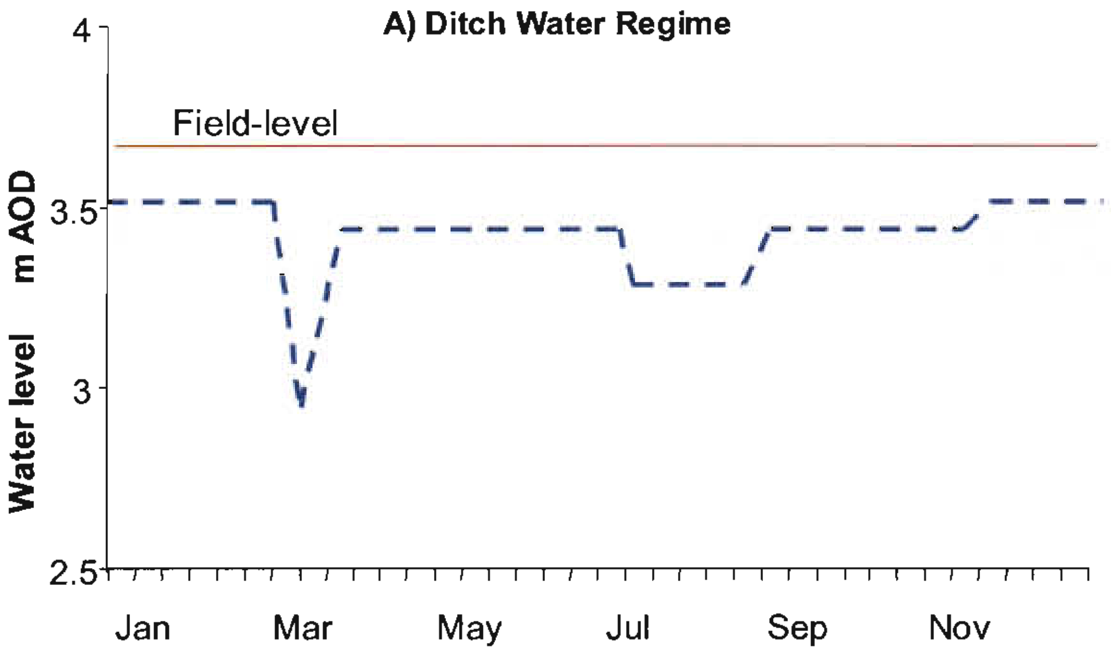
For the communities of particular interest in the current study these qualitative descriptions are summarised in Table 3.1. Bryan Wheeler and others have used a broad classification to characterise the hydrological situations under which fens occur *e.g.* floodplain fens, open-water transition fens, spring fens, basin fens, valley fens and soakways (Fojt 1994; Wheeler 1984). An alternative approach to assessing wetland vulnerability (Lloyd *et al.* 1992) appears less useful for the present purposes. The fens of Cambridgeshire are mainly topogenous in origin, and overwhelmingly floodplain fens, evolving on waterlogged (often periodically inundated) sites along rivers. A few open- water transition fens would have occurred around the Fenland meres, but basin fens (developing in waterlogged, usually closed basins) would have been very rare in the Fenland, and may effectively be discounted from the Great Fen project area. What is increasingly clear as the subject of eco-hydrology develops is that small differences in micro-topography can have a marked impact on vegetation composition (Silvertown *et al.* 1999), and researchers increasingly stress the reinstatement of any such relief as a pre-requisite to successful habitat restoration (*e.g.* Jansen *et al.* 2001).

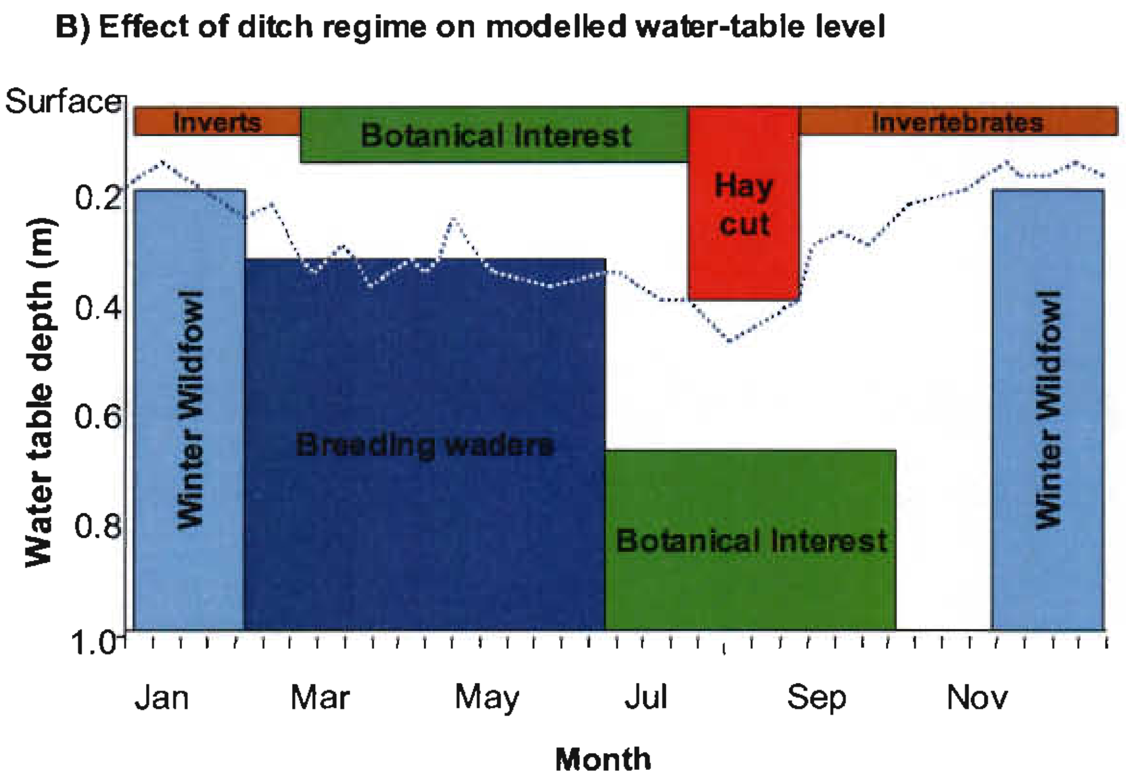
Characterisation of the water-regime requirements of individual species and *NVC* communities has been a theme of a programme of research focusing on wet grasslands led by the University of Cranfield in which CEH has participated (Gowing 2000; Gowing *et al.* 2002). This approach quantifies the water-regime in terms of Sum Exceedence Values (SEV), with two stresses calculated for each site (or microsite) *i.e.* "drought stress" representing the level of soil drying experienced and "aeration stress" representing the extent to which high soil water-tables prevent aeration of the plant roots. A brief exposition of the derivation of SEVs is provided in Appendix 3. The tolerances of wet grassland communities of the NVC may be separated using the SEV axes (see Appendix Figure A3.2). Here three grassland communities of some interest to the Great Fen project may be distinguished. The drier meadow grassland **MG5** is shown to have a high tolerance for drought, but to be confined to sites where aeration (waterlogging) stress is minimal. The wet meadow community **MG8** occurs in low-stress situations where drought and waterlogging are both of short duration. Finally, **MG13** inundation grassland cannot withstand long periods of drought, but appears to be the most tolerant mesotrophic grassland type to flooding/waterlogging.

Application of the SEV approach to natural habitats has helped to further focus the attention of ecologists on the timing of events (both within and between years), and their impact on community composition. Agricultural scientists had long discussed critical growth stages, where particular conditions at certain times of the year can have marked effects on flowering, fruit production and productivity (Gowing *et al.* 1994). Habitats that may be otherwise similar in the amount of water present may nonetheless differ depending on when that water is supplied to the site (Keddy 2000).

Figure 3.1: *Management of water-levels to achieve multiple objectives at West Sedgemoor* (After Spoor *et al.* 1996, adapted for the *Wet Grassland Guide*)

Note: Peat site with ditch-spacing of 30m. The approach showed that it was possible through careful water-management to meet the varying needs of different species groups. The white zone in graph B) comprises the range of acceptable water-table levels for all the different species groups, whilst where the water-table crosses a "species-group box", there is a potential conflict between that water-level and conservation of that biodiversity interest. The approach also shows that farming interests can be integrated into the management system. The prescription derived from this modelling approach required a rapid drawdown of levels in spring to prevent excess surface water that could damage the botanical interest. Raising water-levels soon afterward enabled the soil to be kept moist for breeding waders, and a further drop in levels in mid-late summer facilitated the hay cut.





The application of this critical stage approach to wetland management can be understood through the example of the RSPB's wet grassland reserve at West Sedgemoor in Somerset (Figure 3.1). From this schematic summary, it can be inferred that the same water-table at different times of the year can either have positive or deleterious impacts on biodiversity interests. Research using model predictions and monitoring led to a revised Somerset ESA Tier 3 (raised water levels) being advanced, whereby levels be slightly lowered in March-April to prevent anoxia and sward death at this critical time for grass growth (Gowing 1996). When applied in an unmodified form, maintaining raised water-levels through March led to an impoverishment of the species-rich semi-natural hay meadows at the long-term experimental site of Tadham Moor, without any concomitant development of a diverse wetland vegetation (Mountford *et al.* 2001). Appendix Table A3.1 provides some insight into when, within the cycle of the seasons, particular water-levels might be appropriate, but it must be acknowledged that most of the available information does not allow strictly quantitative prescriptions.

Other attempts to quantify the water-regime of wetland communities can be found in the mainland European literature. Looking at methods and strategies for wet grassland restoration, Schrautzer *et al.* (1996) separated three different grassland habitats on the basis of the mean annual groundwater table, an index of groundwater fluctuation and duration of flooding (Table 3.2). The habitats investigated were a *Calthion* (an alliance that includes *NVC* **MG8** and **M22**), "abandoned wet meadows" (possibly allied to *NVC* **MG9** and **MG10**) and the *Lolio-Potentillion* (an alliance related to MG11, and also MG12/13) (Rodwell 1991-2000). These grasslands lie within *Broad Habitats* **BH6** and **BH13**.

Table 3.2: *Hydrological parameters (median) of different wetland habitats in Northern Germany.* (After Schrautzer *et al.* 1996).

Hydrological parameter	*Calthion*	Abandoned wet meadows	*Lolio-Potentillion*
Mean annual groundwater table (cm)	-14 (-10 to -17)	-16 (-13 to -18)	-30 (-20 to -42)
Groundwater fluctuation index	16 (4 to 20)	26 (13 to 30)	125 (100 to 156)
Flooding period (% of year)	6 (3-8)	0	15 (8 to 22)

Table 3.3: *Selected environmental conditions for fen communities in the Biebrza valley, Poland.*

(After Wassen *et al.* 1990).

Environmental variable	*Glycerietum maximae*	*Caricetum elatae*	*Lolio-Cynosuretum*
Flooding	100	63	0
Groundwater level (cm below mire surface)	4.0 ±6.5	1.6 ±7.3	13 ±2.0
Calcium in groundwater (mg/l)	102 ±14	102 ±29	51 ±3
pH in groundwater	7.5 ±-0.3	7.3 ±0.2	6.9 ±0.3
Nitrogen in groundwater (mg/l)	1.72 ±1.11	1.25 ±0.9	0.50 ±0.14
H_2PO_4 in groundwater (mg/l)	0.19 ±0.16	0.11 ±0.07	0.00 ±0.00
Potassium in groundwater (mg/l)	0.88 ±0.32	1.42 ±2.04	4.38 ±5.62

Data from the Biebrza valley in northeast Poland (Wassen *et al.* 1990) refer to a range of swamp, fen, carr and grassland communities, some of which are closely allied to those that have occurred in Fenland, and which might be the subject of restoration: *Caricetum elatae* (*NVC* **S1**) and *Glycerietum maximae* (*NVC* **S5**). These are compared with the improved grassland *Lolio-Cynosuretum* (*NVC* **MG6**). Table 3.3 reports selected hydrological and nutrient conditions for these communities.

Such information allows some prescriptions to be provisionally set for a few fen-meadow and swamp communities, which might be restored on a confined area with some within-site engineering to provide a range of water-regimes. However, in terms of restoration planning at the landscape scale (as in the Great Fen Project), another approach is required.

3.1.2 *Evapotranspiration: quantifying the water-regime*

In terms of the water resource of the area, the element of key interest is the quantity of water that will be "lost" through evapotranspiration from restored wetlands and how this will differ from the present agricultural land-use. Water loss through evapotranspiration is a major output in the water budget of most wetlands. Various experiments have been conducted to estimate actual evapotranspiration from wetlands. Laine (1984) investigated the effects of tree species and water-table elevation on evapotranspiration from forested bogs. The study showed that evapotranspiration was close to the potential evapotranspiration rate, and there were only slight differences between plots carrying different species. Sturges (1968) reported summer evapotranspiration rates from a spike-rush (*Eleocharis quinqueflora*) community at *ca* 80% above potential rate and Nichols and Brown (1980) measured evaporation rates from *Sphagnum* moss at 130-150% of the open water evaporation rate.

Fens have received relatively little attention in the scientific literature, but the research that has been conducted indicates a wide range of values. A lysimeter study conducted in a sedge-dominated community in the Netherlands indicated that evapotranspiration was 74-81% of open water evaporation (Koerselman and Beltman 1988). A study in northern Ontario (Canada) found that at a site where the growing season commenced with standing water, evapotranspiration rates were approximately 85% of open water, whilst at a drier site the rate was always about 60% of open water evaporation (Lafleur, 1990). In another Canadian study, evapotranspiration from sedge fen was found to equal open water evaporation (Roulet and Woo 1986). At Wicken Fen, actual summer evaporation from litter (*i.e.* **M24** vegetation) over 3 summers (1984-1986) was found to be 64-80% of the potential evapotranspiration rate (Gilman 1988). Water table observations in the same study showed that rates of decline below sedge fen (**S24** *etc*) were 69% ± 29% of that below the litter. This was attributed to lower transpiration and possibly greater interception from the sedge (Gilman 1988). In a more recent study, again using dipwell data, actual summer evapotranspiration at Wicken Fen over 4 years was estimated to range from 46-66% of *MORECS* potential evapotranspiration (McCartney *et al.* 2001). However, in this later study, there was no attempt to identify different evapotranspiration rates from different vegetation communities.

Actual evapotranspiration from wet grassland has been shown to be very variable and highly dependent on duration of inundation or soil saturation. A hydrological study of West Sedgemoor (used for grazing and hay production) concluded that on average the evapotranspiration from the Moor was 95% potential evapotranspiration (Gilman *et al.* 1990). In a study of Elmley Marshes in Kent it was found that actual evapotranspiration rates sometimes exceeded potential rates when the watertable was at or above the soil surface. When the water table was below the ground surface the measured evapotranspiration was approximately equal to potential until the soil moisture deficit reached a critical point (*ca* 40 mm), whence it declined (Gavin, 2001). These findings have been confirmed in a recent study of evapotranspiration at Tadham Moor in Somerset, where between June and October 1999 evapotranspiration was found to exceed potential evaporation (Et) by a factor of 1.035 (Acreman *et al.* in prep.).

Studies of reedbeds have indicated evapotranspiration losses significantly in excess of potential evaporation. Smid (1975) conducted Bowen ratio measurements on several days between June and October 1973 in Czechoslovakia and found that evapotranspiration equalled open water evaporation. Other studies in central Europe (*i.e.* Austria, Poland, Slovakia), using a variety of techniques, have resulted in estimates ranging from 80 to 300% open water evaporation (Fermor *et al.* 2001). Observations made over several years (1995-2000), at a recreated reedbed at Ham Wall in Somerset, indicate evapotranspiration rates of up to 123% of Penman potential evapotranspiration in some summer months (Gilman *et al.* 1998; Acreman *et al. in prep.*).

In attempting to assess vegetation water requirements, the approach adopted in the current study is the crop coefficient methodology summarised in *FAO drainage and irrigation paper 56* (Allen *et al.* 1998). This approach was originally developed for irrigation scheduling, but in recent years has been applied to vegetation cover other than arable crops (*e.g.* Fermor *et al.* 2001).

Weather parameters, plant characteristics, management and environmental aspects influence evapotranspiration from vegetated surfaces. In the crop coefficient approach distinctions are made between a reference crop evapotranspiration (ETo)[3] and vegetation evapotranspiration under standard conditions (ETc). ETo is a climatic parameter expressing the evaporating power of the atmosphere. It relates to the evapotranspiration from a hypothetical well-watered grass reference crop. ETc refers to the evapotranspiration from a vegetation cover under optimum moisture conditions. Thus:

$$ETc = ETo \times Kc$$

Where Kc is a "crop" coefficient that integrates the effects of both crop transpiration and soil evaporation and is specific to the vegetation. Kc is expressed as either a monthly difference or is related to the stage of vegetation development. The Kc values are directly proportional, so that a value of 1 indicates twice as much evapotranspiration as a value of 0.5. In attempting to derive crop coefficients for different wetland types, a complication is that in <u>all</u> the studies actual evapotranspiration rates have been determined under non-standard conditions. Environmental factors, such as soil salinity, low soil fertility and in particular water shortage or water logging will have affected actual measured evapotranspiration. Furthermore, comparisons have been made with different reference evapotranspirations. In many of the more recent studies the potential evapotranspiration referred to is that derived from micro-meteorological measurements made at the same location. However, very often (as in the current study) the only long-term data available at potential reedbed restoration sites are *MORECS* data. This source provides a reference potential

[3] In some cases the measured reference evaporation used is open water evaporation (Eo).

evapotranspiration for a grass sward that is based upon the Penman-Monteith method of calculating ETo (Monteith, 1965). Table 3.4 provides a summery of crop coefficients taken from the literature, in which the reference evapotranspiration is known to be Penman-Monteith derived in this way.

Based on these data, a best estimate of the crop coefficient is presented for each wetland type. For comparison coefficients for some arable crops grown in the area are also presented. Two assumptions were made. Firstly, that although the *MORECS* grass PE and the FAO potential evapotranspiration (*i.e.* Et) are not identical[4], they are similar and any differences introduced in calculating the reference evapotranspiration are greatly outweighed by other errors. Secondly, that sedge fen has similar characteristics to reeds grown in moist soil, and so in terms of water requirements it lies between wet grassland and reeds in standing water. Summer and winter averages are presented in Table 3.5. These results indicate that, when water is available, evapotranspiration from wetland habitats will exceed that from arable crops. This is partly because the growing season for the crops does not generally extend over the whole of the summer period.

Table 3.4: *Crop coefficients (Kc) (monthly) for different wetland types*

	Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Reed (standing water)	1	0.81	1.01	0.70	0.90	0.85	1.33	1.40	1.68	2.15	1.89	1.16	1.10
	2	-	-	-	-	-	-	1.68	1.26	1.46	1.75	1.11	-
	3	-	-	-	1.10	1.10	1.10	1.10	1.16	0.83	-	-	-
	4	1.00	1.00	1.00	1.00	1.10	1.20	1.20	1.20	1.20	1.20	1.10	1.00
	Best est.	**0.91**	**1.00**	**1.00**	**1.00**	**1.05**	**1.21**	**1.35**	**1.32**	**1.41**	**1.61**	**1.12**	**1.05**
Reed: moist soil/ sedge fen	4	**0.70**	**0.70**	**0.70**	**0.90**	**1.05**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**	**0.90**	**0.70**
Wet grassland	2	-	-	-	-	-	-	1.40	1.30	1.27	1.27	0.99	-
Grass Pasture	4	0.40	0.40	0.40	0.95	0.95	0.95	0.95	0.95	0.85	0.85	0.40	0.40
	Best est.	**0.40**	**0.40**	**0.40**	**0.95**	**0.95**	**0.95**	**1.18**	**1.13**	**1.06**	**1.06**	**0.70**	**0.40**
Potatoes	4	-	-	-	0.5	0.75	1.15	1.15	0.75	-	-	-	-
Sugar beet	4	-	-	-	0.35	1.20	1.20	1.20	1.20	0.70	-	-	-
Cereals (wheat, barley, oats)	5	-	-	-	0.40	1.15	1.15	1.15	0.55	-	-	-	-

1 = Fermor, 1997 and Fermor *et al.*, 2001. Derived as average from three locations in the UK: Teesside International Nature Reserve, Walton Lake and Himley Sewage Treatment Works. Reference evaporation is *MORECS* ETo (grass).

2 = McCartney 2001 – estimates based on field data from 1999 at Ham Wall and Tadham Moor in Somerset. Reference evaporation is *MORECS* ETo (grass). For the wet grassland at Tadham Moor, the values are underestimates, since some soil moisture deficits occurred and consequently there will have been some environmental stress on the grass.

3 = Gilman *et al.* 1997 – estimates based on field measurements made at Ham Wall reedbed in Somerset in 1996 and 1997. In the report, the ratio of actual to potential evapotranspiration is presented as a percentage of

[4] Both MORECS Grass PE and FAO reference potential evapotranspiration (ETo) are determined using the Penman-Monteith formula for a short well-watered grass (Monteith, 1965). However, in the FAO calculation a fixed values of 70 sm^{-1} is used for surface resistance (Rs) while in the MORECS calculation Rs is assumed to be 80 sm^{-1} in the summer and 40 sm^{-1} in the winter months.

Et, in which Et is derived from an on-site weather station. For the present study, the coefficients have been re-computed using *MORECS* Et as the reference evaporation.

4 = Allan *et al.* 1998 – Reference evaporation is FAO – Penman-Monteith, ETo. For the present study, values have been estimated assuming reed development stages given in Fermor, 1997 (*i.e.* initial *ca* 40 days commencing on 1st April, mid phase 190 days and final (dormant phase) remainder of the year); grass pasture development phases in Allan *et al.* 1998.

5 = ASCE 1996

Table 3.5: *Average crop coefficients for different vegetation types*

	Winter average	Summer average
Reed – standing water	1.12	1.22
Reed – moist soil/Sedge Fen	0.82	1.13
Wet grassland	0.56	1.04
Potatoes	-	0.53
Sugar beet	-	0.98
Cereals	-	0.73

A useful attempt at setting water-depth prescriptions for wetland restoration options has been derived from the work of Gilman *et al.* (1998) and subsequent work on the Avalon Marshes project (Somerset County Council 2000). A summary of these recommendations for lowland wet grassland, commercial reedbeds, fen and open water in the decade following inception of a wetland restoration scheme is given in Appendix Table A3.4.

3.2 Water Quality: fertility and nutrient levels

Numerous studies have shown that water chemistry is a key factor determining the composition and maintenance of different wetland habitats (*e.g.* Beltman *et al.* 1996; Vitt 1994; Wassen 1995). However, consistent sharply defined water quality thresholds that distinguish different wetland habitats do not exist. Moreover, large-scale comparison of wetland water chemistry can be very difficult because of: i) regional differences in the chemical characteristics of precipitation, ii) seasonal variability in wetland water chemistry and iii) different methods for sampling and analysing water (Bragazza and Gerdol 1999). Work on wetland restoration frequently stress that any scheme should begin with a nutrient-poor substrate. Ecological restoration activity is usually aimed at lowering soil fertility, with the abiotic target being "base-rich, nutrient poor water". It is notable that the parameters selected by different workers make cross-comparison between studies, and hence generalisation prior to designing a scheme, difficult. For example Dutch work on raised water-levels (rewetting) of degraded wetlands sets soil nitrogen targets for semi-natural fen at 0.9-2.8 kg N/m^2, whilst noting that restoration schemes had not yet reduced the nitrogen content below the range 4.4-7.8 kg N/m^2 (Richert *et al.* 2000).

3.2.1 *Fens and reedbeds*

As well as the hydrological classifications (topogenous *vs* soligenous *etc*) discussed above, fens may be sub-divided into three main types on the basis of concentrations of mineral elements in the surface waters (*i.e.* poor fens, moderate-rich fens and extreme-rich fens: Vitt, 1994). Much of the published research still functions at this qualitative level, providing correlations between fen type and phosphorus and potassium without necessary setting quantitative limits on the occurrence of different communities (van Duren *et al.* 1997). Water pH in fens is generally above 4.0, reaching values in excess of 7.0 in extreme rich fens, while calcium concentrations in surface water can be 2-3 mgl^{-1} in poor fens to up to 50 mgl^{-1} in extreme rich fens (Bragazza and Gerdol 1999). The work of Wassen in the Netherlands and Poland has shed some light on the nutrient preferences for fen and swamp vegetation, though some of the potentially most useful work remains as a rather qualitative ranking, stressing the requirement for "calcareous phosphate poor water" (Wassen, 1995; Wassen and Joosten 1996; Wassen *et al.* 1989, 1990). Some of this research is only of marginal relevance in community terms to the Great Fen, where it focuses on mires of the *Caricion davallianae*, but taken as a whole it constitutes one of the best bodies of quantitative study of the water and nutrient-relations of fens. For example Table 3.3 summarises both pH and groundwater concentrations of Ca, K, N and P for swamp communities. Information on **S4** reedbeds suggests a much wider amplitude on all these parameters (Rodwell 1991-2000), and that water-depth is the primary determinant.

3.2.2 *Fen-meadows and lowland wet (mesotrophic) grassland*

Walker *at al.* (2001) reviewed the available data, both published and unpublished, for the typical "target" soil pH, exchangeable phosphorus (P) and exchangeable potassium (K) for some 20 *NVC* lowland grassland communities and sub-communities. Values for mesotrophic grasslands vary considerably:

- **MG5** typically has a pH of 5.2-6.2, with exchangeable P of 1 mg/kg and K 50-150 mg/kg
- **MG8** has pH *ca* 6.0, P of 6-8 (-16) mg/kg and K of 140 mg/kg
- **MG13** has a target values for pH of *ca* 7.4, and P of 27 mg/kg

The typical soil nutrient status of **M24** *Molinia caerulea-Cirsium dissectum* fen meadow was studied for Welsh stands (Blackstock *et al.* 1998) and reviewed in the context of restoration by Walker *et al.* (2001). In the upper 15cm of the soil, the pH was *ca* 5.08, rising to 5.29 between 15-30 cm. Exchangeable sodium was about 1.36 m molc/kg, and that of calcium 51.6. Target soil pH for restoration in the Fenland might range from 4.4-7.2, with a mean of 5.3 and with preferred values for more calcareous stands of such fen-meadows somewhat higher (Walker *et al.* 2001). Available P might be 2 mg/kg and exchangeable K 10 mg/kg. Comparable values for an **M23** rush-pasture might be pH = 5.4-5.6, P = 3.2-6 (-14) mg/kg and K varying widely from 10-140 mg/kg.

3.2.3 *Interaction between raised water-levels and soil nutrients*

Experiments conducted in mainland Europe have shown that rewetting stimulates the creation of anaerobic environments and has a major effect on the availability of nutrients (Koerselman and Verhoeven 1995). The rewetting of relatively acidic fen peat soils may lead to increased availability of nutrients for wetland plants adapted to anaerobic conditions. Rewetting may increase nitrification thereby increasing nitrogen availability. Furthermore, anaerobic conditions may increase the phosphate availability, due to low redox potentials that cause the dissolution of iron phosphates (van Duren *et al.* 1997).

To summarise:

- Addition of nutrient rich surface water (section 2.1.4) to acidic fen soils may cause problems.
- Some concern exists that surface water pH may be too high for the restoration of the full range of fen communities (poor and rich) - although it will be diluted by acidic rainfall.
- Generally waters will not be well buffered because very little groundwater inflow

3.3 Constraints on restoration and overcoming them

3.3.1 *Summary*

The following summary is précised from that of Walker *et al.* (2001), reviewing methodologies for the restoration and re-creation of semi-natural lowland grassland - see also Appendix Figure A3.5, which presents a provisional decision support tree for the restoration of such habitats. That diagram, and the summary below, take no account of the financial aspects of restoration schemes, and assume that resources are available for implementation, management and monitoring. The principles outlined here are largely relevant to the range of wetland habitats that the Great Fen project will restore. In wetlands, the influence of the water-regime is central, and there are complex interactions with other constraints. The stress must be on the role of hydrology, both through quantity and quality of water.

I. ***Constraints to ecological restoration on ex-agricultural land***

Most constraints arise from the past agricultural management of the site selected for restoration. Assess constraints that apply to the site under consideration prior to designing the restoration.

a) Abiotic constraints:

- **Atmospheric deposition** of nutrients leading to high fertility (notably NO_x affecting nutrient-poor sites).
- **High residual soil fertility** from the previous agricultural regime *i.e.* increased availability of phosphorus (fertiliser residue, ploughing *etc*), nitrogen (increased mineralisation) and potassium. Phosphorus or nitrogen may be the limiting nutrients in semi-natural grasslands.
- **"Restoration water"** will also need low nutrient levels and an appropriate pH for target community.
- **Re-distribution** of soil nutrient pools through ploughing.
- **Altered pH** due to 1) acidification from atmospheric sulphur input or 2) elevated pH through past liming.
- **Indirect effects** *e.g.* better drainage may increase nutrient supply and availability through oxidation and mineralisation, notably on peats.
- **Loss of soil structure and function**: alteration of drainage and reduction of organic matter (hence reduced soil stability). Especially important on peats, where soil function may be irreversibly altered together with a reduction in hydraulic conductivity.

- **Soil water-regime and quality**, influenced by past drainage and flood-control, as well as natural and anthropogenic variation in the micro-topography of the site. Wetland communities are very sensitive to slight changes in water-regime (depth of water-table, times/duration of water-logging or flooding).
- **Re-wetting may be insufficient** to re-create soil structure and nutrient regime.
- **Floodplain function** and connectivity between river, wetlands and other floodplain features.

b) **Biological constraints:**

- **Lack of propagules** of desirable species *e.g.* impoverished/altered seed-banks, altered seed inputs through past cultivation (and/or intensive grazing) and isolation of site.
- **Excess of propagules** of ruderal and competitive species. Existing soil seed-banks are seldom suitable for the restoration of semi-natural habitats.
- **Impoverished composition of extant habitats** through past husbandry *e.g.* use of herbicides, fertilisers, intensive grazing, introduction of productive (alien?) strains *etc.*
- **Limited dispersal range** of desirable species; isolation of source sites and restoration sites, as well as reduced means of seed transport between them.
- **Established competitive species** specifically adapted to conditions of high fertility and circumneutral pH.
- **Changes to soil microbial communities** *e.g.* reduction in fungal biomass relative to bacterial, possibly brought about by past use of fertilisers.

II. *Overcoming constraints through site pre-treatment*

Site pre-treatment mainly comprises methods for amelioration of chemical constraints, in particular reduction of site fertility and alteration of pH to a target level. Note that some habitats are not inherently nutrient-poor and sites may not require such treatment.

a) **Reduction of site fertility** comprises three stages or broad approaches:

1. Assay site, and compare to target values for semi-natural template
2. Increase the off-take of nutrients and/or limit their supply.
3. Remove and dilute the existing nutrients.

b) **Methods:** **1) Where starting point is ex-arable:**

- **Leave fallow** for ≥ 10 years, subject to repeated mowing (suitable for free-draining soils)
- **Sow with crops** (barley, linseed, rye or rye-grass) and repeatedly crop without nutrient inputs.

c) **Methods:** **2) Where starting point is either ex-arable or improved grassland:**

- Topsoil stripping or sod-cutting (to mineral layer), at least to plough depth (15-25 cm) to remove nutrient pools (*e.g.* Patzelt *et al.* 2001). Not always successful due to increased mineralisation. May be combined with excavation of trenches to prevent stagnation of water and leaching of cations (*e.g.* Jansen *et al.* 1996).
- Deep ploughing to dilute nutrient pools.
- Addition of materials that are inert (rubble, quarry waste), that adsorb/fix nutrients (lignitic clay) or provide a carbon source (straw, bark) to increase microbial biomass.
- Add chemicals to adsorb or "fix" phosphorus *e.g.* aluminium sulphate, calcium oxide, iron chloride, iron oxide, iron sulphate or Al/Fe-rich drinking-water residue.
- **Use of helophyte (productive marsh plants) filter** in the water supply to the site to strip nutrients.
- **Raising water-levels** are a useful method, but periods of waterlogging/flooding need to be timed to favour target habitats *e.g.* for **MG8** avoid waterlogging into April. Rewetting previously drained peats can release nutrients, leading to a route for succession that was not intended (Koerselman and Verhoeven 1995).

d) **Deciding on right strategy**: the following two different bands of soil fertility (extractable phosphorus) and acidity (pH), as compared to the community target that will require differing management strategies:

- Available P values <10 mg l^{-1} above the target and/or pH <0.5 unit higher than that of target: restore over 10 years (or more) using non-intrusive means (cutting and grazing).
- Available P > 10 mg l^{-1} and 0.5 pH units higher than target: topsoil stripping/chemical amelioration probably necessary as well as species introduction.

III. *Increasing botanical diversity and introducing species*

a) Requirements for success

- Restoration is unlikely to be successful if one relies on seed bank/rain alone, though better progress may be expected at sites only recently converted from semi-natural habitats (*e.g.* van Groenendael *et al.* 1989).
- Success depends on site conditions.
- Reversion from arable will succeed but may require long time-scales (>100 years, possibly much longer).
- Success normally requires some intervention *e.g.* species introduction.
- Proximity to good semi-natural sites may be an advantage.

b) Use management of existing habitats to remove dispersal barriers

- **Potential vectors for seed** include movement of stock, machinery and floodwater, though evidence is not compelling for their use in restoration.
- **Cutting alone** can reduce nutrient levels (standing crop). On wet soils mowing may encourage grasses and rushes, not forbs and low sedges.
- **Grazing** produces a mosaic of types and/or heights. Conflicting evidence on whether or not intense grazing encourages forbs and species-richness.
- **Timing of any defoliation** (cutting and/or grazing) influences the course of succession and dominance but not necessarily its speed.
- **Create gaps** as regeneration niches through grazing, cutting or use of herbicide – time the creation of gaps to coincide with germination period of target species.

c) Species introduction - take account of genetic considerations (Maunder 1992)

- **Introduced genotypes** may lead to: a) loss of genetic variation, b) loss of associated fauna; and c) risk of introducing invasive taxa or pathogens.
- **Nature conservation** may be affected through a) failure of non-adapted genotypes; b) "restored" vegetation may not resemble local native vegetation; c) missed opportunity to restore locally adapted forms of native plants; and d) loss of integrity of ancient wildlife areas.
- **Use local provenance** material wherever possible. Note that both commercial and local seed sources may have limited success in establishment or factors leading to skewed composition.

d) Methods for the introduction into ex-arable sites (Manchester 2002)

- **Seed mixtures**: Greater success follows from complex mixtures tailored to the particular site. Species-poor mixtures may be useful where the receptor site has only recently been converted from grassland or lies adjacent to a high-quality site. Sow and mow regularly, aftermath grazing may increase diversity. Seed gathered from semi-natural site may not germinate on ex-arable. Consider serial sowing campaign to counter soil and water-regime degradation.
- **Sowing rate and proportions for grassland**: Use 80-85% grass and 15-20% forb by weight. Rate usually 20-40 kg ha^{-1} – higher rates may reduce weeds and achieve faster cover.
- **Nurse crops**: used to facilitate germination and establishment, achieving rapid cover, suppressing weeds and ameliorating microclimate. In practice variable in helping establishment of seed mixtures. Methods to later suppress the nurse crop may be needed.
- **Hay-bales/turves *etc***: provide native strain plants, and can produce a good facsimile of semi-natural vegetation in 40 years, is most successful if fresh hay used and is a low cost traditional method. Disadvantages include a) impact on source site (including seed removal and effect on invertebrates); b) formation of barrier to seedlings by litter; c) skewed sward composition (grass dominated) produced due to differences in ripening season; and d) mixture varies depending on where within source field hay was cut. Hay seed may need stratification and other methods to break dormancy (Patzelt *et al.* 2001).
- **Seedbed preparation**: a good seedbed is vital, though what this constitutes will vary with soil type. Normally a fine firm bed is desirable. Light soils generally require a coarser bed. Consider stale bed techniques to reduce competition from weeds.

3.3.2 *The particular case of habitat fragmentation*

The surviving rich fens of Britain are few, and crucially often far between. As outlined above, for many botanical taxa there is little evidence that reliance on the seedbank will provide the target community, especially here where the majority of the Great Fen area has been drained and under arable cultivation for well over a century. In the comparable case of Wicken Fen, Moorhouse (1999) reviewed the problem, and discussed methods of species dispersal. In the Great Fen, the project begins with two major blocks of semi-natural wetlands, and several scattered fragments with impoverished vegetation. In addition there is a drainage and network that provides some refuge for aquatic and marginal species, as well as a degree of connectivity between the main elements of the Great Fen area. Following an analysis of the patch sizes and applying, with caution, metapopulation concepts, some general suggestions might be made (Webb 1997).

The normal assumption is that only larger patches of restored habitat that are close to the source sites, such as the two NNRs, will be effectively colonised. Manchester (2002) has shown that even an area of receptor wetland habitat directly abutting a source site did not significantly benefit from natural colonisation over the first 7 years of restoration. This observation has been made many workers within Britain and mainland Europe and led them to recommend the use of species introduction and habitat translocation as a method of creating a nucleus around which a restored habitat might effectively develop (Bakker and Olff 1995; Walker *et al.* 2001). It is believed that such introduction is also more likely to be successful when applied to large blocks of restored habitat, rather than many small fragments - a development of the "SLOSS" argument ("single large or several small" Shafer 1990). Concern over considerations of genetics and ecosystem function (see 3.3.1) has led to understandable concern on behalf of those promulgating restoration schemes. In the Great Fen project, the eventual goal is a very large area of restored wetland habitat that links the source sites of Woodwalton and Holme Fens. However the intermediate stages by which this site develops present a number of possible approaches, the two main ones being the "buffer" and "stepping stone" strategies, together with a range of options as to the degree to which the Steering Group wishes to interfere or steer the natural processes of fenland evolution. These options are discussed in section 5.

3.4 Case studies and costs

Over the past decade, CEH Monks Wood conducted inventories of wetland restoration schemes (Mountford *et al.* 1999; Treweek *et al.* 1991), using structured questionnaires to all those institutions with a key role in wetland restoration. These surveys focussed mainly on gaining a national perspective as to the degree to which extant and/or planned restoration schemes met BAP targets wet grasslands *etc.* For the present project, these databases were searched, and supplemented with a new literature survey to identify examples of other (non-grassland) habitats that occur within the fenland landscape. The search was extended to include non-British (mainly Dutch) examples, especially for those instances where the scale of the restoration was comparable with the Great Fen Project.

The financial data gathered by Mountford *et al.* (1999), and that held in databases on grazing marsh and other wetland restoration schemes proved to have only the most generalised allusion to scheme costs. Such material would not inform the Great Fen process in any meaningful way, and some remained confidential to the exponents of the schemes. The *Wet Grassland Guide* (Benstead *et al.* 1997) provided numerous case studies on techniques and benefits to be gained from implementing particular management or restoration techniques, though these were not costed. A better, and more relevant, indication of costs is given by looking at equivalent major schemes such as the Wicken Fen vision and, within the Netherlands, Lauwersmeer and the Oostvaardersplassen (Kampf 2000). To cost a scheme as extensive and long-term as the Great Fen requires a thorough site engineering survey that is outwith the remit and scope of the present project (see Section 6).

Some very general figures may be derived from the particular schemes, but their applicability to the Great Fen Project is by no means precise. Hirons (1995) stated that land acquisition and restoration of wet grasslands were amongst the highest encountered, especially if (as with the Great Fen) the land is presently under arable. Hence costs of £1 million for purchase of a "reasonably-sized site", with wardening and management costing £50,000-200,000 *per annum*), dependent upon the stock type.

Table 3.6 *Prescribed/estimated costs of implementation of the UK National Biodiversity Action Plan for six priority habitats. Costs are expressed in £K.*

BAP RESTORATION COSTS at the NATIONAL SCALE									
WET WOODLAND									
	Current expenditure			**First 5 years (to 2003/4)**			**Next 10 years (to 2013/4)**		
Current expenditure (per annum)									
Total average annual cost (per annum)				2214.5			1997.2		
Total expenditure to 2004				11072.6					
Total expenditure 2004-2014							19972.1		
REEDBED									
Total area to be maintained & enhanced: 5,000 ha	**Year 1997**			**Year 2000**			**Year 2010**		
(£000 per annum)	low	central	high	low	central	high	low	central	high
	40	90	110	90	180	230	190	310	420
Area to be re-established: 1,200 ha	**Year 1997**			**Year 2000**			**Year 2010**		
	low	central	high	low	central	high	low	central	high
	50	100	170	110	200	340	130	230	410
LOWLAND MEADOWS									
	Current expenditure			**First 5 years (to 2003/4)**			**Next 10 years (to 2013/4)**		
Current expenditure (per annum)	1802								
Total average annual cost (per annum)				443.2			655.8		
Total expenditure to 2004				2216.2					
Total expenditure 2004-2014							6557.7		
FENS									
Area to be maintained & enhanced: 1,200 ha	**Year 1997**			**Year 2000**			**Year 2010**		
(£000 per annum)	40			70			70		
EUTROPHIC STANDING WATER									
	Current expenditure			**First 5 years (to 2003/4)**			**Next 10 years (to 2013/4)**		
Current expenditure (per annum)	377								
Total average annual cost (per annum)				587.7			659.5		
Total expenditure to 2004				2938.5					
Total expenditure 2004-2014							6595.0		
GRAZING MARSH									
Area to be maintained & enhanced: 300,000 ha	**Year 1997**			**Year 2000**			**Year 2010**		
Area to be rehabilitated: 10,000 ha									
Area to be re-created: 2,500 ha									
(£000 per annum)	4,200			8,400			13,200		

Engineering a site with simple ditch sluices *etc* for water control can be appreciable in an area as extensive as the Great Fen. Unit costs (as of 1994) were outlined by Coleshaw (1995):

a)	100cm diameter pipe: 3m length £14.50 & 90° bend £7.50	Total £22.00 plus VAT
b)	150cm diameter pipe: 3m length £27.50 & 90° bend £17.50	Total £45.00 + VAT
	Time needed to install	ca 2-3 hours
c)	Blockwork chamber (ca 1.2m x 1m x 1.2m) with two inflows and one outflow	
		Total £100.00 + VAT
	Time needed to install	1-2 staff-days

Costs for major schemes to restore water-meadows were summarised by Scholey (1995), where the National Trust, the then National Rivers Authority (NRA) and the Countryside Commission (CC) were involved together at Sherborne in Gloucestershire:

- CC input included revenue of £150,000 *per annum*, plus priming funds of £43,000.
- The National Trust had contributed £46,500
- NRA: ditch excavation £300,000
- Sluice gates £250 each; fencing £22,688; hedge laying £500
- Bridges: a) foot 12 @ £140; and b) vehicular 7 @ £300.

To set the context on what might be available to fund schemes of the scale and focus of the Great Fen, it is worthwhile recording the potential overall costs for implementing BAP targets as they have been calculated for both the UK as a whole, and at a more local scale. Table 3.6 suggests that, for the period 2004-2014, the total moneys available for the ecological restoration of wet woodland, grazing marsh, lowland meadows and standing waters would be in excess of £46 million, with a further annual expenditure on fens and reedbeds of *ca* £270K. In Cambridgeshire (Table 3.7), costs are estimated for three priority habitats: wet woodland, meadows and pastures, and drainage channels. These costs are calculated in terms of individual activities, some calculated on an annual or an area basis, and it is thus less straightforward to calculate an overall budget. However, the figures for Cambridgeshire do allow some of the proposed activities in the Great Fen to be costed.

3.5 Ranking the restorability of Broad Habitats

In designing wetland restoration programmes it is important to consider whether the restoration of target vegetation communities will be practicable given the techniques, resources and time available. Wetland communities have been ranked according to 'ease of recreation' on a five point scale **(I-V)** where I represented communities which are likely to be relatively easy to re-create and V represents those which are likely to be very difficult, or impossible (Table 2.9 after Treweek *et al.* 1993). It should be noted that this table is based on subjective assessment, given the current level of knowledge of community restoration, and should be used only as a provisional guide. Considerably more research is required to establish the necessary techniques and time-scales for the restoration of different communities (Wheeler *et al.* 1995).

Nevertheless, it can be stated with some confidence that the most easily restored wetland vegetation communities (category I) are aquatic communities with open water vegetation dominated by duckweeds and pollution tolerant macrophytes, together with those emergent swamp communities which tend to be dominated by single, competitive species. The most restorable mesotrophic grasslands are those which reflect some degree of agricultural improvement, or which are relatively species-poor. In the context of the Great Fen Project, reedbeds **(S4)**, inundation grasslands **(MG13)**, other types of lowland wet grassland and the simpler ditch macrophyte communities should all be achievable within the first 1-2 decades of the scheme.

Table 3.7 *Key actions, delivery mechanisms and potential costs of implementation of the local Cambridgeshire Biodiversity Action Plan for three priority habitats.*

BAP RESTORATION COSTS in CAMBRIDGESHIRE		
Targets and key actions requiring additional funding	**Delivery mechanism**	**Potential cost**
HAY MEADOWS and PASTURES		
Bring 20ha of second tier County Wildlife meadow and pasture sites into favourable management	Grassland biodiversity advisor (5 yrs)	30000/yr
	Agri-environment schemes	115/ha/yr
	Flying flock (first 3 yrs)	120000?
	Land purchase	15000
Create 50ha meadows/pastures on suitable sites	Land purchase	194,500
	Establishment works	25,000
	Maintenance 10 yrs for 50ha	280/ha/yr
Identify mineral site for creation of new meadow/pasture	Agri-environment schemes	115/ha/yr
Monitor the management of meadow and pasture sites every 3 years	Survey contracts	8375 every 3 yrs
Investigate the establishment of a larger seed base for the collection of local provenance seed	Feasibility study	5000
Organise an annual publicity event	BAP co-ordinator	500
WET WOODLAND		
Identify all wet woodland sites by 2005	Survey	1000
Initiate measures to achieve favourable condition in 100% of wet woodlands within SSSI and in 70% of the total resource by 2010	WGS-FWPS	35/ha/yr
		525/ha
	Woodland biodiversity advisor	30000/yr
	Land purchase (6 ha)	47000
Initiate restoration of 20ha to native wet woodland. Complete restoration to site-native species over half of this area by 2010 (and all of it by 2015)	Land purchase (5 ha)	39000
	WGS-FWPS	525/ha
Establishment of 100ha of wet woodland by 2010 (and 200ha by 2015)	WGS-FWPS	1050-1350/ha
		525/ha
	Land purchase	194500
DRAINAGE DITCHES		
Introduce buffer zones to 25% of all ditches in the county	Agri-environment schemes	280/ha/yr (arable CSS)
Improve water quality in ditches		
Bring all ditches in SSSI into favourable management		

The more species-rich and less pollution-tolerant aquatic and swamp communities fall into the second category, as some of them require particular conditions of water reaction or purity, and thus attention to water quality amelioration (section 3.2 and 4.2.2). Species-rich mesotrophic grasslands which tend to require relatively long time-scales for their establishment are also included, together with two wet woodland types which can be planted successfully, but require creation or maintenance of high water-tables. Great Fen habitats in this category would comprise communities like Alder woodland (**W6**) and coarse nutrient-rich fens dominated by *Phalaris* (**S28**) or reed and nettle (**S26**). It will be noted that most of the vegetation types characteristic of grazing marsh were considered to be relatively easy to restore, a conclusion that reflects the artificial nature of that landscape in contrast to more 'natural' mire and wooded wetlands.

The most species-rich aquatic vegetation, and that with the most specific habitat requirements in terms of water quality might be allotted to category **III**, together with the best tall-herb fens (**S24** *etc*), fen-meadows (**M24** *etc*) and the other woodland communities (**W2** and **W4**). These are not necessarily technically difficult to restore, but require relatively long time-spans (Wheeler *et al.* 1995). These are the main medium to long-term targets of the Great Fen project, and a speculative time-span of 50-100 years might be made to achieve a reasonable facsimile of semi-natural habitats.

The acid bog types that are included in the fourth category are outwith the goals of the Great Fen Project, though their presence in the Core Area in the early nineteenth century may imply that in the very long term, it is desirable that some areas be encouraged to develop toward such habitats. Unless natural processes alone, with an "infinite" timescale, are adopted, some 'stripping' of nutrients from the soil, or deliberate soil impoverishment is likely to be necessary. The mire communities included in the fifth category are more characteristic of upland areas, and are unlikely to be re-creatable within a region either still partially under agricultural use (as within the first century of the Great Fen project). For the foreseeable future, the Great Fen area will remain heavily influenced by such management on the adjacent uplands or in the fenland to the west and north. However, bog pool and blanket bog communities are included here for illustrative purposes, and would only be restorable over very long periods. Rill and spring communities require extremely pure water supplies. Restoration programmes for wetland communities that require special habitat conditions or long timescales for restoration are likely to require more detailed and specific sets of ecological objectives.

Table 3.8 *Wetland NVC communities of lowland England - ranked according to likely ease of re-creatability from **I** (relatively simple to restore) to V (apparently very difficult to restore)* (after Treweek *et al.* 1993)

Wetland habitat	**I**	**II**	**III**	**IV**	**V**
Ditches and pools	**A1-2, A12, A15, A16, A19 S12, S14, S22-23**	**A4, A9, A21 S13, S17, S19-21**	**A11**		
Other open water	**A3, A5-8, A10**	**S16**	**A11, A17, A18**		
Moist mesotrophic grassland	**MG6, MG9, MG10, MG13**	**MG4, MG5, MG8 MG11, MG12**			
Swamp and tall-herb fen	**S4-7**	**S2, S26, S28**	**S24, S25, S27 M9, M13, M22-24 M27**		
Acid bog, poor fen			**M25**	**M16, M29**	**M1-6, M8 M14, M17 -20, M35, M37, M38**
Wet Woodland		**WI, W6**	**W2, W4, W5**		

4. PLANNING RESTORATION IN THE GREAT FEN

4.1 Overall goals

The Great Fen Project Steering Group particularly sought a framework within which the information gathered could be integrated and manipulated. Much the best platform for this approach is a Geographical Information System (GIS) (Acreman *et al.* 1999: Swetnam *et al.* 1998; Treweek *et al* 1995; Wadsworth and Treweek 1999), where spatially referenced data-sets can be linked to predictive eco-hydrological models (*e.g.* Gowing *et al.* 1994). As outlined in Section 1, five questions are here addressed within this framework:

- *Which habitats can practically be created within the project area?*
- *Which habitats can be created given realistic site modification work?*
- *Within a stated tolerance, what areas of each habitat can be created?*
- *How will these areas be affected by managing water-levels?*
- *Which habitats and what areas should the Great Fen Project aim for?*

The fundamental role of water (availability and quality) sets the context within which options can then be assessed *i.e.* comparison of site conditions within Project area with those recorded tolerances for target habitats defined above (section 3). As further illustrated in section 5, a menu of restorable habitats has been created for the Great Fen area. The menu options are assessed in terms of the amount of site modification/engineering (*i.e.* water storage capacity) required for successful restoration. It has been assumed that a range of wetland habitats might potentially be restored on the Great Fen dependant upon the scale of intervention in water-management and site-engineering.

In discussion with the Steering Group, stress was placed on rapid restoration of low-maintenance habitats, with medium- and longer-term development of specialist habitats (and communities) such as tall-herb rich fen (*e.g. NVC* **S24**) and fen meadows (*e.g.* **M24**). To that end, the overall strategy has been to restore habitats that are valuable in themselves (reed-swamp, wet mesotrophic grassland *etc*) but which may, under suitable management, act as precursors of these more highly valued habitats. This approach means that during the short term, restoration will produce a greater extent of some particular habitats than it is expected will eventually occupy the Great Fen area.

To summarise, it is expected that the early phase of the Great Fen restoration will involve the production of extensive areas of a relatively few readily restorable habitats. In the medium and longer term some areas of these initial habitats will continue to be maintained through management, whilst other areas are allowed or encouraged to develop into a range of other fenland habitats. Such a strategy combines rapid biodiversity returns, with increasing diversity and complexity of the habitat mosaic with succeeding decades.

4.2 Options for water-management

It is likely that recreation of wetland habitat will be almost entirely restricted to areas below 2m AOD, thus excluding the area to the south of the catchwater drain and some parts of the former Whittlesey Mere. Furthermore, it is envisaged that the area to the east of the Great Raveley drain will not be converted to wetland, leaving approximately 22.3 km^2 of the Core Area on which wetland habitat either exists (*i.e.* Woodwalton Fen and Holme Fen) or could potentially be recreated (see Figure 5.2). This represents the area for which water requirements have been estimated and compared with water availability in work reported here.

4.2.1 *Water availability*

Using historic time series (1963-2000) a simulation of summer and winter hydrological fluxes into the Core Area has been attempted (Figure 4.1). The water inputs have been estimated on the basis of present management of the system and indicate the water that would have been potentially available for wetland restoration in each year. The hydrological fluxes comprise:

i. rainfall (derived from *MORECS*)
ii. upland runoff, estimated by weighting the Alconbury Brook flow (section 2.1.3.3)
iii. present licensed abstractions (*i.e.* 0.67 Mm^3y^{-1} in summer and 0.64 Mm^3y^{-1} in winter), which it is assumed can be maintained by diversion from the Nene. These values represent the upper limit of present abstractions (section 2.1.2.2).

It has been assumed that all upland runoff is available to maintain the recreated wetlands, meaning that other regions in the Core Area would be rain-fed only. Missing data from the Alconbury Brook flow record mean that there is no estimate of upland runoff in years 1993 and 1994 and in the summer of 1967 and winter 1968.

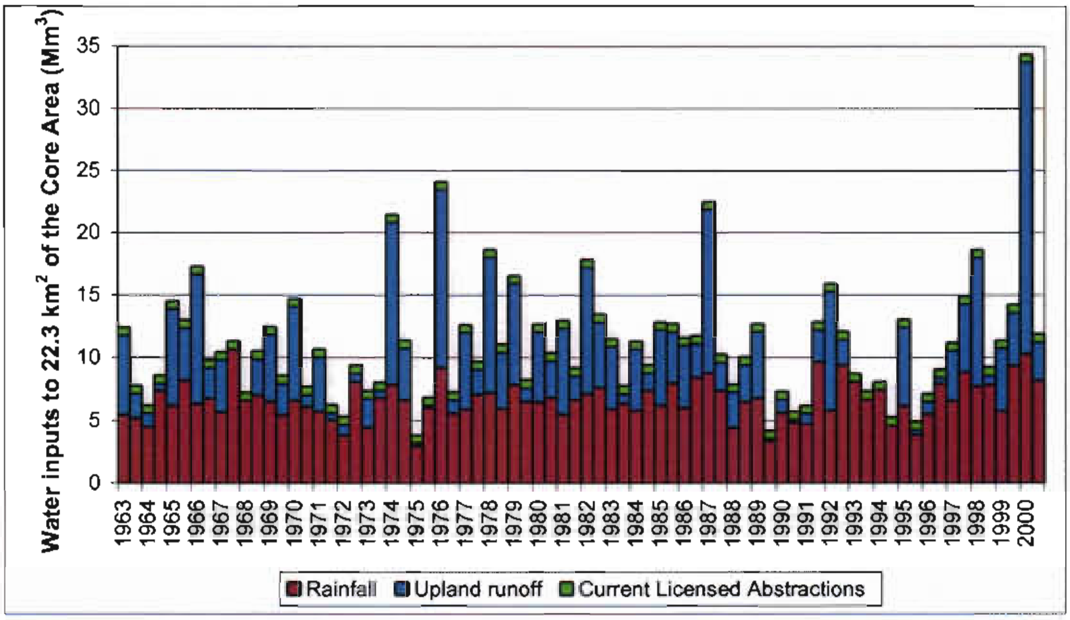


Figure 4.1: *Estimated water inflow into the Core Area in HY1963-HY2000*

4.2.2 *Water requirements of restored wetland habitats*

The Cranfield University study predicted that the greatest hydrological constraint to the area of wetlands that could be recreated in the Core Area occurs in "dry" winters when summer moisture deficits are not alleviated by winter rainfall (Cranfield University 1999). However, the analysis conducted in that study appears to have underestimated the component of winter "upland" runoff (section 2.1.3.3) and made no allowance for existing licensed abstractions and diversions from the R. Nene. Under the present management regime, in most winters excess water is removed from the area by pumping (section 2.1.3.4). The *Middle Level Commissioners* support the contention that generally there is plenty of water available in the winter months (David Phillips *pers. comm.*). Consequently, it seems that it would be a rare occurrence that deficits could not be made up through a combination of rainfall, upland runoff and when necessary increased winter diversions from the R. Nene.

It seems likely that shortages of water in summer months, when agricultural demand is high, will be the greatest constraint to wetland restoration in the Core Area. Using the crop coefficients estimated (section 3.1) and *MORECS* potential evaporation, a simulated time series of summer water demand was derived for three wetland habitats (*i.e.* reedbed, sedge fen and wet grassland) for hydrological years 1963-2000. Missing data in HY1967, HY1993 and HY1994 meant that these years had to be removed from the analyses. For each wetland type it was assumed that the whole 22.3 km^2 of the Core Area was covered with that particular habitat. A further assumption made for the reedbeds was that 30mm of standing water, stored in the reedbed, could be used as an initial reservoir to be depleted through the summer. Comparing potential evapotranspiration losses with the estimated total summer inflow into the Core Area gives an indication of the shortfall that would have occurred in each year (Figure 4.2). It is important to note that this shortfall is an estimate of the difference between the habitats experiencing no water stress and being stressed as a consequence of water shortage. The magnitude of the deficit is a crude indicator of the degree of stress the vegetation would experience if no additional water were supplied. Of course in any natural system the vegetation will experience water stress in many years and in very dry years some vegetation will die. However, if the system was sufficiently resilient, large enough areas would survive and over time the habitat would recover.

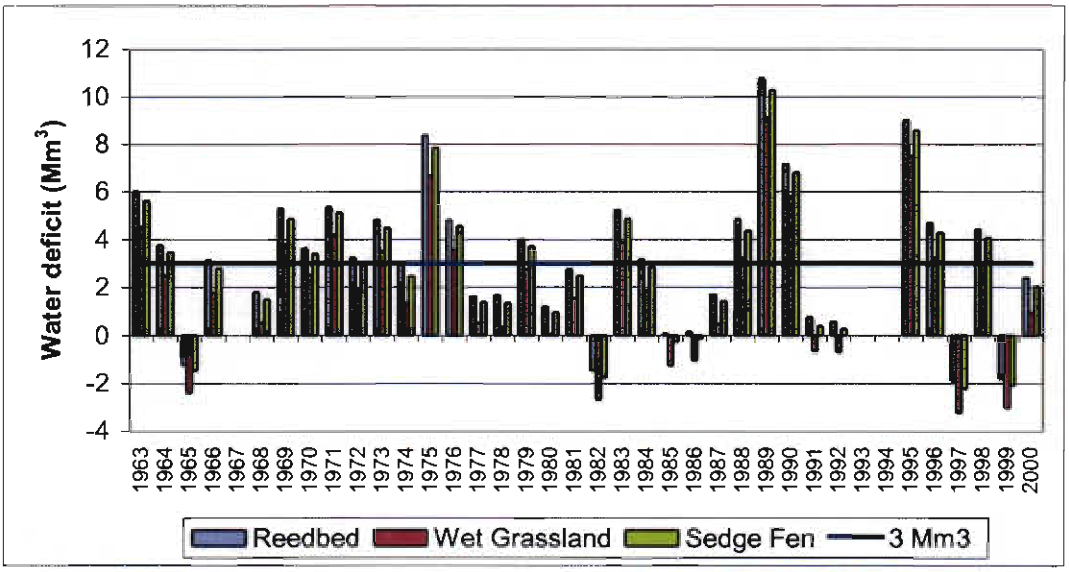


Figure 4.2: *Water deficit if the entire Core Area was covered with each wetland habitat*

These data indicate that, under present conditions, if the 22.3km^2 Core Area was covered with wetlands:

i. there would be insufficient water to meet the full evaporative demand in the summer months in many years
ii. as would be expected from the estimated crop coefficients (section 3.1), shortfalls are greatest for reedbed and least for wet grassland
iii. the average shortfall for reedbed is 3.2 Mm^3 and the greatest shortfall would have been in the summer of 1989 (*i.e.* 10.8 Mm^3)

These results indicate that ideally some water storage would be available to enable additional water supply to the recreated wetlands in very dry summers. If winter water were stored (*i.e.* in a reservoir), this would provide extra water for the summer. Figure 4.2 indicates that to ensure **no** water stress in one year in two, about 3 Mm^3 of water would need to be stored and available for wetland "irrigation".

Estimates of the winter discharge for the Bevill's Leam pumping station, indicate that winter discharge from the Core Area would have exceeded 3 Mm^3 in 32 of the 38 years, HY1963-HY2000 (Figure4.3). In these years there would have been sufficient water generated within the Core Area and the upland catchment to fill a reservoir. In the remaining years, to ensure the storage was filled at the start of the summer, it would have been necessary to abstract additional winter flow from the Nene at Stanford. In some low rainfall years all 3 Mm^3 would have to be obtained from the Nene (*i.e.* 1964, 1972, 1973, 1975 and 1988). This represents 1.5 % of the mean **winter** runoff of the Nene at Orton (204 Mm^3 = 125 mm). If managed correctly a reservoir could provide winter flood storage capacity. Operating rules would need to be developed to ensure that the in most years the storage was filled at the end, rather than the start of the winter, with available flood storage capacity at all times.

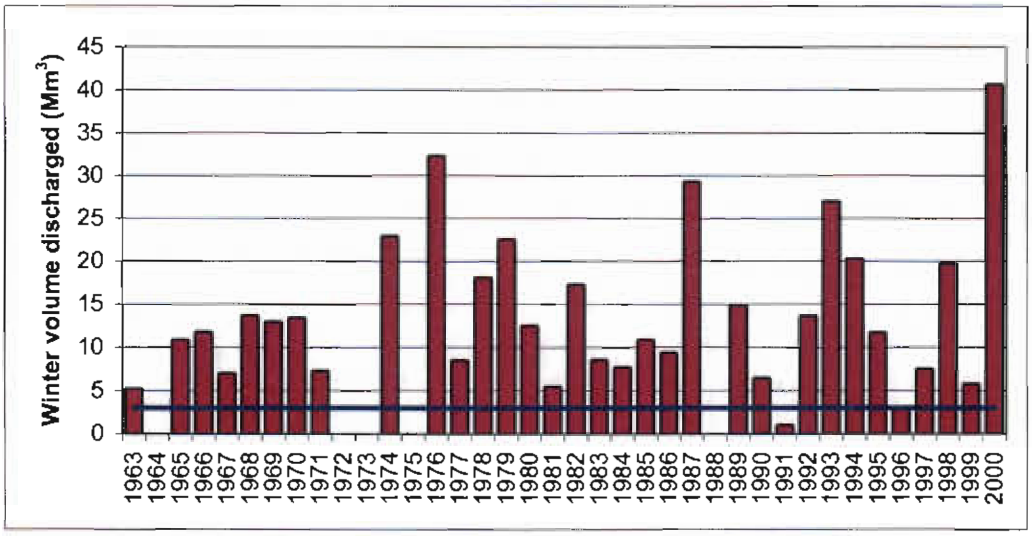


Figure 4.3: *Volume discharged from Bevills Leam Pumping station: HY1963-2000. Note from 1963–1990 estimated from rainfall (section 2.3.4) and from 1991 to 2000 determined from pump records.*

A simple soil moisture accounting model, operating on a monthly time step, was used to identify periods of stress. The model can be used to predict the importance to the water balance of upland runoff, irrigation and within-soil storage. Stress is defined here as ***soil moisture deficits greater than the permanent wilting point***. The results from the model indicate that if no additional water is used at Woodwalton and Holme Fens, and if stress is acceptable in 1 year in 5, then:

- Storage of $3Mm^3$ provides sufficient water to sustain *ca* 17 km^2 of wetland
- Storage of 1 Mm^3 provides sufficient water to sustain *ca* 12 km^2 of wetland

If there were no storage, the proportion of Core Area on which wetlands could be restored would be constrained by water availability to about 10 km^2. This estimate is significantly greater than that presented in the Cranfield University study in which maximum areas of single habitat of 1.44 km^2 of reedbed and 3.83 km^2 of wet grassland were derived. The difference is attributable to differences in estimates of upland runoff and the assumption in the current study that summer water deficits could be made up in all years through rainfall and, when necessary, with diversions of winter flow from the Nene. All these areas include the existing area of Woodwalton and Holme Fen. Figure 4.4 shows the relationship between volumes of water stored and the areas of wetland that could be recreated.

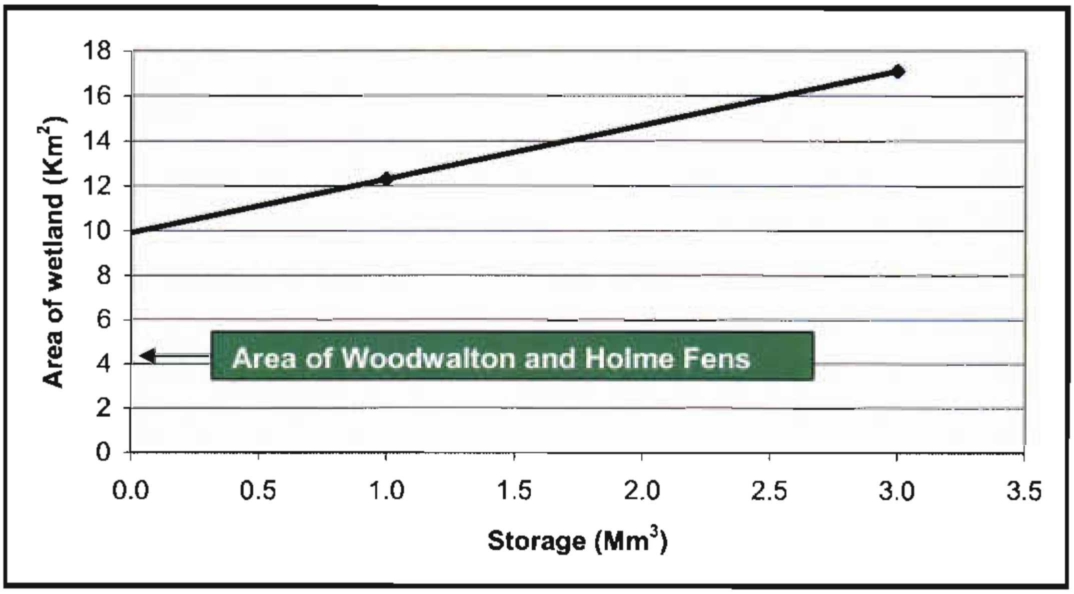


Figure 4.4: *Relationship between volumes of stored water and the areas of wetland that could be therefore be recreated*

4.2.3 *Great Fen project: impacts of climate change*

4.2.3.1 Climate change in the Great Fen Project Core Area

In 2001 the *Intergovernmental Panel on Climate Change* (*IPCC*) concluded that "most of the warming [of the Earth's atmosphere] observed over the last 50 years is likely to be attributable to human activities". These activities comprise increasing concentrations of so called "greenhouse gases" in the atmosphere (*i.e.* CO_2, NOx and CH_4). Associated with the warming of the atmosphere will be changes in the climate. However, these are difficult to predict for two reasons:

1. Because there are still a large number of uncertainties in many of the processes that will be affected by climate change *e.g.* the role of forests and wetlands in the carbon cycle.
2. Because the interaction of complex factors means that the impacts will vary substantially from one geographical location to another.

In a complex way, climatic variables control almost all ecosystem attributes and functions (Weltzin *et al.*, 2000). Climatically mediated changes may alter plant community structure through modification of abiotic driving variables such as temperature and hydrological and biogeochemical processes. It is possible that future changes in climate may have undesirable impacts on the wetland habitats to be established in the Great Fen project.

On the basis of assessments made by the *IPCC*, a set of national-level climate change scenarios have been developed for the UK, using modelling experiments performed by the Hadley Centre with their HadCM2 model (UKCIP 1998). Four possible climate futures are predicted for the UK. These are the *UKCIP98* climate scenarios and are labelled as *Low*, *Medium-low*, *Medium-high* and *High*. These scenarios span a range of emissions and different climate sensitivities reflecting uncertainties in future global warming rates. The scenarios are based on four different descriptions of how the world may develop in decades to come. It is not possible to assign relative confidences to the scenarios since they depend on choices made by society – they simply reflect four alternative views of the future. In this study, time and resource constraints have meant that it has not been possible to conduct a full analyses of the possible implications of climate change on the Great Fen project. In this section data from a single scenario are presented simply to **illustrate** the possible effect of climate change on the hydrological issues pertaining to the project. Data from the *Medium-high* scenario are presented since it approximately samples the mid-range of the possible global climate change.

Table 4.1 summarises key seasonal and annual mean changes for the *Medium-high* scenario for 30-year periods centred on the 2020s, 2050s and 2080s (2020s = period 2010-2039; 2030s = 2020-2049; and 2080s = 2070-2099). The *Medium-high* scenario assumes a 1% per annum growth in atmospheric greenhouse gases over the century. The data presented are anomalous with respect to a baseline period 1961-90 for a grid square for the southeast of the UK, approximately centred on the Core Area. The model simulations suggest:

- A warming rate of just under 0.3°C per decade, but with slightly less warming in the winter than in the summer.
- A modest increase in annual rainfall, but with a general tendency for wetter winters and drier summers.

- An increase in annual potential evapotranspiration. Winter potential evapotranspiration, which is most sensitive to temperature and wind speed changes, increases but mostly in the last decades of the century. Summer potential evapotranspiration increases early in the century largely as a consequence of lower cloud cover and hence greater radiation inputs.

Table 4.1: *Change in mean annual and seasonal climate parameters (wrt 1961-90) for 30-year periods for the UKCIP Medium-high climate change scenario derived from the HadCM2model (after UKCIP, 1998).*

	2020s	2050s	2080s
Temperature (°C)			
Annual	+1.3	+2.0	+2.8
Summer	+1.4	+2.2	+2.7
Winter	+1.3	+2.0	+3.0
Rainfall (% change)			
Annual	+3	+1	+5
Summer	-3	-16	-16
Winter	+7	+11	+19
Potential Evapotranspiration * (% change)			
Annual	+7	+14	+17
Summer	+7	+15	+16
Winter	+7	0	+14

Notes: In these simulations - summer = June-August, winter = December-February

* Potential Evapotranspiration calculated using the Penman formula (assuming a short grass covered surface) with temperature, vapour pressure, radiation and wind speed as inputs).

These changes will affect restored wetland habitats in the Core Area directly, but also indirectly, particularly through alteration of the hydrological regime *i.e.* runoff from the upland catchment and also in the River Nene from which diversions are required if the wetland habitats are to be maintained. In quantitative terms the impacts of climate change on the hydrology of a given catchment are very difficult to determine since the effects are complex and interactions are important. For example, lack of rainfall may mean that whilst potential evaporation increases, actual evaporation falls. However, in very broad terms the predicted increases in potential evapotranspiration will compound the effect of the decreases in summer precipitation on water availability for the Core Area.

Various modelling assessments of the effects of climate change on UK stream-flows have been conducted (*e.g.* Arnell *et al.*, 1997). These include simulation of the consequences of climate change on the runoff in Harper's Brook, a tributary to the Nene with a low-lying, predominantly agricultural catchment of 74.3 km^2 (Arnell and Reynard, 1996). This catchment has a mean annual rainfall and runoff of 632mm and 177mm respectively, and a BFI of 0.49. Consequently, it is not dissimilar to the upland catchment of the Core Area and importantly, it lies within the same grid square as the Core Area for the *UKCIP* climate change simulations. However, it is important to note that the results published were obtained using data from earlier climate change simulations than those reported in *UKCIP*, 1998. Nevertheless, it is believed the model results are indicative of the likely change in runoff in the region.

In general terms the best-estimate climate change simulations indicate altered average annual runoff at Harper's Brook of between –16% and +2% by 2050. They also indicate an increase in the seasonality of flow with increased frequency of low (summer) flows and an increase in high (winter) flows (Table 4.2). Approximate changes in the best-estimate mean monthly flows are presented in Table 4.3.

Table 4.2: *Change in low and high flow frequencies for Harper's Brook in 2050 (after Arnell and Reynard, 2000).*

% change in Q95	Average annual days below current Q95	% change in Q5	Average annual days above current Q5
-5 to –24	22-36	13-43	22-30

Notes: Q95 is the flow exceeded 95% of the time, frequently used as an index of low flows

Q5 is the flow exceeded 5% of the time

Table 4.3: *Approximate best-estimate % change to mean monthly runoff for Harper's Brook in 2050 (after Arnell and Reynard, 1996 - taken from figure 6)*

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
-10 to 10	-5 to 5	-15 to 0	-18 to - 4	-23 to –5	-32 to –9	-32 to -11	-30 to -10	-28 to -5	-29 to –4	-25 to - 2	-12 to 7

4.2.3.2 Implications of climate change for the success of the Great Fen Project

The *UKCIP HadCM2* simulation data from the *Medium-high* scenario (ensemble mean) for 2050s for the grid square centred on 0.0 E 52.5 N has been used in conjunction with the Arnell and Reynard runoff simulation data derived for Harper's Brook to determine the possible impact on water availability within the Core Area. The monthly changes in rainfall, runoff and potential evapotranspiration (Table 4.4) were applied to the HY1963-HY2000 data derived for the Core Area (section 4.1). Monthly changes were simply added or subtracted from the historic time series. No allowance was made for changes in distribution of for example rainfall (*i.e.* changes in the numbers of rain-days per month).

The impact of the change in rainfall and upland runoff on water availability within the Core Area is shown in Figure 4.5. The data indicate that winter inflows will increase, by on average 1.17 Mm^3, but summer inflows will decrease by on average 1.37 Mm^3. The decrease in summer inflow in conjunction with the higher summer potential evapotranspiration would significantly increase the water requirements of recreated wetland habitats. Consequently climate change may mean that there is a need for substantially more water than estimated under present climate conditions (section 4.2.2).

Table 4.4: *Average changes in monthly rainfall, potential evapotranspiration and runoff derived from UKCIP98 Medium-high forecast and Arnell and Reynard (1996) for the 2050s*

	Rainfall		**Potential evapotranspiration**		**Runoff**
	mmd^{-1}	**Mm**	**mmd^{-1}**	**Mm**	**% change**
Jan	0.35	10.9	-0.01	-0.3	0.0
Feb	0.13	3.7	0.00	0.0	0.0
Mar	0.05	1.6	0.03	0.9	-7.5
Apr	-0.02	-0.6	0.11	3.3	-11.0
May	0.07	2.2	0.11	3.4	-14.0
Jun	-0.17	-5.1	0.20	6.0	-21.0
Jul	-0.39	-12.1	0.63	19.5	-22.0
Aug	-0.46	-14.3	0.87	27.0	-20.0
Sep	-0.15	-4.5	0.79	23.7	-17.0
Oct	0.21	6.5	0.14	4.3	-17.0
Nov	0.44	13.2	0.05	1.5	-13.5
Dec	0.30	9.3	0.02	0.6	-2.5

The impact of the change in rainfall and upland runoff on water availability within the Core Area is shown in Figure 4.5. The data indicate that total winter inputs into the Core Area will increase, by on average 1.17 Mm^3, but summer inputs will decrease by on average 1.37 Mm^3. The increase in winter inputs is due to rainfall only because, despite the increased rainfall, the volume of winter runoff from the upland area decreases slightly. This is probably the result of increased soil moisture deficits (particularly in the early winter) arising as a consequence of the increased evaporation and decreased rainfall in the summer months. The greater the soil moisture deficit at the start of the winter, the more rainfall will be required to make up the deficit and the greater the delay in generating winter runoff.

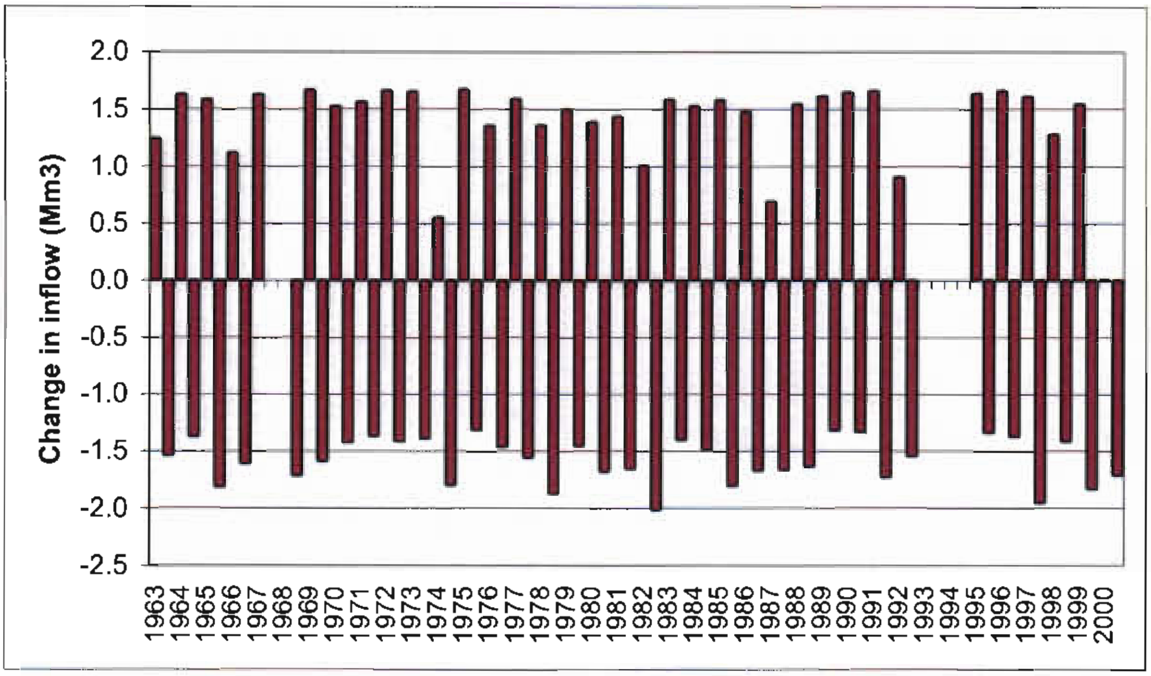


Figure 4.5: *Predicted impact in 2050s of total summer and winter inflow (i.e. rainfall and upland runoff) as a consequence of climate change*

The decrease in summer inflow in conjunction with the higher summer potential evapotranspiration would significantly increase the water requirements of recreated wetland habitats. Consequently climate change may mean that there is a need for substantially more water than estimated under present climate conditions (section 4.2.2). Greater volumes of water may need to be stored in order to sustain the wetlands in the summer, possibly necessitating greater winter diversions from the Nene at Stanground. Although such diversions may be feasible, another facet of climate change that needs to be considered is sea level rise. The *Medium-high* scenario predicts climate-induced sea-level rise in East Anglia for the 2050s of 28cm. However, as a consequence of isostatic adjustment (East Anglia is sinking) the total change in average sea-level will be 37cm (UKCIP, 1998). This change will result in large reductions in the return periods of high tide levels and may necessitate maintenance of higher winter river flows in the Nene for environmental purposes (*i.e.* to reduce saline intrusion). Thus, it is not clear that it would be possible to divert substantially more water from the Nene.

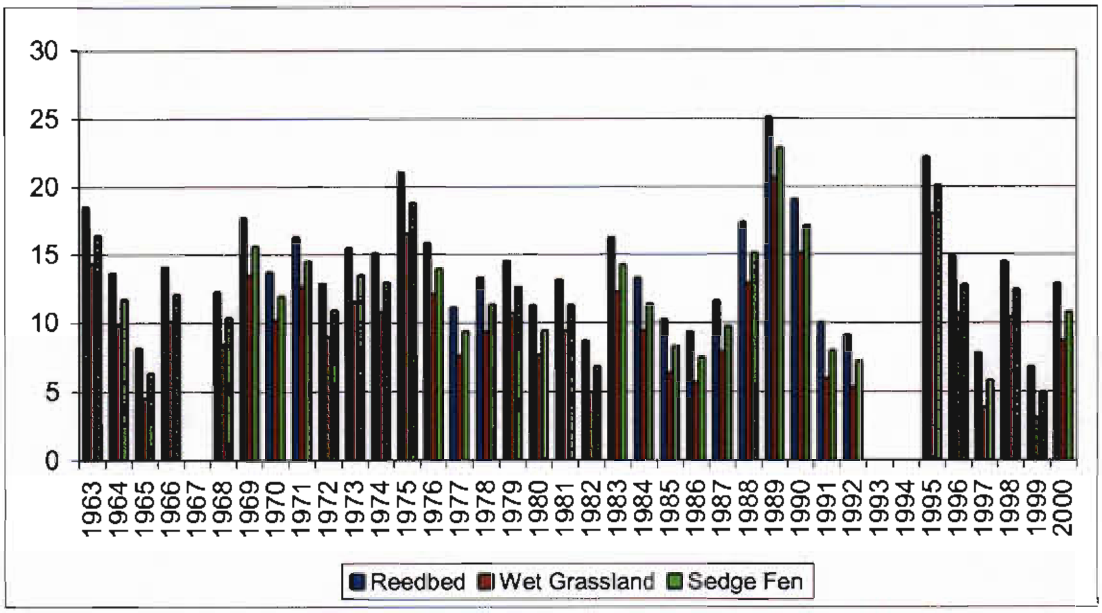


Figure 4.6: *Water deficits, allowing for climate change in 2050 if the entire Core Area was covered with each wetland habitat (cf Figures 4.2).*

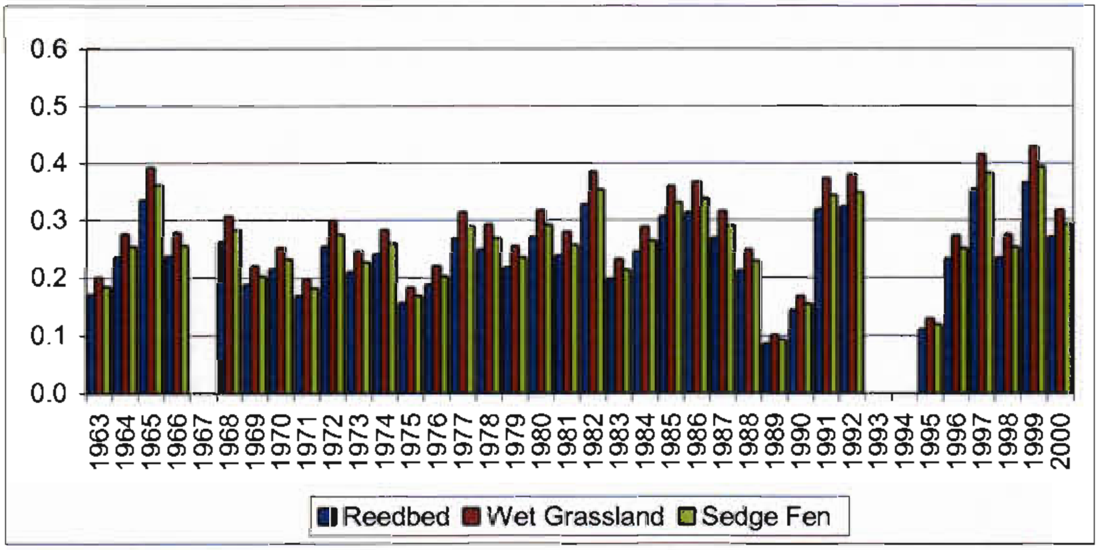


Figure 4.7: *Estimates of the proportion of the Core Area that could be used for restoration of different wetland habitats, under the climate change scenario, if there was no water storage (cf. Figure 4.4).*

If there were no water storage, the proportion of the Core Area on which wetlands could be maintained in *ca* 2050 would, on the basis of the same assumptions used previously (*i.e.* section 4.2.2), be of the order of 20% (*i.e.* 7.5 km^2) (Figure 4.7).

A thorough investigation of the range of possible consequences of climate change should be conducted before the project proceeds. Given the large uncertainty in the likely consequences of climate change it is essential that flexibility is built into the scheme so that future management options are not constrained.

4.3 Modelling the Hydrology Within the Great Fen Area

4.3.1 *Objectives and approach*

The objectives of the modelling approach taken for the Core Area (see also section 4.2.2) were to estimate the:

I. Water balance within the area
II. Area of fen and wet grassland habitats that can be supported
III. Inter-annual variation in the water balance (and the sequences that occur) and hence
IV. Potential stress on the desired habitats.

This approach has four primary limitations:

1. Many parameters have been estimated using "expert judgement" and previous experience.
2. Meteorological data are monthly but some phenomena (notably flooding and surface run-off) occur at much finer time scales.
3. There are few data on the soil physical properties or on regional groundwater movements.
4. The area is heavily managed but the model assumes a homogeneous objective of ***conservation***.

Since a complete 4-D model (extent, depth and time) of water fluxes is beyond the scope of this project, instead the philosophy adopted employed a model comprising linked 2-D models (depth and time) that are extrapolated to the spatial domain using the digital terrain model (DTM). For the purposes of the modelling, it was assumed that the restored Great Fen Area would consist of a mosaic of habitats:

- dry grassland
- wet grassland and
- fen-open water

Each habitat was modelled as a separate compartment, and the three compartments were hydrologically linked by four fluxes of water:

- Drainage from the dry grassland into the fen-open water compartment
- Drainage from the wet grassland into the fen-open water compartment
- Surface flooding from the fen-open water onto the wet grassland
- Groundwater flooding from the fen-open water onto the wet grassland.

Two types of external resources may be included:

- Irrigation of wet grassland <u>during the summer</u>,
- Topping up the fen-open water compartment <u>over the winter</u>.

In addition the meteorological data can be manipulated by scaling the values up and down to simulate a changed climate. The three models are described below (sections 4.3.2-4.3.4).

4.3.2 *Dry Grassland Habitat Model*

The model is shown schematically in Figure 4.8, and consists of three compartments: a root zone, subsoil and a geological layer. The water balance is characterised by the moisture content in the root-zone and the position of the water table in the subsoil. Five fluxes were estimated at each time step, the drainage flux (F5) providing the link to the other models.

Table 4.5 summarises the data (and default values) that were used in the model to describe the Dry Grassland Habitat. Within the model the "area" is used to indicate the relative area occupied.

Figure 4.8: *Schematic Representation of the Dry Grassland Model*

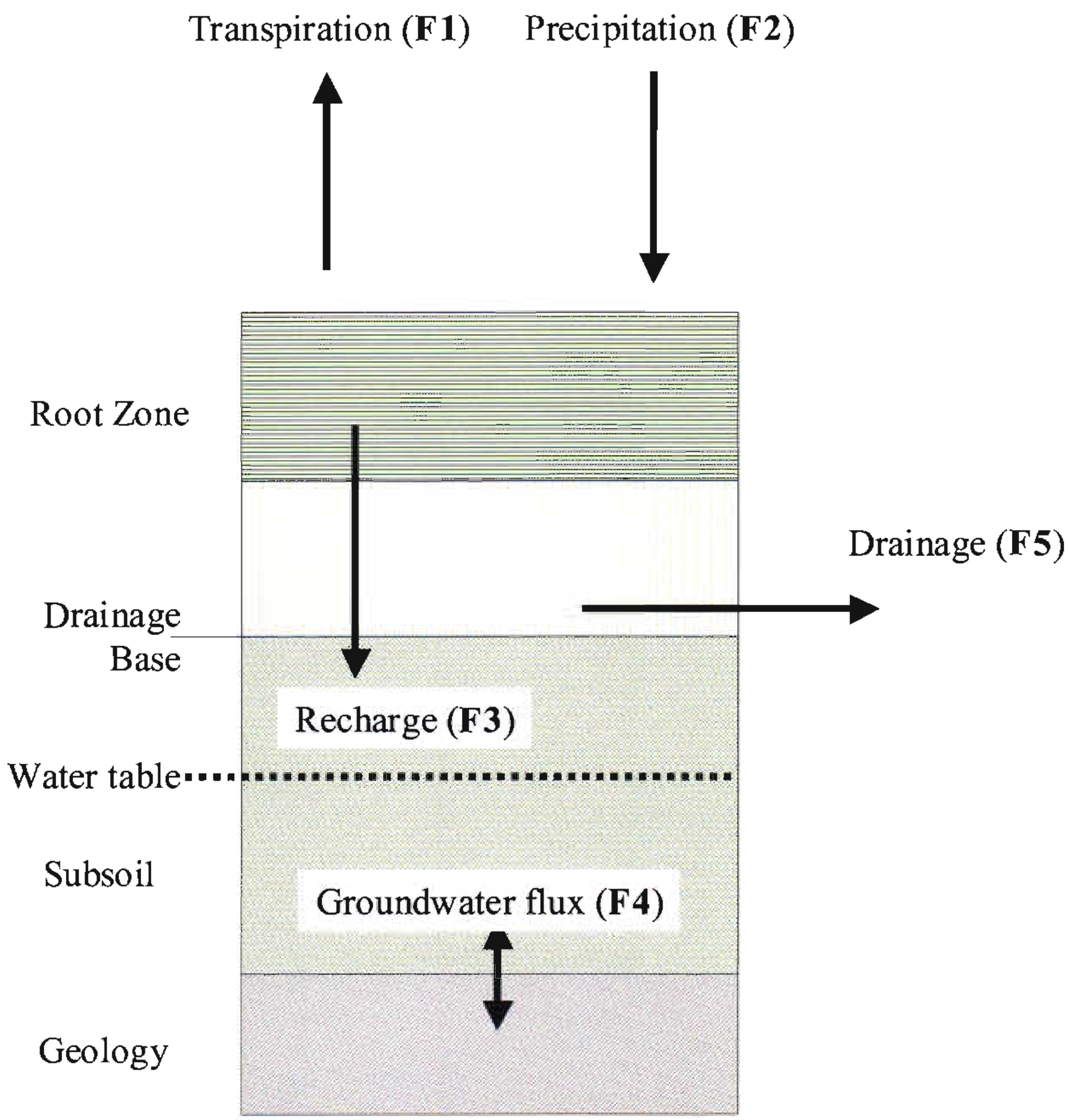


Table 4.5: *Data employed and default values for model of Dry Grassland Habitat*

Parameters	Default values
Root Zone depth	300.0mm
Root Zone moisture capacity	
Saturated	68%
Field Capacity	49%
Stress point	23%
PWP (permanent wilting point)	17%
Subsoil	
Drainage Base	2000mm
Subsoil porosity	51%
Seepage (Loss)	0.10 mm/day
Extent	
Area	1000
Surface elevation	3250mm

4.3.2.1 Calculation Process

At each time step the following calculations of fluxes were made (capillary rise and the lateral groundwater flow were not modelled):

a) The actual evapotranspiration (AEt) (**Flux F1**) was estimated from:
- the potential transpiration (PEt),
- the crop type and
- the moisture content in the root zone.

PEt is provided by the MORECS data set, the crop factors are supplied from the literature to give a potential rate for that crop type. Moisture content is that calculated for the previous time step. If the soil is dry (> 5,000 cm suction) the AEt rate is reduced, so that by the time the soil becomes very dry at the permanent wilting point (16,000 cm suction) AEt falls to zero. The moisture content at saturation (0 suction), stress point (5000 cm suction) and PWP (16,000 cm suction) were estimated using expert opinion and are characteristic of a soil mid way between a loam and a pure peat.

b) Rainfall (**Flux F2**) is provided by the MORECS data set. Note that the moisture content in the root zone is increased by precipitation (**F2**) and decreased by AEt (**F1**).

c) If the root zone becomes saturated the excess water recharges the subsoil (**Flux F3**).

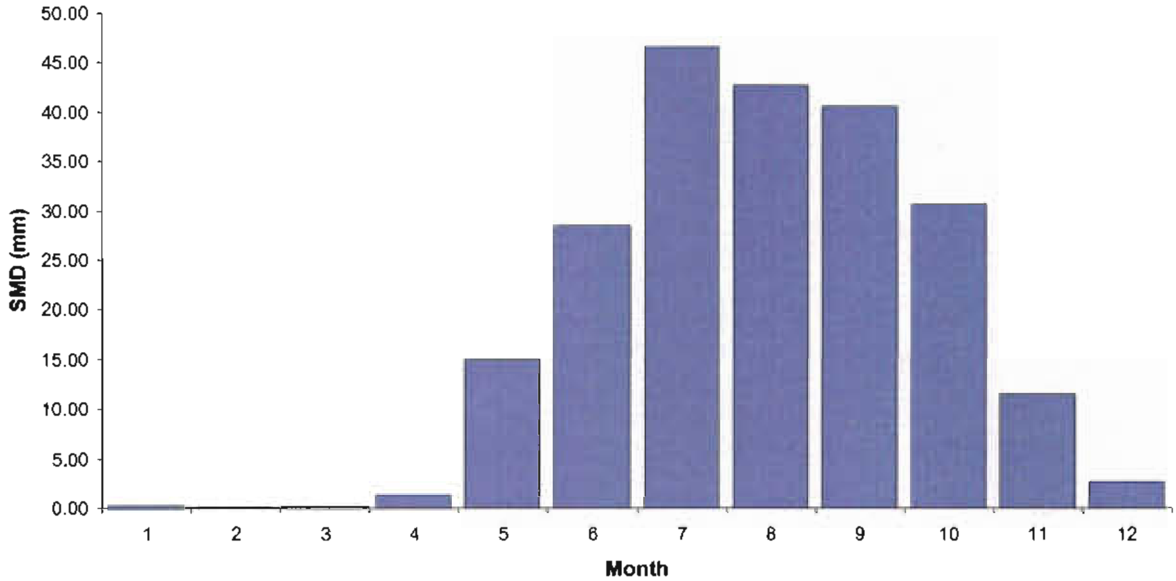
d) The position of the water-table is increased by recharge (**F3**) and may be increased or decreased by the groundwater flux (**Flux F4**) depending on which direction it is flowing. **Flux F4** may be upwards from artesian pressure or downwards from drainage. There are no data on groundwater flux in the Great Fen area or how it might vary seasonally or spatially. Because of the underlying clay layer within the Core Area, it is assumed that the groundwater flux is small. However, the model is sensitive to this parameter.

e) If the height of the water table is greater than the drainage base, the excess water drains away to become the drainage flux (**Flux F5**).

4.3.2.2 Typical Results

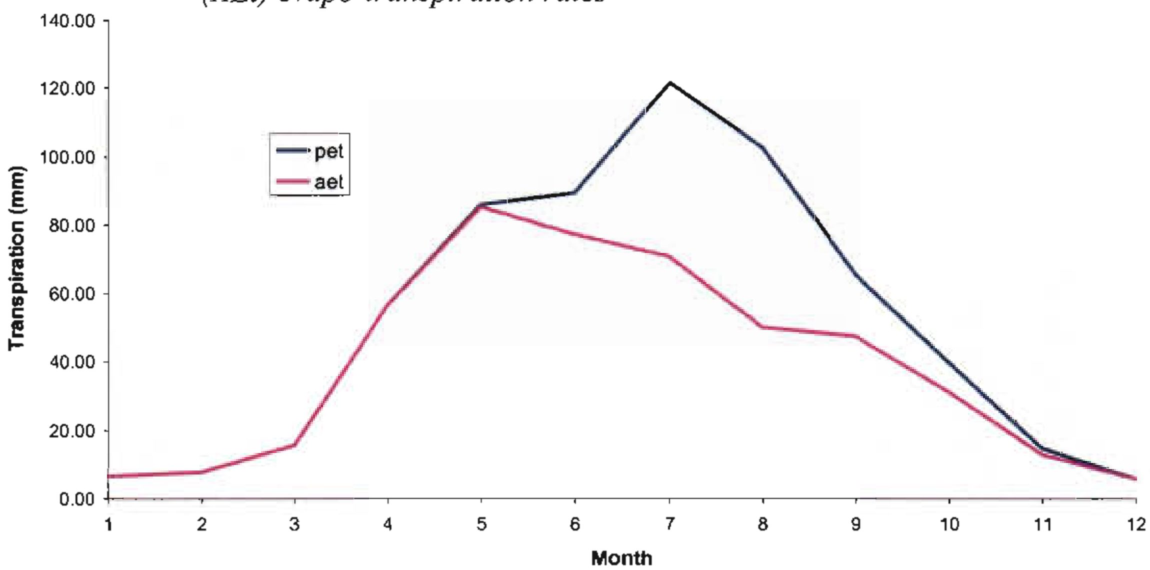
Figure 4.9 shows the predicted average Soil Moisture Deficit (SMD) over a whole year (average results from 1963 to 2001), the SMD being the depth of water that would be required to bring the soil in the root zone back up to field capacity. In this case it is assumed that the effective root zone depth is 300mm. It can be seen that the model predicts that the SMD starts to increase (slowly) in April, but that it rapidly increases through May and June to peak in July. The SMD remains high through August and September and then declines through October and November.

Figure 4.9: *Dry Grassland Habitat Model – predicted average soil-moisture deficit*



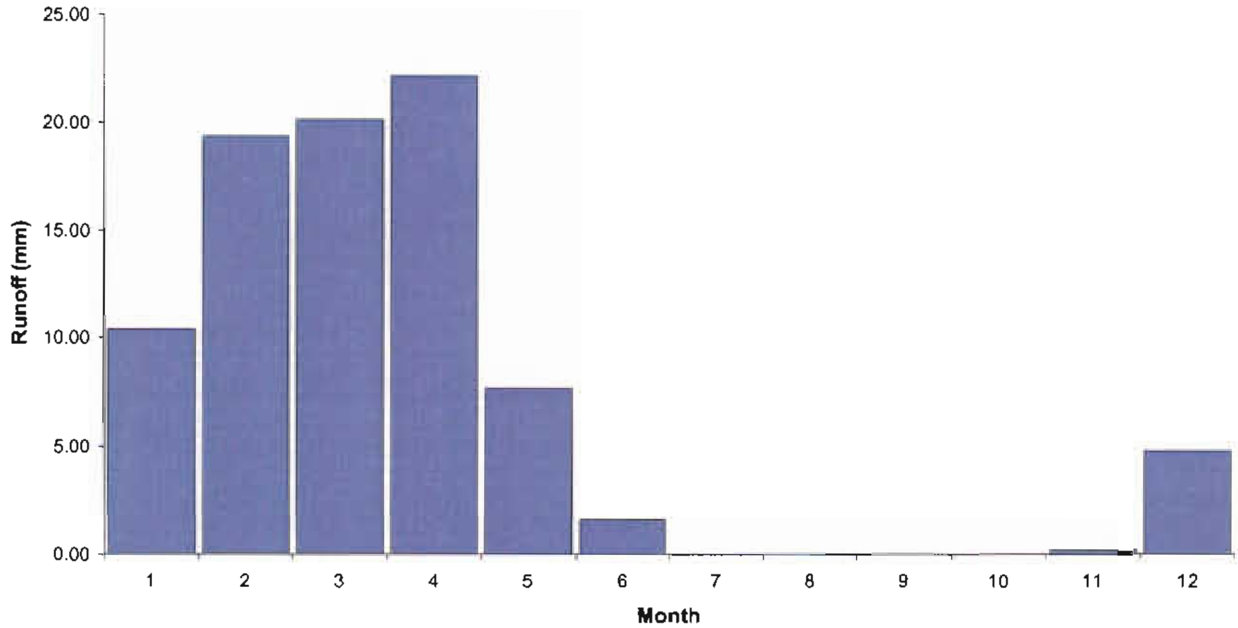
The build up of the SMD decreases the Actual (AEt) compared to the Potential (PEt) evapo-transpiration. Figure 4.10 shows that the actual rate starts to diverge from the potential in May, and in July and August it is considerably below the potential rate.

Figure 4.10: *Dry Grassland Habitat Model – predicted average potential (PEt) and actual (AEt) evapo-transpiration rates*



The annual pattern of SMD shown above has implications for the amount of runoff that occurs and when within the year it happens. Figure 4.11 depicts the average runoff (drainage flux) for each month. From these results, it can be seen that most runoff is predicted to occur in February, March and April when the root zone soil has been saturated by winter rainfall and the water table has had time to increase to the drainage base. The model predicts that nearly 90% of the annual drainage flux will occur during the period December to April.

Figure 4.11: *Dry Grassland Habitat Model – predicted average annual runoff*



Because of this temporal aspect the relationship between annual rainfall and runoff (Figure 4.12) is quite "noisy", but the relationship between winter and spring rainfall and runoff is much clearer (Figure 4.13), although there is still considerable amount of variation. Not only is there considerable variation between annual rainfall and runoff but also the pattern over the years (Figure 4.14) is very variable with noticeable sequences of wet and dry years.

Figure 4.12: *Dry Grassland Habitat Model – Rainfall vs Runoff*

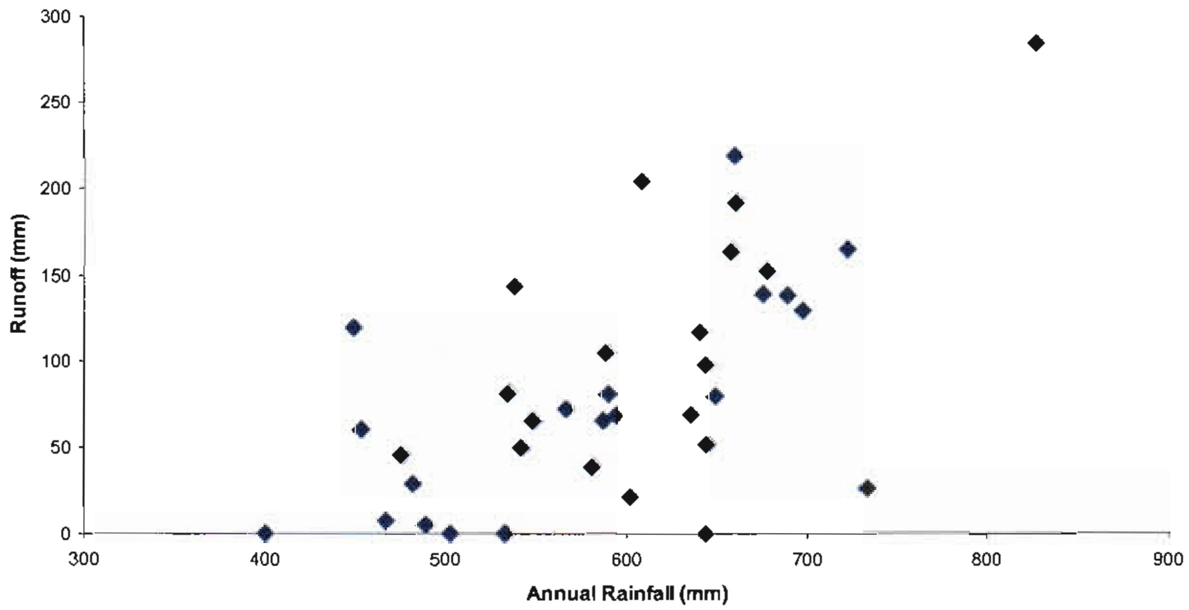


Figure 4.13: *Dry Grassland Habitat Model – Rainfall vs Runoff for December-April*

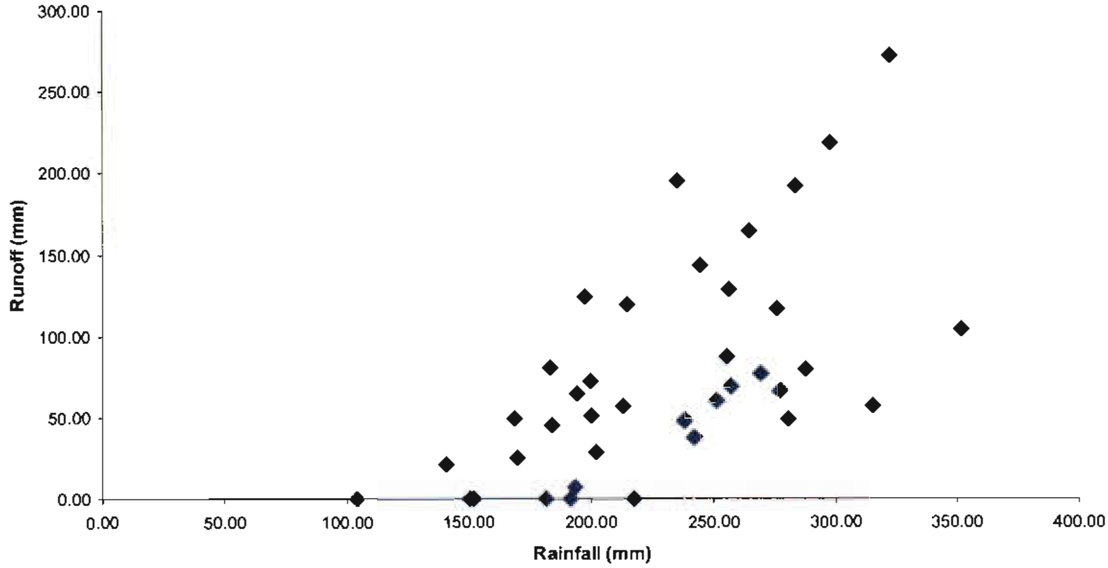
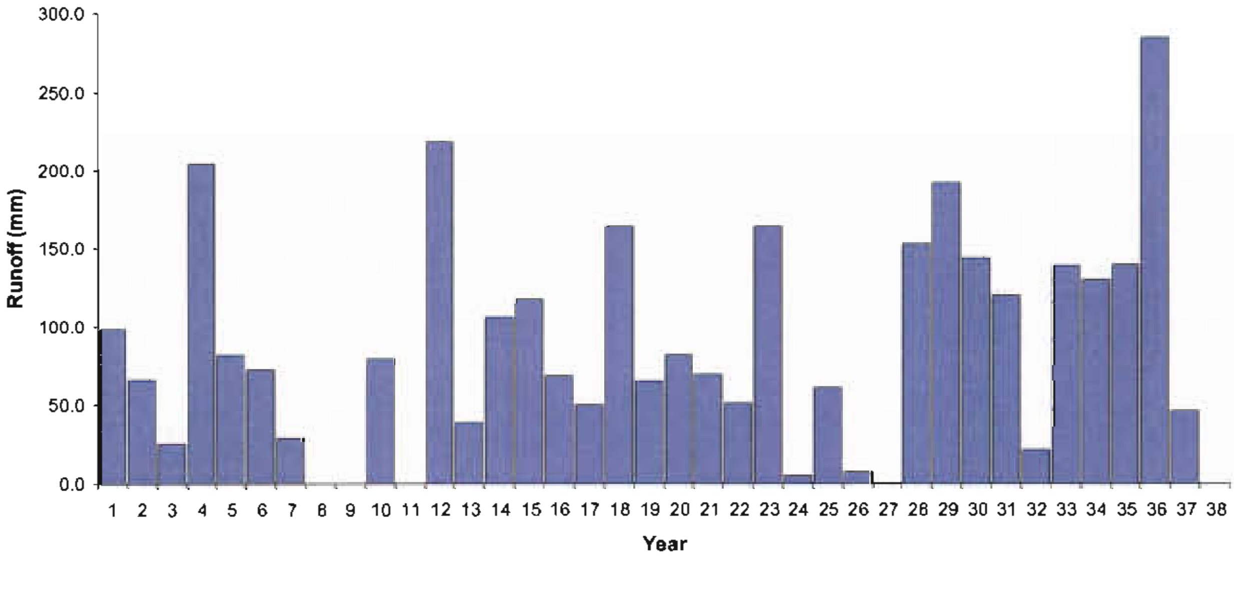


Figure 4.14: *Dry Grassland Habitat Model – Predicted Annual Runoff*



4.3.2.3 Validation / Verification / Sensitivity

There are no data that can be used to directly verify the model. Comparison of these modelled results with the runoff figures for the Alconbury Brook catchment (section 2.1.3.3) show:

- slightly lower total runoff (15% rather than 18%); and
- a higher proportion of winter run-off (88% rather than 75%).

As the Alconbury Brook catchment is more undulating and lies on soils with a higher clay content, these differences are not unexpected.

The temporal pattern of SMD is as one would expect, but the average values are lower than might be predicted, which may be because the model assumes that summer rainfall is perfectly captured. In practice, intense summer storms can bypass the soil (by flowing through cracks) or runoff the surface (when rainfall rate exceeds the infiltration rate). Both these factors would increase total runoff towards that observed from Alconbury Brook, and increase the amount of summer runoff (again closer to that observed).

The model predicts most runoff to occur in the spring, after the root zone and subsoil are fully replenished by winter rainfall and predicts virtually no runoff at other times. Under current conditions the pumps operate more evenly than the model suggests.

Fluctuations in the water-table position seem unrealistically small. However, as there are no known data on water table fluctuations, it is difficult to be sure whether this concern is valid or not.

The drainage flux (**F5**) is very sensitive to the value of the ground water flux (**F4**). It is generally assumed that, because of the clay layer under the Fens and the low elevation, this flux will be small or negligible. However, even small variations cause major differences. By default the model assumes a downward flux of 0.1mm per day giving an average annual runoff of 86mm. If the groundwater flux was truly zero then the runoff increases to 121mm, while downward flux of only 0.2mm per day decreases average annual runoff to 51mm.

The drainage flux (**F5**) is also very sensitive to the amount of water that can be stored in the root zone. Increasing the effective depth of the root zone to 400mm reduces the drainage flux by nearly 50%, while decreasing it to 200mm increases the runoff by a similar amount. A rooting depth of 300mm may seem quite shallow, but most plants have the greater part of their roots near the surface and the root zone represents that depth where the majority of the water is extracted, rather than the maximum depth to which the plant can send its roots.

4.3.2.4 Implications

Within the dry grassland habitat model, the most sensitive parameter is the value of the groundwater flux and some data on this parameter would be most welcome. A further flux (capillary rise from the groundwater towards the root zone) has not been included as it depends critically on the position of the drainage base and the silt content of the soil. If capillary rise were significant, then it would act to reduce the amount of runoff generated.

Most climate change scenarios suggest higher evaporative demand in the summer plus lower summer rainfall, but an increase in winter rainfall. Applying the UKCIP98 climate scenario to the model produces some interesting results:

- Average maximum SMD increases from 46mm to 60mm (~+30%).
- Differences between PEt and AEt increase (higher SMD and higher evaporative demand).
- Peak runoff occurs earlier (February instead of April).
- Volume of runoff increases significantly from 87mm per year to 116mm (~30% increase while annual rainfall increases by only ~2%).

The implication seems to be that the dry grassland habitat will be parched for most of the summer, but that more water is potentially available to top up the fen environment. This prospective increase in runoff would be negated by the development of more drought tolerant deeper-rooted plants on the Dry Grassland Areas.

4.3.3 *Wet Grassland Habitat Model*

This second model takes a similar structure to that of the Dry Grassland Model (section 4.3.2), but employs three extra fluxes:

- *Flooding of surface water from the "Fen-Pond" habitat* - occurs when the water level in the pond is higher than the wet grassland.
- *Groundwater flooding from the Fen-Pond* - occurs when the water level in the pond is above the elevation of the bottom of the root zone.
- *Irrigation* (if permitted) - could occur in anticipation of a developing SMD *i.e.* triggered at a relatively low SMD.

The crop factors for Wet Grassland are systematically higher than those for the Dry Grassland plants. Unless irrigation is permitted Wet Grassland can only persist in a narrow elevation range in relation to the open water habitat. If the grassland is flooded for more than a couple of months over the winter it is likely to suffer. Similarly without irrigation if the water table falls too low then the soil will become parched and the plants will suffer. Table 4.6 provides a summary of parameters and default values for the Wet Grassland Model

Table 4.6: *Data employed and default values for model of Wet Grassland Habitat*
Note: the "area" is again used to indicate the relative area occupied.

Parameters	Default values
Root Zone depth	300.0mm
Root Zone moisture capacity	
Saturated	68%
Field Capacity	49%
Stress point	23%
PWP (permanent wilting point)	17%
Subsoil	
Drainage Base	2000mm
Subsoil porosity	51%
Seepage (Loss)	0.10 mm/day
Maximum horizontal groundwater flux	0.10mm/day
Extent	
Area	500
Surface elevation	2050mm
Irrigation schedule	
Maximum monthly application	0mm
Application amount (per month)	0mm
SMD "trigger" for irrigation	25mm

4.3.3.1 Calculation Process

Calculation of fluxes follows that method described above, with the following exceptions:

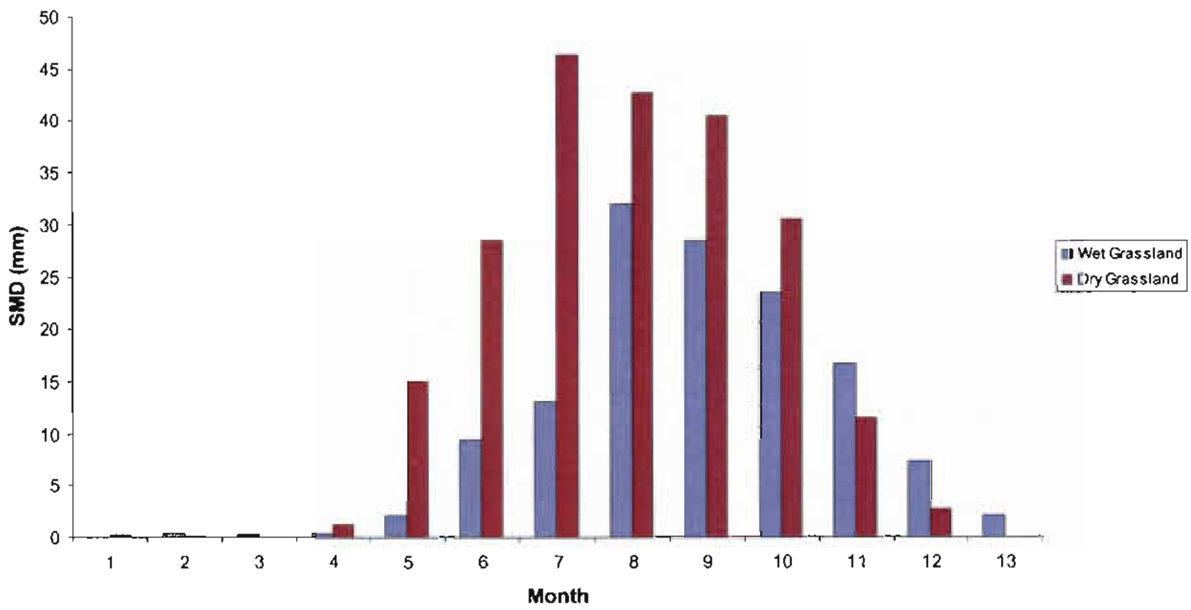
- If the surface water level in the fen-pond is greater than the ground level of the wet grassland habitat, the depth is equalised depending on their total area.
- If the surface water level is above the position of the bottom of the root zone in the wet grassland, a fixed flux flows into the wet grassland.

In practice, the horizontal groundwater flux between the wet grassland and fen environments will depend on the saturated hydraulic capacity, the distance to be moved and the densities of both sub-surface drainage features (tiles drains, ditches *etc*) and surface water drains. As data on all these factors are lacking, the expedient of assuming a small fixed rate was taken (by default the same magnitude as the vertical groundwater flux used in the Dry Grassland Habitat model).

4.3.3.2 Typical results

Because of the more intimate relationship with the fen-pond habitat, the SMD is lower in the Wet Grassland habitat than in the Dry Grassland and the peak values are achieved slightly later in the year (Figure 4.15). Because this compartment is slightly lower and wetter, there is also fractionally more runoff than from the dry grassland habitat.

Figure 4.15: *Predicted Average Soil Moisture Deficit (SMD) in Wet and Dry Grasslands*



4.3.4 *Fen-Pond Habitat Model*

The Fen-pond model resembles the Wet Grassland Habitat model other than:

- The irrigation factor is replaced by the potential option to "top up" the pond over the winter period.
- A "weir" controls the maximum water level that can be achieved.

Transpiration was calculated assuming coverage by reeds rather than by open water. It should be noted also that the soil is deeper and "peatier" than the grassland communities. Table 4.7 indicates the parameters and default values.

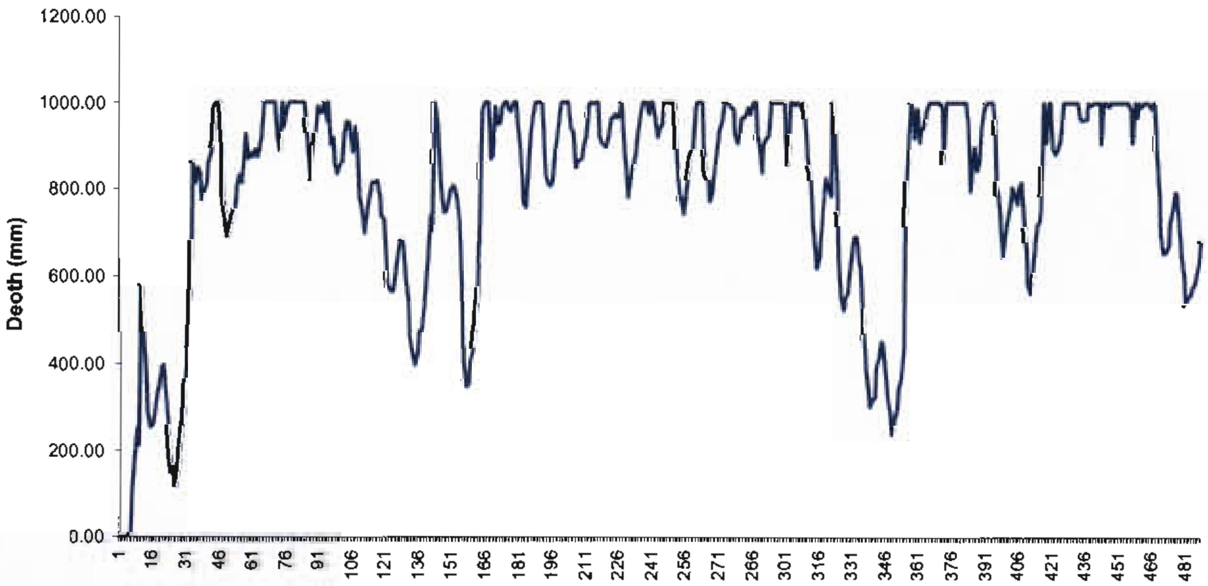
Table 4.7: *Data employed and default values for model of Fen-pond Habitat*

Parameters	Default values
Root Zone depth	500.0mm
Root Zone moisture capacity	
Saturated	86%
Field Capacity	71%
Stress point	32%
PWP (permanent wilting point)	27%
Pond control	
Weir height	1000mm
Critical depth	950mm
Maximum inflow (per winter month)	20mm
Extent	
Area	250
Surface elevation	1000mm

4.3.4.1 Typical Results

By default the model is run assuming that some of the water that is currently pumped out of the area can be diverted to topping up the pond over the winter period. Figure 4.16 illustrates the predicted depth of water in such a pond over the whole period. The persistence in the pattern of runoff translates itself into periods of uniformly high water levels and sequences of years where the pond never recovers over the winter.

Figure 4.16: *Fen-pond Habitat – Pond depth allowing for a winter top-up*



4.3.4.2 Sensitivity of the model

The model is sensitive to both the area contributing to its existence, its target depth and whether it can be topped up over the winter. Figure 4.17 illustrates that, without any external resources, a pond of a metre deep will dry out completely given sequences of dry years such as those observed in this area. Not unsurprisingly, a shallower pond goes dry and stays dry for extended periods on several occasions (see Figure 4.18). It would also seem difficult to maintain such a shallow open-water habit given the vigour with which reeds grow.

Figure 4.17: *Fen-pond Habitat – Effect on pond depth of NOT allowing for a winter top-up*

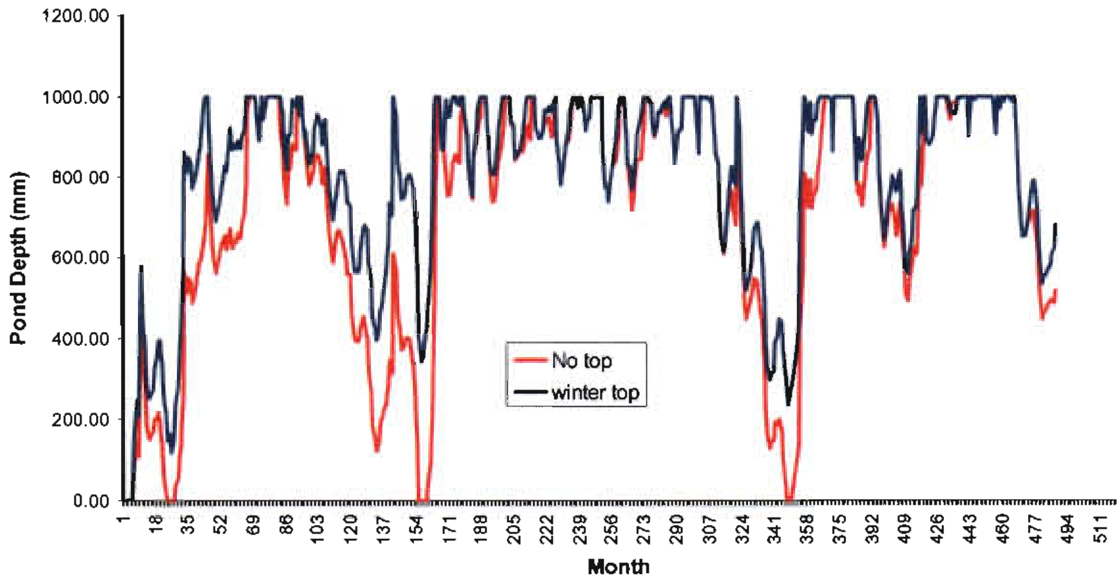
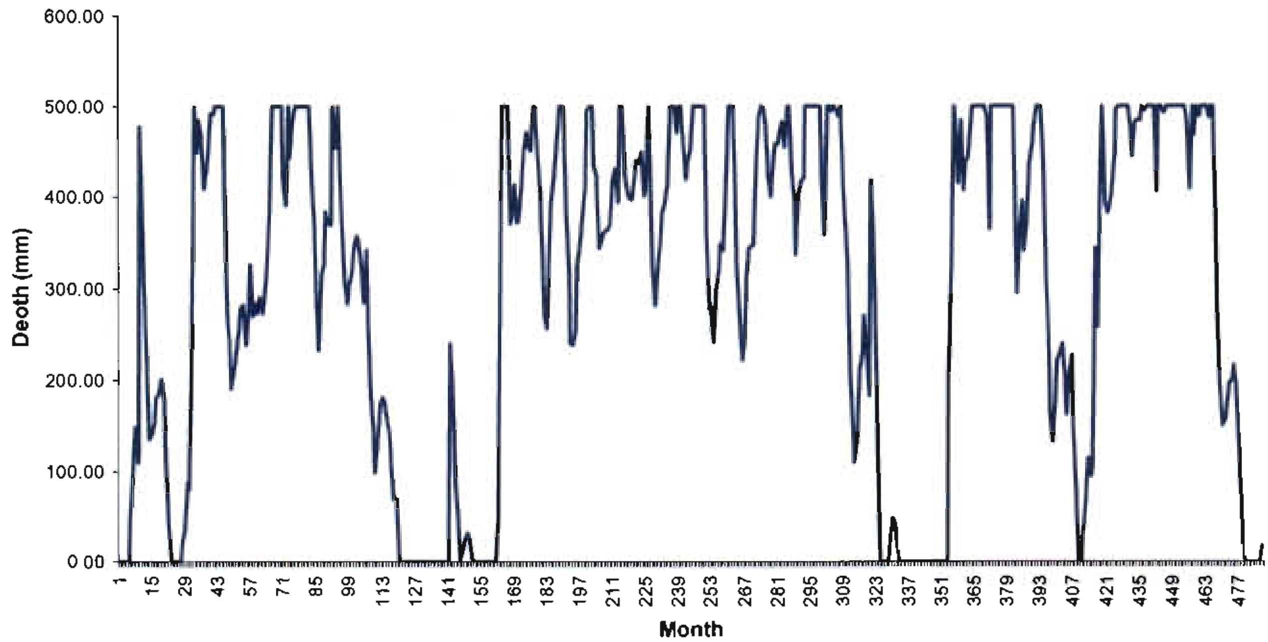


Figure 4.18: *Fen-pond Habitat – predicted depth changes in a shallow pond*



By default the area of the Fen-pond community is 25% of that of the Dry Grassland community and half that of the Wet Grassland community. Figure 4.19 portrays the effect on the pond depth of equalising the areas of Fen-pond and Dry Grassland. It can be seen that the most that could be achieved would be a vernal pond, unless water could be diverted into the site during the winter (Figure 4.20). Even under such a management system, the long-term stability of the pond is in doubt unless unrealistically large amounts of water could be transferred into the area (the current limit is 25mm depth per month).

Figure 4.19: *Fen-pond Habitat – Predicted depth changes with equal areas of Fen-pond and Dry Grassland, together with NO winter top-up*

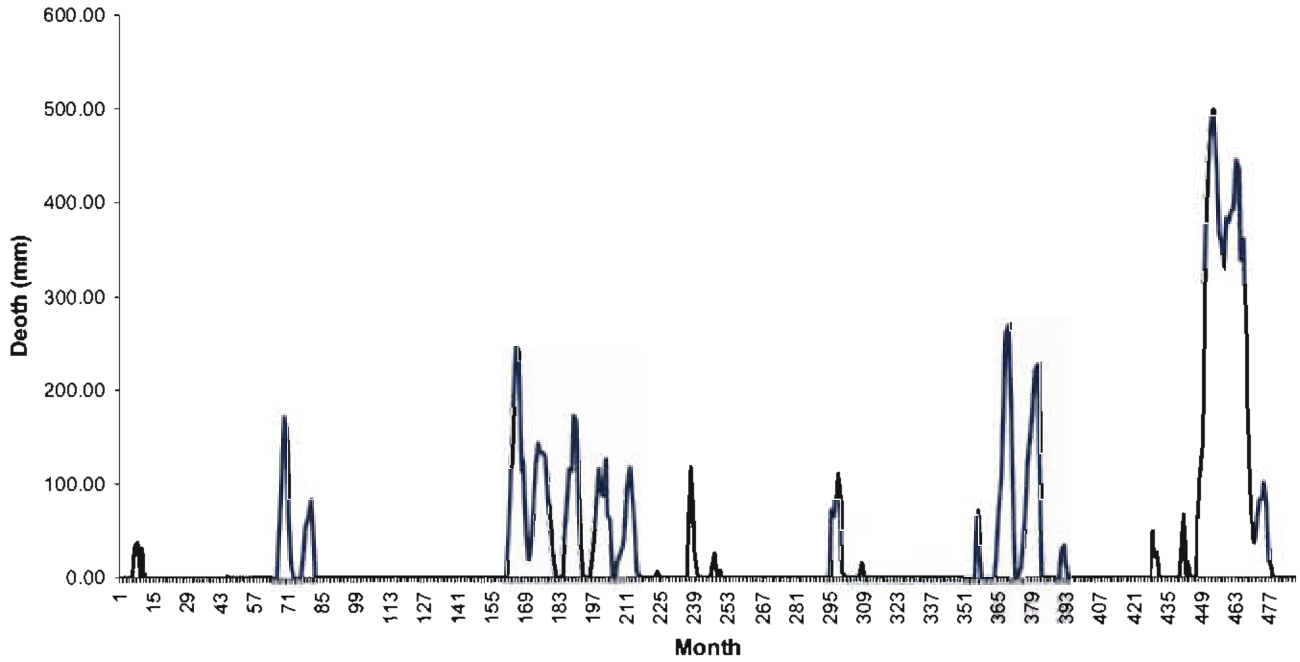
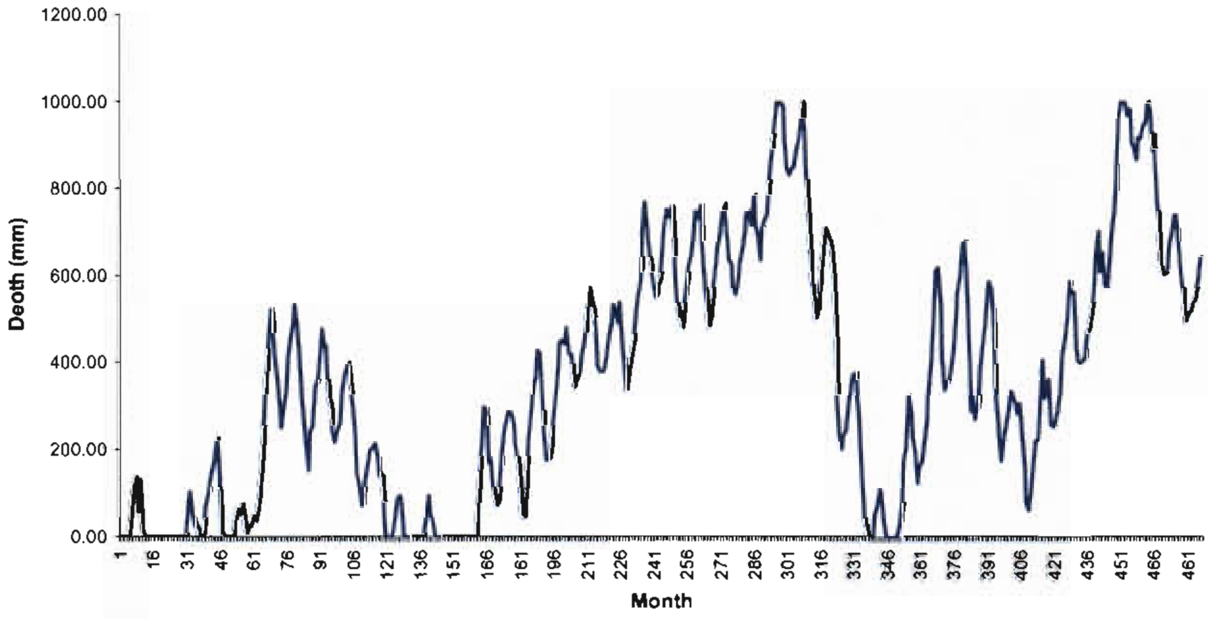


Figure 4.20: *Fen-pond Habitat – Predicted depth changes with equal areas of Fen-pond and Dry Grassland, but WITH a winter top-up*



As discussed above, the climate change scenario UKCIP98 indicates greater winter rainfall in the future and hence significantly more runoff. However, reduced summer rainfall and increased evaporative demand in the summer would also have an effect. Figure 4.21 indicates that, on balance, climate change will not have a very major impact on the system - in some years the water level will drop a little more, but not by very much. Of course, climate change and no ability to divert up land runoff leads to an unreliable pond (Figure 4.22).

Figure 4.21: *Fen-pond Habitat – Depth of pond with winter top up AND with and without climate change*

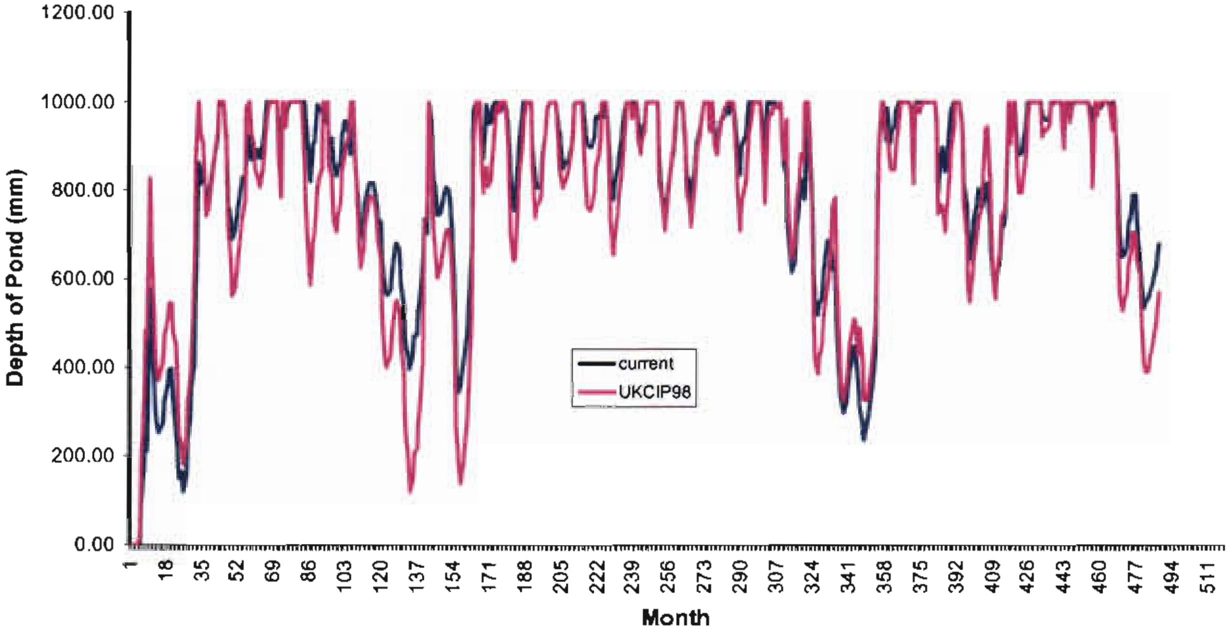
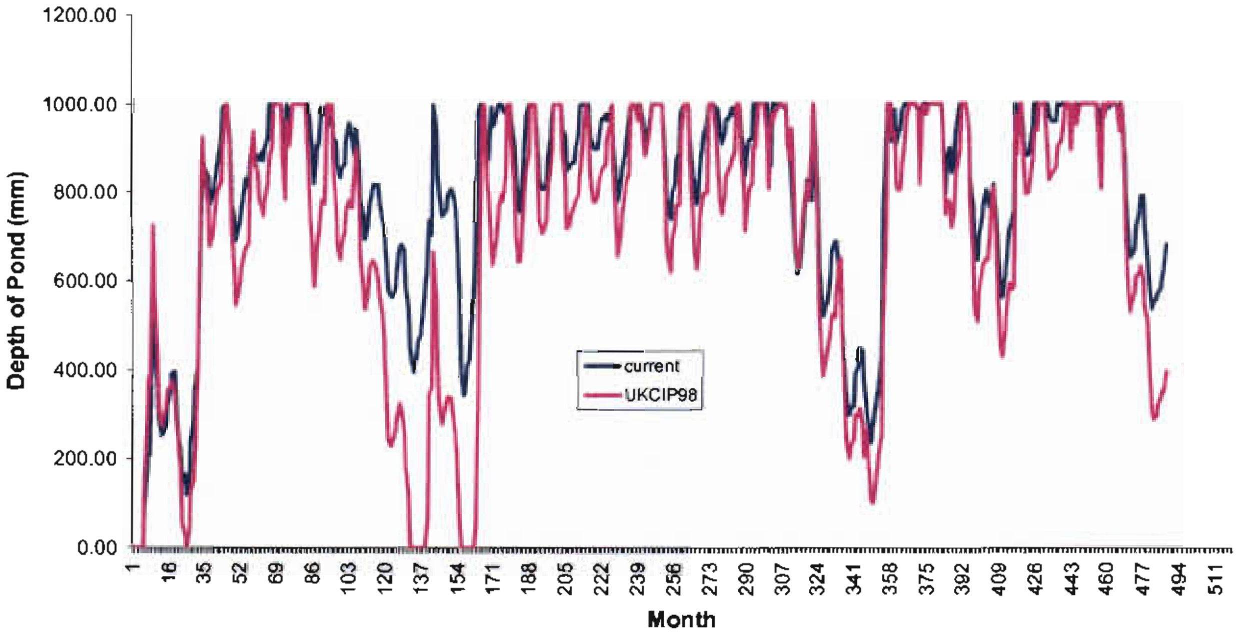


Figure 4.22: *Fen-pond Habitat – Depth of pond <u>without</u> winter top up AND with and without climate change*



4.3.5 *Implications from the Modelling*

It must be stressed that there are insufficient data for a quantitative assessment of the accuracy of the modelling process, though qualitatively the results are in agreement with expert judgement and previous experience in modelling the Fen area. However, previous experience also urges caution, not least because of the idiosyncratic nature with which the water management is carried out.

Because of the lack of observed data, the model was deliberately designed to be as parsimonious as possible. Even so it contains well over 30 parameters, and the results are known to be very sensitive to some of the values (and to the assumptions as to how the system might work). A full sensitivity analysis has not been carried out.

The first drainage activities within the fen were designed to carry water from the uplands through the Fens as quickly and efficiently as possible (Godwin 1978; Sheail 1976). The results of this modelling exercise unsurprisingly agree with that strategy. Without upland runoff only small patches of fen could be maintained, most of the Great Fen Area would be utilised to "harvest" winter/spring runoff to recharge the Fen area.

Given the shallowness of the topography, the vigour of reeds and the need for a reasonable depth of water it seems likely that an open water habitat would require some land shaping to achieve permanence.

There are many climate change scenarios and only one has been explicitly tested. The results of that suggest that the outcome of climate change is not necessarily an adverse factor for the full range of habitats that the Great Fen Project seeks to restore. Runoff is predominantly a winter/spring phenomena, and higher winter rainfall will increase the ability to top-up the wetter habitats. The dry habitats will become significantly more parched over the summer and some thought may have to given to what are desirable habitats for that environment.

5 SUMMARY: SCENARIOS and PRIORITIES

5.1 **Targets in the short, medium and long term**

The range of possible habitats and communities that could be restored is assessed here in terms of the practicality of intervention to achieve restoration. These results are summarised through a series of maps depicting the outcome of different water-storage scenarios. The overall targets for fen restoration in Cambridgeshire (and other counties) are given in Appendix Table A2.8. Here it is stated that the first target is to rehabilitate priority sites *e.g.* the National Nature Reserves at Holme, Wicken and Woodwalton. The context of this rehabilitation target is described as the recreation of the habitat and species quality that was found in the late nineteenth century *i.e.* contemporary with the drainage of Whittlesey Mere and the purchase by the National Trust of parts of Wicken Sedge Fen.

5.1.1 *Targets from the past*

An appreciable body of research and resultant literature has been produced to indicate the condition of the Fenland at various times over recent centuries. A magisterial and synoptic account, tracing change from the late Quaternary period onward, was produced by Godwin (1978), though the primeval fens that are described there are probably outwith the vision implicit in the Cambridgeshire BAP, and even within the Great Fen Project. The past, present and future of one of the four significant fen reserves, Wicken has been well researched (Friday 1997; Rowell and Harvey 1988), and provides a description of some contemporary habitats that are realisable on the Great Fen, as well as a vision of wetland restoration on the grand scale (Friday and Colston 1999).

The environmental history and current ecology of the Great Fen area itself has been the subject of much attention, beginning with Poore's work some 50 years ago (Poore 1956). Here it is made clear that the situation within the Great Fen area differed appreciably from that in the eastern reserves such as Wicken. Not only was the water system within Woodwalton Fen entirely artificial, but also the evidence strongly suggested vegetation with a much greater representation of acid raised bog. Such vegetation survived in fragmentary form into recent years, but may not represent the most "restorable" options for the first few decades of the Great Fen. Since its founding in 1963, Monks Wood has paid attention to its fen hinterland, working especially within the two Great Fen NNRs. The catastrophic changes that occurred within the Great Fen were traced by Sheail and Wells, providing an analysis of the documentary evidence (1980 and 1983).

Possibly the most useful source of material for the Great Fen is the series of maps, dating from 1632 to 1974, included within John Sheail's account of land-use history in the Great Fen area (Sheail 1976). Two particular maps (figures 6 and 7) give a picture of the landscape and habitats to which the present project might allude. These sources date from 1824-35 (early Ordnance Survey maps) and around 1840 (Tithe Commutation Survey). Some calcareous meres (Ugg, Trundle, Whittlesey etc) survived, fringed in "marsh", but the two NNRs and much of the land between is mapped as "(fen) pasture" - presumably lowland wet grassland, fen-meadow, rush-pasture and possibly transition to tall-herb fen. Blocks of arable already occupied Conington Fen and land south and south-west of Woodwalton Fen. Parts of what is now Holme Fen NNR were depicted as "rough fen" implying both the presence of tall-herb fen and possibly early stages in the development of the present woodland cover. From other sources marshalled by Sheail, it is clear that the *Sphagnum* bog that marked out the Huntingdonshire fens from those of Wicken and Chippenham were amongst the first habitats to be greatly reduced, and that a blueprint for restoration based upon the mid- to late nineteenth century must necessarily focus on wet grassland, herbaceous fen and carr (or other wet woodland).

5.1.2 *Practical targets for the future*

From the outset of the project, the Steering Group has retained an underlying concern to maintain flexibility, and not to design a menu for restoration that precludes future options. Whilst being prepared to invest in the early phases in some substantial capital expense, any such works should maintain the scope for altering the approach in the future *e.g.* water controls that allow a number of different outcomes in terms of habitat restoration. It was agreed by the Steering Group that the first habitats that the scheme should aim for must be (reasonably) easy to produce (see Table 3.8), so as to provide relatively immediate biodiversity benefits. It was further agreed that such habitats should have the potential to develop further, since it is acknowledged that the desired habitats of NNR standard could not be produced in the short term. Rather, restoration will be a staged process.

In adopting this approach of practical targets, CEH has stressed rapid restoration of low-maintenance habitats, with a potential to develop under sympathetic management into more highly-valued habitats such as tall-herb rich fen and fen meadows. The restoration scenarios outlined below assume that wetland restoration would initially focus on reedbed and more species-poor wet grasslands. From such beginnings fen and fen-meadow respectively could develop, given appropriate management.

Less attention has focussed on carr, since wooded fen habitats are, at present, very well represented in the NNRs of the Core Area - indeed activity has sought to reduce their extent (see Appendix 5, and especially aerial photographs of Woodwalton fen taken in 1960 and 1986). Nonetheless, some tree-planting as a means of encouraging more rapid carr development in other parts of the Core Area would be desirable, especially to mask potential eyesores such as drawdown in storage ponds or for other shelterbelt functions. However, attention in the scenario below is specifically on those herbaceous communities that will develop in the first phase of the Great Fen, and on where they might evolve.

Such a rationale and the scenarios derived from it, do leave important parts of the Core Area where wetland restoration may not be practical in the short-medium term, and might indeed require quite far-reaching engineering works should such restoration be attempted even in the longer term. Discussion with the Steering Group recognised that wetland habitats were by no means the only priority for restoration in Cambridgeshire. Hence (as outlined in section 4.3) considerable areas of a dry grassland habitat would form one major element of all the scenarios that appear practical. Once again, in the short-medium term, such drier grasslands would be likely to be rather species-poor and, unless extensive mowing/grazing were practical, would be related to **MG1** *Arrhenatherum elatius* grassland (Rodwell 1991-2000). However, the variation in soil type within the Core Area allows for other possibilities, particularly where some more intensive defoliation intervention is possible to prevent scrub encroachment, suppress coarser grasses and open up regeneration niches.

Amongst the options, admittedly highly speculative at this stage, that might be practical, and which could repay further investigation are:

- ❑ On higher lying and free-draining calcareous soils, as for example derived from the "stonewort marl" *etc* on the beds of the former fen meres, an ***open calcicolous sward*** could be restored. The Core Area has much in common bio-climatically with the Breckland, with (for Britain) very low precipitation and a relatively Continental temperature regime. It should be entirely possible to restore a Breck grassland, possibly forming a mosaic with low scrub of *Ulex* and *Cytisus* and with shelter belts to help prevent erosion of the light dry soils. Such an extensive new area might be especially useful in the planned reintroduction of arid-ground vertebrates such as Great Bustard and Stone Curlew.
- ❑ Much of the remaining peat within the Core Area presently has an acid pH (<5) and some of the areas in the south and west of the area stand sufficiently high for wet grassland restoration to be less practical (Duncan 2002). In such areas, a more calcifuge dry grassland might be restored eventually, possibly one related to **U1** *Festuca ovina-Agrostis capillaris-Rumex acetosella* grassland (Rodwell 1991-2000). Such swards are fragmentary in the region at present, and would represent a further extension of Breckland habitat to the west.

- Finally, several marginal parts of the Core Area, notably near Higney Wood, Big Holt and Middle Farm west of Woodwalton Fen NNR, lie on base-rich clay soils with impeded drainage. In Cambridgeshire, such soils are the chief habitat for older woodlands, and locally also support a distinctive calcicolus grassland, as for example at Bentley Meadows, Upwood. Although such examples of this grassland type are ancient, there also exist related species-rich swards of considerable nature conservation value that have evolved within relatively recent times *e.g.* along the cuttings of the main railway created in the mid-nineteenth century. Restoration of comparable grasslands as part of the Great Fen Project mosaic should be eminently practical, and might be considered together with some tree planting.

5.2 Considerations in planning approaches

5.2.1 *Background*

Geographical Information Systems (GIS) linked to eco-hydrological models represent the most powerful tool for planning such restoration activity (Russell *et al* 1997; van Horssen *et al.* 1999; Wadsworth and Treweek 1999). These methods may be employed in informing site selection in the context of the neighbouring land-use and of the hydrology. GIS can be employed to map relative wetness (or some surrogate such as elevation) and land cover, bringing the information together to identify suitable sites.

In more ambitious and useful planning of both habitat management and ecological restoration, a fully integrated ecological, socio-economic and hydrological approach can be taken, as exemplified by the European Union's *LIFE* project on the River Dommel on the borders of Belgium and the Netherlands (Pieterse *et al.* 1998; Venterink *et al.* 1998). The methodological structure for this *LIFE* project is given in Appendix Figure A3.3, together with an outline of the components of one of the eco-hydrological models (Smart/Move) that was constructed for the Dommel work (Appendix Figure A3.4). Acreman *et al.* (2000) are presently working on a somewhat similar approach in the Somerset Levels and Moors.

5.2.2 *Application to the Great Fen Project*

For the Great Fen Project, a number of factors were taken into consideration, both from the context of the Core Area, and from the CEH research itself that would influence the choice of scenarios for restoration. Further development of scenarios for the Steering Group requires that together they arrive at some decisions as to what is likeliest to be acceptable (to the partners and other stakeholders) in terms of water storage and use of upland runoff, diversions from the Nene *etc*. The implications of these decisions are discussed below (section 5.3.2). At the outset, some factors might be taken as "givens" in scenario construction, others as plausible possibilities:

- The quantity of water-supply might not be a problem *per se*, and restoration of reedbed and/or lowland wet grassland might proceed over >30% of the area without any requirement for water storage.
- Should one be able to add a further 3 Million Mm^3 of water storage, on the water-budget calculations that have been made, there is flexibility to restore target habitats over most of the Core Area.
- Altitude and micro-topographic variation might be taken as a surrogate for flood depth. Thus those habitats that it was most practical to restore would be reedbed at lower elevations, with development of fen later, whilst lowland wet grassland would be encouraged at intermediate elevations, with potential development to fen-meadow and carr. Drier grasslands would occupy higher-lying parts of the Core Area. In the late stages of the present research, *LIDAR* data from the entire Core Area became available from the Environment Agency, and were used to refine the mapping of the micro-topography.

- Full digitised information on peat depth was only available for part of the site, but might in future be used as an overlay to further influence where the scheme pursues fen/fen meadow (deep peat) or reed and lowland wet grassland (shallow peat). (Ashworth 1997).
- Amelioration of the nutrient content of the water supply might determine where any storage (and hence location of reedbeds) be sited. Three complementary or alternative options:
  - by the Catchwater Drain southwest of Woodwalton Fen
  - by the Nene off-take near Yaxley Lode
  - on the main drain from the Conington/Sawtry Fens through the Core Area.
- Location of storage (and reedbeds) might also be influenced by proximity to the NNRs and vital considerations of amenity and recreation.

These considerations led to a series of questions that need to be addressed in designing the scenarios, and indeed in eventually realising the Great Fen Project:

i) ***If storage is necessary***, where should it actually be located? In such an area of relatively minimal topographic variation, the engineering imperatives may not vary much from site to site. However, the storage (as "fen-pond" - see section 4.3) might need to be extensive, depending on depth and the need for earth-moving. A further factor in determining location would be the need to use an area with the least potential for fen restoration *e.g.* with shallow peat depths? Further amenity/aesthetic considerations need to be addressed *e.g.* whether a large reservoir is consistent with the overall project vision. Several smaller storage reservoirs would increase the scope for fen restoration without necessarily being too visually intrusive. Panoramic views of the existing landscape in the Great Fen area were earlier provided to the Steering Group as part of the project reporting procedure.

ii) How many **independently** manageable hydrological blocks does the Core Area have at present? This needs to be addressed as a means of assessing the scope for restoring different habitats in different parts of the Core Area, and maintaining the flexibility that the Steering Group desire. Assuming that each IDB pump discharges from a specific area, there might be 6-7 potentially independent units.

iii) A) Does flexibility of implementation demand more pumps and more within-block (or within-field) ditching and bank work, with concomitant costs? And
B) What are the implications of remaining with the pumps/controls currently in place? Although such questions are basic, the fact that land purchase, and thus implementation of the scheme, is likely to be piecemeal, means that evolution of the control structures themselves must perforce be an iterative process *i.e.* pumping and control requirements will depend on what habitat is restored where, and what other interests (*e.g.* farming and flood-control) must be taken into account at that time and place.

In the light of these considerations, CEH originally sought to set a 50-year goal of a mosaic of fen, reedbed, fen-meadow, lowland wet grassland and carr. Two strategies for habitat restoration could be identified, and were discussed with the Steering Group at a preliminary stage:

I. Expanding as a buffer to the NNRs
II. Restoring a number of "stepping stones" linking the NNRs and other elements

For both these strategies, pros and cons were identified

I. Buffer approach:

a) *Pros*:

- Encourage successful regeneration through natural processes.
- Minimise problems of dispersal.
- Larger continuous blocks provide more security for extant biodiversity.
- The larger wetland would be more robust and less likely to be catastrophically damaged by a local drought *etc.*

b) *Cons*

- Further risk of genetic inbreeding and loss of fitness from continuing isolated sites
- Little immediate visual (and hence amenity) benefit
- Insignificant shortening of the distance between the two NNRs
- Little chance to isolate (and thus control their spread to the NNR) pest problems in the restored blocks.

II. Stepping stones strategy

a) *Pros*

- Early perceptible visual benefit
- Balance of habitat types more easily manipulated
- Purchase of land can be done **as** it becomes available
- Eased flow of genetic material between the NNRs

b) *Cons*

- Small isolated areas would be vulnerable to climate change and human impacts.
- May be difficult to plan integrated water management if constantly having to rearrange water requirements of isolated blocks of land.

However, following a presentation of these approaches to the Steering Group and subsequent discussion, it was decided to adopt a simplified approach based upon the recalculated water-budget and, further, allowing for the possibility of very limited water-storage and restricted use of water both from the upland runoff and from the Nene offtake.

5.3 Scenario Maps

5.3.1 *Main scenario*

Figures 5.1-5.4 presents a scenario for the implementation of the Great Fen Project, with Figure 1 depicting the whole Core Area and Figures 5.2-5.4 providing more detail respectively for the north, west and south-east portions of the Area. The base map is derived from the *LIDAR* imagery obtained by the Environment Agency in mid-summer 2002. Attention focuses here on explaining what these maps portray. Further maps, illustrating a "no diversion" scenario are included in Appendix 4. The underlying calculations on the areas and extent of each habitat type were derived from the modelling approach described in section 4.3. A number of assumptions were made in constructing the map:

a) The four "potential vegetation cover" classes depicted on all four figures are essentially dependent upon relative elevation (*i.e.* lowest point in Core Area taken as 0m altitude), with:

a) Open Water: <1m altitude
b) Reed: 1-2m altitude
c) Wet grassland: 2-3m altitude
d) Dry grassland: >3m altitude

b) An area of **7.2 km²** of fen (containing open-water pond storage within) would be created that would be topped up each winter (December to March) by 3Mm³ of upland runoff. During the summer levels would be allowed to fall naturally. Such a system would be stable, and would not dry out completely. Allowable annual fluctuation in the water-levels within this fen-pond habitat should be within about 500mm (and in most years less). This approach would give a fen-pond that would receive 100% of excess (moisture above saturation) from the wet and dry grassland compartments (as defined in section 4.3). Because of this dependence on runoff from the grassland compartments, there would be a failure of the 500mm rule in some 5-6% of years. The drawdown within the fen-pond compartment would also provide transitional habitat between open water and reed, and also between the reed-fen and the surrounding wet grassland.

c) **5.0 km²** of wet grass could be created that would require irrigation during the summer (May-September) with 1.1Mm³. This water would be pumped in a dry summer, and 0.7Mm³ transferred from Stanground, assuming a 60% efficiency. Such a modelled design would suffer no stress in 80% of years, assuming that there is the capacity to apply up to 50mm of water per month repeatedly to the wet grassland, and assuming that a dry month can be anticipated. It should be noted that 0.7 Mm3 is slightly greater than present licensed summer abstractions, which exclude re-abstraction of winter water released from reservoirs (*ca* 0.52Mm³). Furthermore actual average summer abstraction for use in the Core Area has not exceeded 0.33Mm3 in recent years. Hence, taking into account the needs and concerns of all the partners, it is may be difficult to justify abstractions above this level (see discussion of irrigation in sections 2.1.2.3 and 4.2.2). Therefore to obtain the required 0.7Mm3 would require *ca* 0.4Mm3 of storage of winter runoff within reservoirs. These reservoirs could be either inside or outside the core area and could be similar to present on farm storage.

d) The remainder of the Core Area would initially be restored to dry grassland, which during the summer would be water-stressed for at least one month and in some years for up to 5 months.

A number of problems were identified, including some practical considerations that had to be addressed to take account of the likely development of the Great Fen in its early years:

1) Using altitude as the sole criterion for the occurrence of wet fen and grass would place most of those habitats north of Holme Fen. Some attempt was therefore made to subdivide the Core Area into three unequal blocks bounded by the high level drains, and to allocate the fen-pond and wet grassland *pro rata* within these blocks.

2) A concern is that the recreated wetlands in the North and South appear divided by a zone that is largely dry grassland. Targeted action may be required to ensure connectivity of wetland habitat between the two National Nature Reserves.

3) Some of the larger drains might possibly be large enough to provide useful open-water habitat, but within the micro-topographic variation present in the Core Area, in all probability reeds would be able to invade virtually all the mapped fen-pond areas in time. Maintenance of open areas of water might require management of the reeds, or some limited reshaping of the land, including the digging of some deeper pools. A schematic outline of how such fen-pond storage areas might be designed and engineered is given in Figure 5.5.

4) The fen / wet grass / dry grass mosaic is quite fine, posing potential problems in irrigating the precise areas required. Such a problem might necessitate either simplifying the mosaic or engaging in earth-moving.

In conclusion examination of the map (Figure 5.1) shows the following broad patterns:

- Open water would be most extensive in the area to the north-east of Holme Fen NNR, occupying part of the former Whittlesey Mere. A further important area of water would occur immediately adjacent to the northwest part of Woodwalton Fen NNR (south of Darlows Farm). Such new areas of water will almost certainly require isolation and control in the short term, before restored wetland becomes extensive.
- Reed and fen habitats would occupy large parts of the northern Core Area by open water, and would also be important in the area between Woodwalton Fen and the New Dyke.
- Wet grassland would be present north-west of Old Decoy Farm, and also extensive around the margins of the reed and fen zone in the southern part of the Core Area.
- The most important areas of dry grassland (marked as grey on the scenario maps) would be a) in the north-east part of the former Whittlesey Mere, b) in the central part of the

Area between Halfway Farm and Top Farm and c) in the somewhat elevated area south from Middle farm, Woodwalton (referred to in section 5.1.2).

5.3.2 *Further scenarios*

Discussion with the Steering Group identified other potential scenarios that ought to be addressed. It was agreed that an assessment of the potential habitat distribution be made under the following conditions:

1) Summer abstractions not to exceed the average of what is presently taken (*i.e.* allowing for no input via runoff from the uplands) or additional diversion from Stanground).
2) As 1) but with the further limitation that there also be no winter diversion into storage (*i.e.* into the reed beds)

The calculations and discussion presented in section 4.3 goes some way to addressing these further scenarios. However, as mentioned above (section 5.2.2), mapping of these further scenarios requires that the Steering Group arrive at a joint judgement as to the following questions:

- How reliable as open water areas do the Steering Group require the fen-ponds to be *i.e.* what is the minimum acceptable depth of water that the stakeholders can tolerate?
- Is it likely that no upland runoff can contribute to the Core Area's water-budget in winter?

Taken together, these two factors have a large impact on the way that the scenarios would develop and be depicted in summary maps. Hence, following deliberation of the Steering Group, maps of these further scenarios were provided as a supplement to the main report (bound into the present document as Appendix 4).

Figure 5.1: *The Great Fen: distribution of broad habitats*

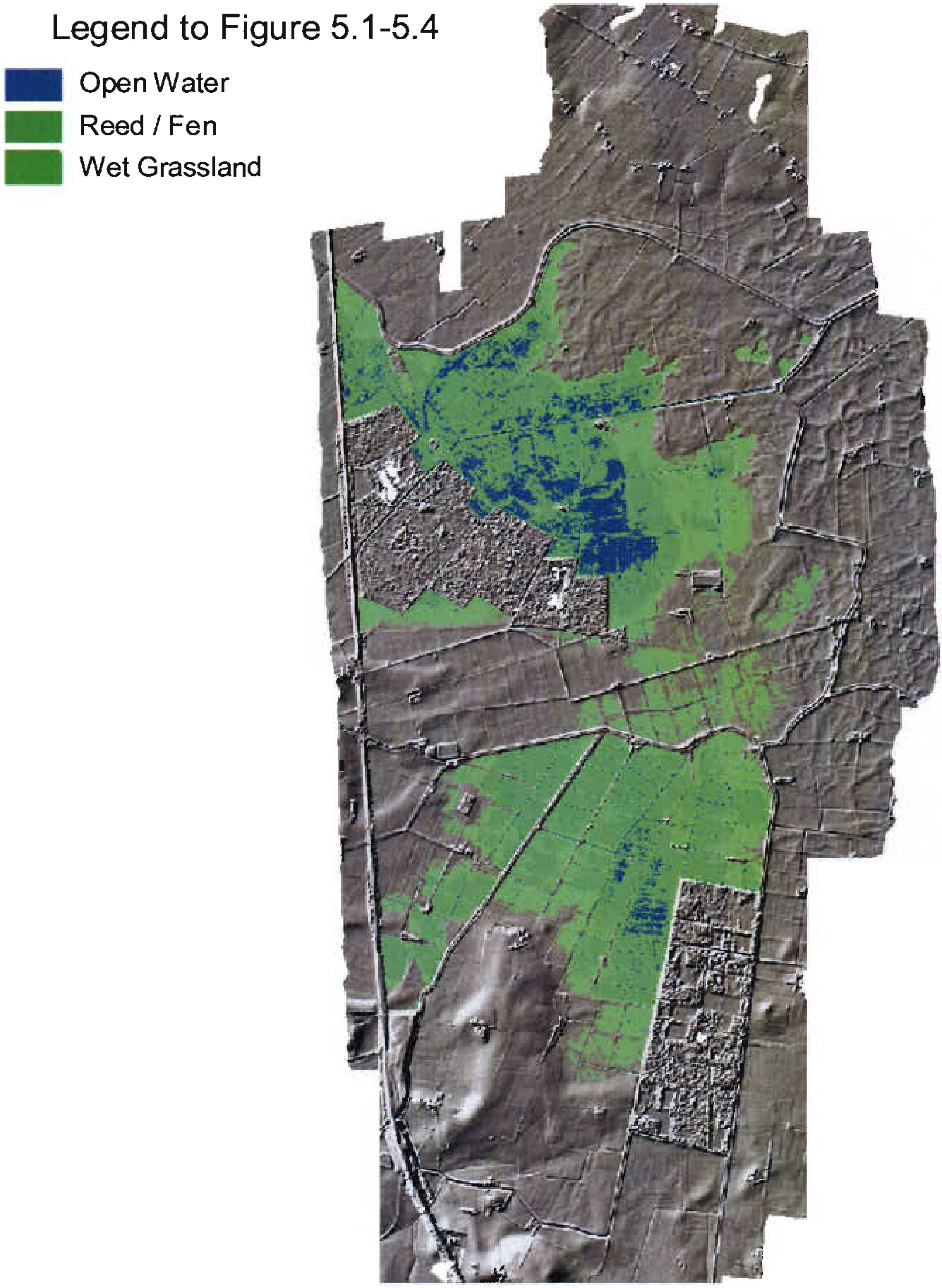


Figure 5.2: *The Great Fen (north section): Broad Habitats – including Holme Fen NNR*

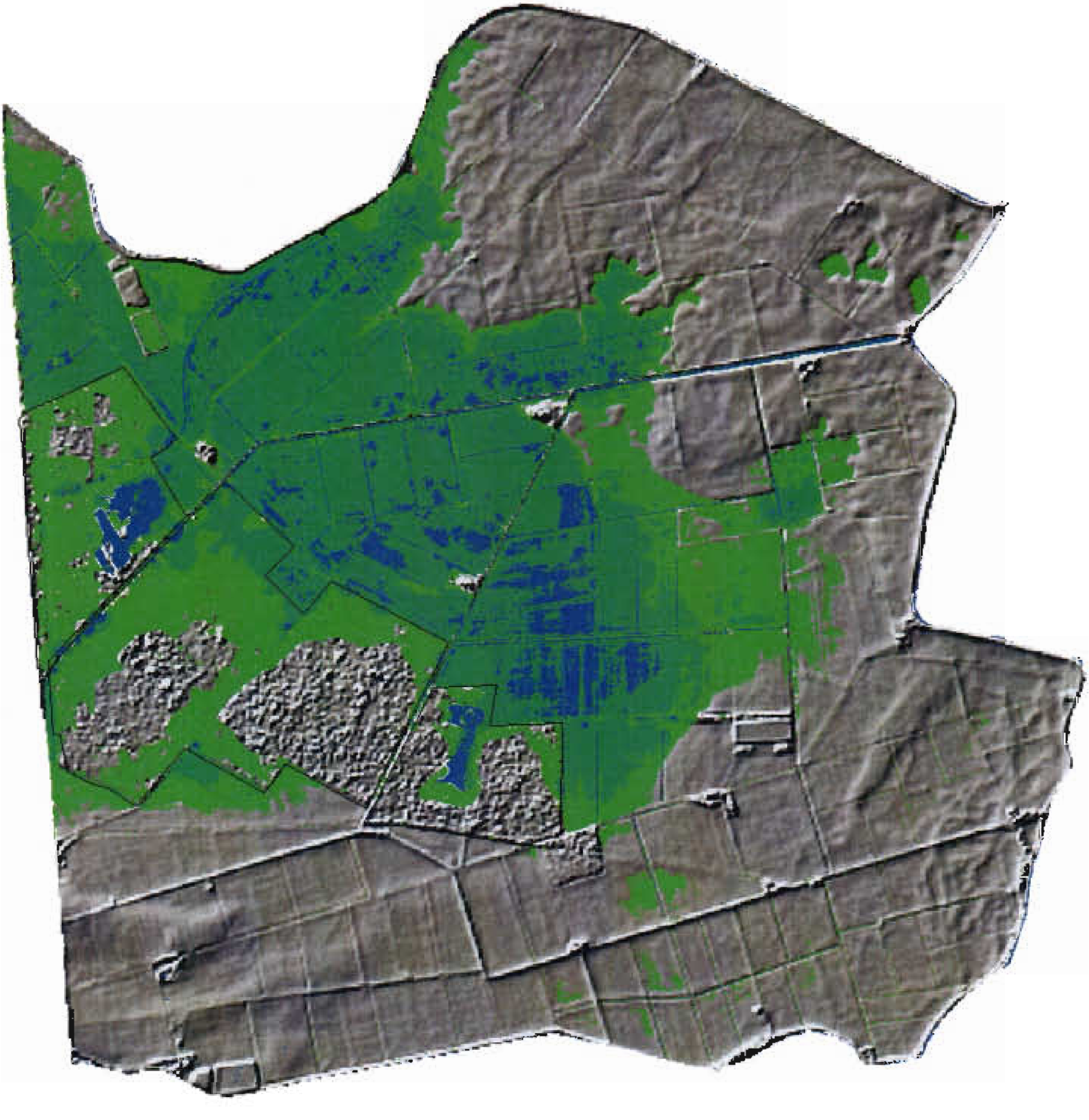


Figure 5.3: *The Great Fen (west section): Broad Habitats*

Figure 5.4: *The Great Fen (south section): Broad Habitats – including Woodwalton Fen NNR*

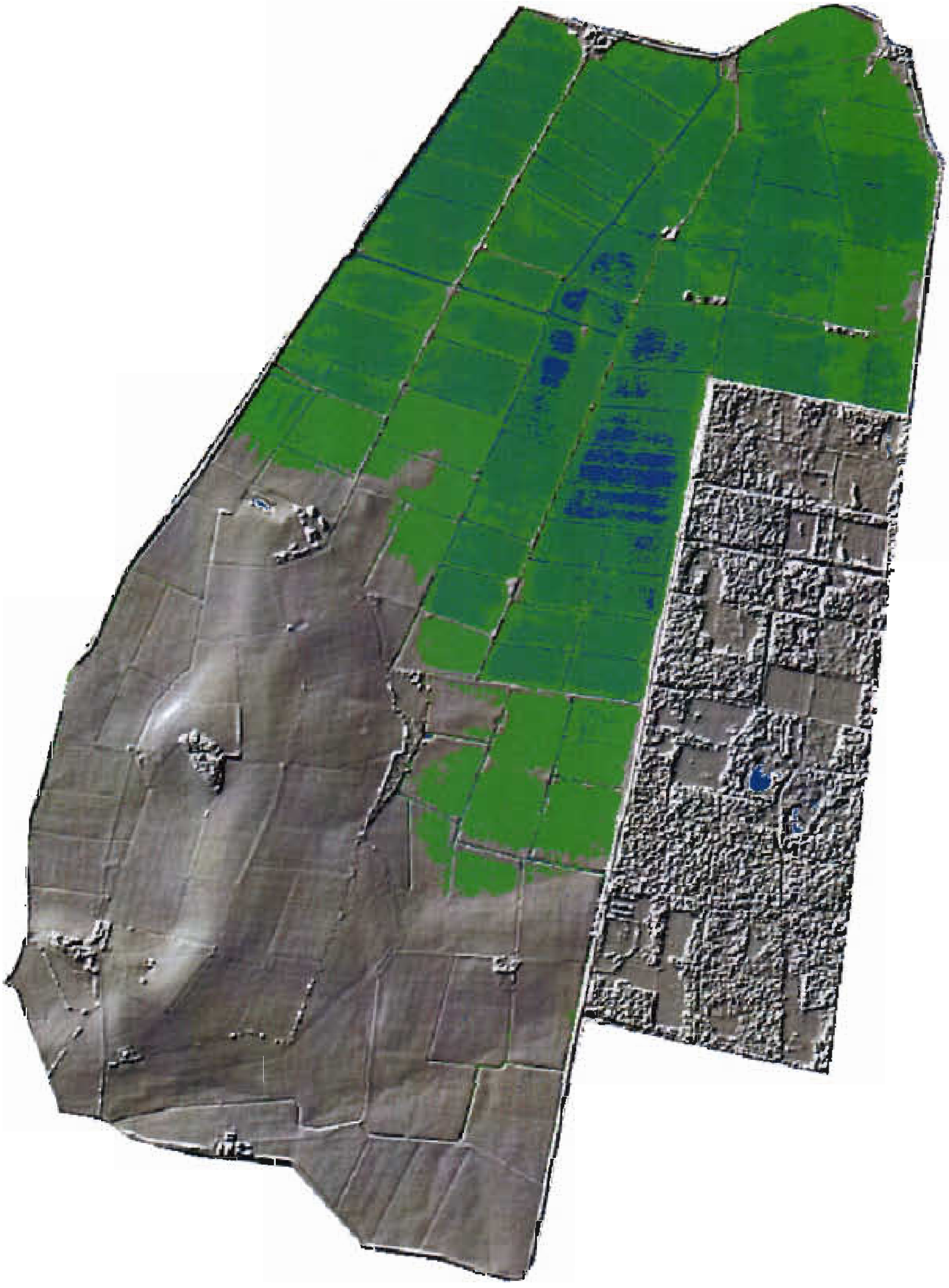
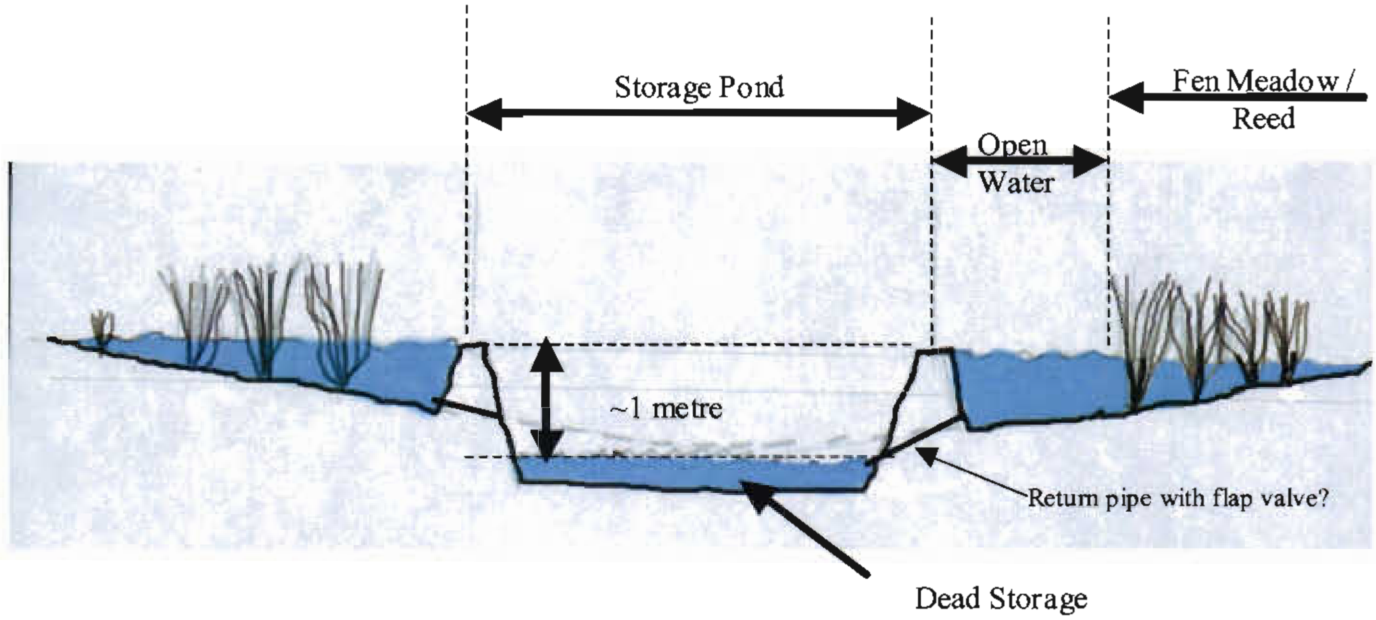


Figure 5.5: *Schematic Representation of an Option for Water Storage*



6 CONCLUSIONS and the NEED for FUTURE RESEARCH

6.1 **Overcoming hydrological constraints**

6.1.1 *The need for water storage*

If there is no water storage within the proposed Great Fen scheme, the area of wetland habitat that could be restored is limited, by availability of water in the summer months, to approximately 10km^2 of the Core Area. To ensure adequate water for wetlands over the whole of the Core Area it is necessary to store water for use in the summer. To maximise management options in the area, it is recommended that consideration be given to storing approximately 3 Mm^3 for summer use. Assuming the Core area could accept this water, in many years this might be obtained by discharging less from Bevill's Leam pumping station. In some years (approximately 1 in 5), it would be necessary to supplement this with water diverted from the Nene at Stanground during the winter months, though there are potential management conflicts with the use of the same system for winter flood flows.

6.1.2 *Effects of climate change*

Climate change will affect the wetland habitats that it is proposed are restored in the Core Area. It is possible that climate change will cause winters to be wetter and summers drier than at present. Data from only one climate change scenario has been presented in the current study. However, this indicates that there may be major consequences for the water resources of the area that could severely constrain the area of wetland habitat that can be maintained. It is recommended that a detailed study of the possible consequences of climate change is conducted.

6.2 **Ecological considerations and priorities for restoration**

Use of the best available data and a rigorous modelling approach strongly suggests that restoration of fenland habitats is a practical proposition for a large the Great Fen Core Area. These wetland habitats could be supplemented with equally valuable dry grassland communities, and other habitats with a highly restricted distribution in the arable Fenland. Given the apparent availability of water, the micro-topographic variation within the Core Area and the eco-hydrological requirements of the Broad Habitats, the following projected areas appear achievable for the Great Fen Project Area (comparison made with national and Cambridgeshire BAP targets - see Appendix Tables A2.5-A2.8):

I. Without additional engineered storage - 10km^2 of wetland habitat (including the two existing NNRs) can be maintained and restored within the Core Area *i.e.*:

- Open Water, reed-swamp and fen complex: 1.7km^2.
  - a) National target for reedbed re-creation is 12km^2, and Cambridgeshire target is 4km^2 by 2010.
  - b) National target for fen are not quantified, whilst Cambridgeshire target speaks of one large wetland (with fen) of 0.2km^2 to be re-created by 2010.
  - c) National and Cambridgeshire targets for open water habitats are qualitative rather than specifying a specific area to be restored.
- Lowland Wet Grassland: 3.4 km^2.
  - a) National target for "coastal and floodplain grazing marsh" is 2.5km^2 of re-created habitat, whilst the Cambridgeshire target is 0.4km^2 by 2010.
  - b) National re-creation target for Neutral Grassland is 5km^2 of lowland meadow by 2010, and for Cambridgeshire 0.5km^2 by the same date.

- Dry Grassland (and other habitats of more freely drained soils): 27.7km^2. BAP targets for lowland meadow are covered under Lowland Wet Grassland.
- Existing National Nature Reserves: >4.9km^2

II. With approximately 3Mm^3 storage for summer use, 17km^2 of extra wetland habitat can be restored within the Core Area *i.e.*:

- Open Water, reed-swamp and fen complex: 7.2 km^2
- Lowland Wet Grassland: 9.8 km^2
- Dry Grassland (and other habitats of more freely drained soils): 15.6 km^2
- Existing National Nature Reserves: >4.9km^2

With the reduced amount of 1Mm^3 storage for summer use (see section 4.2.2), 12km^2 of wetland habitat could be restored, the remainder of the Core Area being dry grassland *etc*. Other BAP targets to which the Great Fen restoration can contribute include wet woodland (Appendix Table A2.4) and, allowing for the possibility of drier conditions within parts of the Core Area (see section 5.1.2), a wide range of calcicolous and calcifuge grasslands, as well as scrub.

Even within the more conservative (zero engineered storage) estimate, the Great Fen Project would meet the entire Cambridgeshire BAP target for fen re-creation, and potentially account for 75% of the local target for reedbeds (indeed 25% of the national target). It should be borne in mind that there is bound to be some confounding of area estimates and targets here, with the 3.3km2 of fen-pond including elements of open water, reedswamp and true fen. However, it is clear that the Core Area could make an extremely important contribution to BAP targets. In terms of lowland wet grassland, the correspondence between, on the one hand, grazing marsh and neutral grassland, and on the other, the re-created wet grassland is not exact. Nonetheless, the planned restoration in the Great Fen would much exceed the Cambridgeshire targets, and approach those at the national scale.

With some storage capacity for summer use, the Great Fen Project could be the most important single contributing scheme to the national wetland BAP targets. When the likely contribution of the Wicken 100 Year Vision (Friday and Colston 1999) and the RSPB's initiatives at Needingworth and Lakenheath are added to the calculation, it is certain that success in wetland restoration in the Fenland basin would meet and exceed the national goals set under the BAP procedure (UK Biodiversity Group 1995; 1998). Attempts to prioritise the habitats for restoration in the Core Area should take into account these other schemes, and assuming that reedbed is the chief objective of the RSPB schemes, then stress in the Great Fen should be made on fen proper and lowland wet grassland.

6.3 **The need for more data and future research**

1) The water-management conclusions were based on best available information in 2002. Before the project commences, there is urgent need for improved hydrological data in order to determine a more accurate Area water budget. In particular the following activities would reduce uncertainty in the budget components, improve understanding of the system and enable better management:
    i. Measurement of actual discharge from the Core Area (*i.e.* pumped and gravity drainage from Bevill's Leam pumping station) and gravity drainage from Lodes End Lock. This would require stage-discharge relationships to be derived for the pump and both sluices as well as details of when the pumps are operated and when gravity drainage occurs. Deriving stage discharge relationships would require some form of dilution gauging (*i.e.* using tracers to determine discharge through the pump and across the sluice). Data from an extant water-level recorder at Bevill's Leam pumping station should be supplemented by installing a new recorder at Lodes End Lock.
    ii. Measurement of runoff from the upland catchment. Water levels and flow should be monitored on the Catchwater Drain, New Dyke and Yaxley Lode (noting that there is an

extant recorder at Abbey Farm). The monitoring of flow in these ditches would be difficult but might be possible using small ultrasonic sensors (*i.e.* starflows). As a minimum, stage boards should be installed and water levels read daily.

iii. <u>Determination of the proportion of the inflow</u> from the Nene at Stanground that is diverted *via* the Pig Water to upstream of Bevill's Leam. This determination would also require use of an ultrasonic device.

iv. <u>Determination of the volumes of water pumped</u>, the times that pumps are utilised and the drainage areas that are controlled by the various IDBs within the area. This calculation would require a survey of the drains and location of sluice gates, diversions and abstraction points to be determined. The efficiency of the pumps in the area would have to be ascertained and logs would have to be kept of periods when they are operated.

v. <u>Determination of actual evapo-transpiration from wetland vegetation</u> (*e.g.* at Woodwalton Fen or Holme Fen). This value could be determined directly using specialised micro-meteorological instrumentation such as Bowen ratio equipment, or a solent anemometer (Acreman *et al.* 2000). These measurements would have to be obtained in conjunction with soil moisture and water table information in order to understand how evapo-transpiration is constrained by limited water supply. Soil moisture and the water-table could be determined using arrays of theta probes and dipwells.

vi. <u>Development of a detailed hydrological model of the Core Area</u> to simulate the hydrological fluxes within the region and the consequences of different management interventions. The model would be developed using data and understanding gained from the other activities. It would need to be configured to characterise hydrological fluxes, based on soil and vegetation characteristics and using the measured inputs of rainfall and actual evaporation. The model would be used to simulate the hydrological implications (*i.e.* in terms of the spatial and temporal pattern of flows, water table elevation and soil moisture content) of different management practices and changes in land-use practices.

Table 6.1 provides a preliminary estimate of the costs of conducting the recommended monitoring over a three-year period. Three years is the minimum time that data would need to be collected to obtain a reasonable estimate of the natural variation in hydrological fluxes.

Table 6.1: *Preliminary estimates of the costs of conducting a 3-year hydrological study of the Core Area and its environs*

Activity	Capital costs (£)	Staff-time* (£)	Total (£)
i) Determination of actual discharge from the Core Area	6,000	12,300	18,300
ii) Measurement of runoff from the upland catchment	7,500	18,500	26,000
iii) Determination of the volume of Nene water diverted along the Pig Water drain	2,500	4,100	6,600
iv) Determination of internal movement of water by the IDBs within the Core Area	1,500	14,300	15,800
v) Investigation of actual evapotranspiration from wetland vegetation at Woodwalton/Holme Fen	15,000	28,800	43,800
vi) Development of a detailed hydrological model of the Core Area	-	40,000	40,000
		TOTAL	172,200

* Over 3 years

2) Further research should be conducted to assess the sensitivity of the analyses conducted in the current study to climate change scenarios. Considerable uncertainty remains in relation to future changes in climate. An inter-comparison of the implications of the full range of present climate change scenarios should be conducted. It is recommended that the recently published UKCIP02 scenarios (which were unavailable to the current study) are used for this research. There is also a need to assess the likely impact of climate change on hydro-chemical functions and water quality within the area. Such a study would largely comprise modelling (cost *ca* £30,000).

3) A full costing of the various options, especially as they relate to major engineering, water-storage, and within-block (or -field) works is required. Attempts at drawing parallels from existing schemes are largely irrelevant. CEH recommends a fully costed scheme be drafted using the various feasibility projects (Cranfield 1999; Duncan 2002; the present report) to set the bounds, and addressing, *inter alia*, the questions identified in section 5.2.2.

4) One element of the latter that requires urgent provision is a good Digital Terrain Model (DTM) for the entire Core Area. This would enable further scenarios to be tested with greater confidence in their relevance, and would identify problems of scheme implementation before any heavy site engineering took place or irrevocable decisions were made.

5) Many of the gaps in ecological knowledge that would aid the success of the Great Fen Project are general rather than specific to the Core Area and this scheme. However, it was clear that detailed geographical information on species and community distribution in the Core Area was often patchy or sparse. The botanical material gathered for the *Atlas 2000* project and for T.C.E. Wells' Huntingdonshire Flora (*pers. comm.*) will go some way to meeting this need for vascular plants. However, the invertebrate distributional data is largely confined to a few key (*ISR*) sites, and does not give much help in providing an assessment of the current resource in the Core Area. In addition, the site-specific data held by the Wildlife Trusts for areas outside the NNRs is meagre and does not further illuminate the national mapped information given in Atlases. Previous Phase I and II survey has been attempted in Cambridgeshire, but it is clear that the picture they provide of the wildlife resource is still very limited, and requires supplementary effort to be of use in refining the recommendations in this report.

6) A continuing theme through all the ecological discussion in this report has been the absence of rigorous quantitative information on the water-regime and nutrient-regime requirements of individual species, communities and habitats. The work of Gowing *et al.* (2002) has gone a long way to meeting this need for lowland wet grasslands, but important gaps exist in other wetland habitats. A new project, sponsored by the Environment Agency in 2002, to provide Hydro-ecological Guidelines for wetland habitats will further marshal existing information, present it in a consistent and useful format, and identify where the most important gaps in knowledge are. The output of this project will help to create a prioritised menu for future research in wetland restoration. It is hoped that such broad and strategic research will contribute to the later success of the Great Fen Project, and related restoration schemes in Fenland.

7) To date, the Great Fen project has proceeded piecemeal, with individual questions dealt with in turn. The successful implementation of such an important land-use change, outstripping in scale anything in the English lowlands over the past 150 years, requires a substantial concerted approach, using eco-hydrological modelling at its core. A template for what is required can be seen in Figures A3.3 and A3.4. (Pieterse *et al.* 1998; Venterink *et al.* 1998), which indicate the materials that must be marshalled. Note that this Dutch example required three separate (admittedly related) eco-hydrological models (*Alnion*, *Smart/Move* and *Ecostream*), together with two contributing hydrological models (*Modflow* and *Streamflow*). This is the kind of strategy that

would go some way to assuring the success of the Great Fen - a project whose importance for British wetland biodiversity cannot be overestimated.

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9 GLOSSARY of (ECO-) HYDROLOGICAL TERMS

Actual Evapotranspiration: The actual evapotranspiration from a vegetated surface under conditions that deviate from standard conditions. Actual evapotranspiration deviates from ETc due to non optimal conditions such as the presence of pests and diseases, soil salinity, low soil fertility, water shortage or water logging.

Bowen ratio: The ratio of sensible heat to latent heat transfer at the ground surface. Determination of the ratio in the field through measurement of temperature and vapour pressure gradients enables actual evapotranspiration to be calculated.

Crop Coefficient (Kc): The ratio of evapotranspiration from vegetation under standard conditions (ETc) to potential evapotranspiration (ETo).

Evapotranspiration: The combination of two separate processes whereby water is "lost" from the soil surface by evaporation and from the vegetation by transpiration.

Open Water Evaporation: The rate of evaporation from an extensive body of open water.

Permanent Wilting Point: The soil moisture content at which the leaves of plants wilt permanently (*i.e.* do not recover their turgor if subsequently placed in a saturated atmosphere).

Potential Evapotranspiration or **Reference Evapotranspiration (ETo):** The rate of evapotranspiration from an extensive surface of 8-15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water.

Vegetation evapotranspiration under standard conditions (ETc): The evapotranspiration from disease-free, well fertilised vegetation grown over a large area, under optimum soil water conditions and achieving full production under the given climatic conditions.

Vegetation Water Requirements: The volume of water needed to meet the water "loss" through evapotranspiration.

APPENDICES

A1 **Appendix 1** Broad Habitats and the *NVC*[5]

In the UK Biodiversity Action Plan 37 *Broad Habitat* categories were defined (UK Biodiversity Steering Group, 1995). Later, the number of terrestrial and freshwater *Broad Habitats* was reduced to 17 (UK Biodiversity Group, 1998), with ten coastal and marine *Broad Habitats* added shortly afterwards. Out of these 27 *Broad Habitats*, only 10 occur with the peatlands of the Fens Natural Area, and these are the only ones whose definition is considered below. The definitions have been shortened to exclude information that is irrelevant to the Fen Natural Area, such as the inclusion of juniper scrub in **BH1**. Those *Broad Habitats* that are central to the aims of the Great Fen Project are indicated *, other habitats may be considered peripheral or "accidental".

Broad Habitats are intended to be comprehensive and exclusive. Although their definitions are often obvious, there was a need for more precise circumscription to define the boundaries between them and guidance is now available for terrestrial and freshwater habitats which also relates *Broad Habitats* to *NVC* units (Jackson 2000). The CEH interpretation follows Jackson (2000) except in a small number of cases, generally due to the scale at which it seemed desirable to view the vegetation. For example, bog pools are treated strictly as bog features , and not within open water. Details of the full cross-referencing between *NVC* units and *Broad Habitats* are available in a spreadsheet, a summary of which is appended here for Fenland Habitats (Table A1.1). In the interests of simplicity, Hill (see footnote) allocated no NVC type to more than two *Broad Habitats,* which (though artificial) clearly indicates the main corresponding types.

Definitions of terrestrial & freshwater biodiversity Broad Habitat types (After Jackson 2000; & Hill 2002)

***BH1: Broadleaved, mixed and yew woodland (and scrub)**. Characteristically dominated by trees that >5m high when mature, forming a distinct (although sometimes open) canopy whose cover is > 20%. Includes stands of both native and non-native broadleaved trees (and yew), where the percentage cover of such trees is >20% of the total tree cover. Stands may be either ancient or recent woodland and either semi-natural arising from natural regeneration of trees, or planted. Recently felled stands are included where there is a clear indication that it will return to woodland.
<u>Scrub</u> vegetation (woody component of shrubs <5m high) and <u>carr</u> (woody vegetation on mire margins) is included if the woody species form a canopy cover of >30% and the patch size is >0.25ha. Stands of *Myrica gale* are included if they are >1.5m tall. Other scrub types are treated as edge features (**BH3**), because hedges are often where they occur. The underscrub community **W24** is treated as partly a neutral grassland (**BH6**). ***Only <u>wet</u> woodland is central to the Great Fen project.***

BH3: Boundary and linear features. Covers hedgerows, lines of trees, walls, stone and earth banks, grass strips and dry ditches, occurring separately or in combinations forming multi-element boundaries. Also includes some of the built components of the <u>rural</u> landscape (roads, tracks, railways and their associated narrow verges of semi-natural habitat), but not where such features occur in urban areas (**BH17**). Canals/ditches that are water-filled for the majority of the year are placed in **BH13**, and rivers and streams in **BH14**, whereas broadleaved woodland rides (and fire breaks) are included in **BH1**. Cereal field margins managed for nature conservation are included in **BH4**. Apart from scrub forming hedges, these features cannot be directly cross-referenced to the *NVC*.

BH4: Arable and horticultural. Covers arable cropland (including perennial, woody crops, and intensively managed, commercial orchards), <u>commercial</u> horticultural land (*e.g.* nurseries, and both commercial vegetable plots and flower growing areas), freshly-ploughed land, annual leys, rotational set-aside and fallow. **BH4** includes cereal field margins but <u>not</u> field boundaries (placed in **BH3**). Note that this type does <u>not</u> include domestic gardens and allotments, which are included in **BH17**.

BH5: Improved grassland. Vegetation dominated by a few fast-growing grasses on fertile, neutral soils, often with an abundance of *Lolium* spp. and *Trifolium repens*. Typically managed as pasture or mown regularly for silage or for amenity purposes. They are often periodically resown and are maintained by fertiliser treatment and weed control. Often temporary and sown as part of the arable rotation and included in **BH5** <u>only</u> if they are >1 year old (otherwise **BH4**). Has few characteristic species, and in addition to **MG7**, also includes *Poa annua-Myosotis arvensis* community **OV12**.

[5] Précised from a text prepared for the analysis of Atlas 2000 data by M.O. Hill (CEH Monks Wood) *Feb. 2002*

***BH6: Neutral grassland**. Characterised by vegetation dominated by grasses and herbs on neutral soils (pH 4.5-6.5), including enclosed dry hay meadows and pastures, together several grassland types that are periodically flooded or permanently moist. Often referred to as mesotrophic grasslands. Plant species assemblages have rather few diagnostic indicator species but lack the strong calcicoles or calcifuges characteristic of base-rich and acid soils respectively. The *NVC* describes 10 types of unimproved and semi-improved neutral grassland that might occur in the Great Fen area (Rodwell 1992): **MG1, MG4-6**, and **MG8-13**. Unimproved or species-rich neutral grasslands are usually managed traditionally as hay-meadows and pastures. Semi-improved neutral grasslands are also included and are usually managed for pasture or for silage/hay. **BH6** differ from **BH5** grasslands by having a less lush sward, a greater range and higher cover of herbs, and usually < 25% cover of *Lolium perenne*. Coastal grazing marsh is also included here (plus 4 *NVC* coastal grasslands (**MC9-12**) that are not necessarily rocky).

***BH11: Fen, marsh and swamp**. A very wide category including reedbeds, swamps, tall-herb fens, flushes, springs, marshes, rush-pastures and wet grassland. Characteristically found on groundwater-fed, permanently, seasonally or periodically waterlogged peat, peaty soils, or mineral soils. Fens are peatlands that receive water and nutrients from groundwater and surface run-off, as well as from rainfall. Flushes are associated with lateral water movement, and springs with localised upwelling of water. Marsh is a general term usually used to imply waterlogged soil; it is used more specifically here to refer to fen meadows and rush-pasture communities on mineral soils and shallow peats. Swamps are characterised by tall emergent vegetation. **BH11** does not include neutral and improved grasslands on floodplains and grazing marshes (included in either **BH6** or **BH5**), nor ombrotrophic mires (blanket, raised and intermediate bogs) which are placed in **BH12**. Also excluded are carrs (fen woodland dominated by *Salix* spp., *Alnus glutinosa* or *Betula* spp.) as these are placed in **BH1**- unless cover is <30%. Mud communities of dried-up ponds and riverbeds (*e.g.* **OV30**) have been included, although they belong strictly to **BH13/14** unless extensive (>0.25 ha).

***BH12: Bog**. Defined strictly only as ombrotrophic (rain-fed) bogs, though (to avoid undue heterogeneity in **BH11**) CEH has put all *Erico-Sphagnion* vegetation (including **M21**), in **BH12** even where it occurs in valley mires. This broad habitat type covers wetlands that support peat-forming vegetation and which receive mineral nutrients principally from precipitation. Two major types are identified: raised and blanket bog. Unless modified by surface drying, aeration or heavy grazing, vegetation is dominated by acidophilous species *e.g. Sphagnum* spp., *Eriophorum* spp. and *Erica tetralix*. The water-table is usually at or just below the surface. **BH12** also includes modified bog vegetation (resembling wet or dry dwarf shrub heath) but occurs on deep acid peat that would have once supported peat-forming vegetation. Also included are modified bogs dominated by *Molinia* or *Eriophorum vaginatum*.

***BH13 Standing water and canals**. Includes natural systems such as lakes, meres and pools, as well as reservoirs, canals, ponds and gravel pits. It includes the open water zone (which may contain submerged, free-floating or floating-leaved vegetation) and emergent water fringe vegetation. Drainage channels (ditches *etc*) with open water for at least the majority of the year are also included. Standing waters are usually classified according to their nutrient status and this can change naturally over time or as a result of pollution. The three main types are: oligotrophic (nutrient-poor), eutrophic (nutrient-rich), and mesotrophic (intermediate). Open water transition swamps are placed in **BH11** if the zone is >5m wide, or the area >0.25 ha. Mud communities are also referred to **BH11**.

***BH14: Rivers and streams**. Treated in much the same way as **BH13**, this broad habitat covers rivers and streams from bank top to bank top (or the extent of the mean annual flood). Includes the open channel, water fringe vegetation (with the same proviso as for **BH13**) and exposed sediments and shingle banks. Adjacent semi-natural wetland habitats, even if intimately linked with the river, are covered elsewhere.

BH17: Built-up areas and gardens. Covers urban and rural settlements, farm buildings, caravan parks and other man-made built structures such as industrial estates, retail parks, waste and derelict ground, urban parkland and urban transport infrastructure. It also includes domestic gardens and allotments. Does not include amenity grassland (included in **BH5**). Most of the characteristic species are neophytes, while the commonest species are widespread natives and archaeophytes. Few *NVC* communities are really typical of the built environment.

Appendix Table A1.1 Correspondence between subdivided *Broad Habitats* and *NVC* communities (for explanation - see TEXT)

BROAD HABITAT No.	1d	1e	3	4(i)	4(ii)	4(iii)	5	6a	6c	6e	11a	11b	11c	11d	11e	12(ii)	12(iii)	13	14	17
COMMUNITY NAME (NVC)	Broadleaved wood (Wet)	Lowland oak & ash	3-Linear and boundary featur	Arable & horticulture (arable)	Arable & Hort (Horticulture)	Aravle & Hort (Farm ruderal)	5 - Improved grassland	Neutral grass (Lowland mea	Neutral grass (Inundation)	Other neutral grass	Fen *etc* (Reedbed)	Fen *etc* (Swamp and tall her	Fen *etc* (Flush and spring)	Fen *etc* (Marsh, rush, wet gr	Fen *etc* (Mud & bare wet)	Bog (Blanket bog)	Lowland bog (Erico sphagnio	13-Standing water and canals	14-Rivers and streams	17-Built-up areas and garde
Lemna gibba community (A1)																		1		
Lemna minor community (A2)																		1		
Spirodela polyrhiza-Hydrocharis morsus-ranae (A3)																		1		
Hydrocharis morsus-ranae-Stratiotes aloides (A4)																		1		
Ceratophyllum demersum community (A5)																		1		
Ceratophyllum submersum community (A6)																		1		
Nymphaea alba community (A7)																		1		
Nuphar lutea community (A8)																		0.5	0.5	
Potamogeton natans community (A9)																		0.5	0.5	
Polygonum amphibium community (A10)																		1		
Potamogeton pectinatus-Myriophyllum spicatum community (A11)																		0.5	0.5	
Potamogeton pectinatus community (A12)																		0.5	0.5	
Potamogeton perfoliatus-Myriophyllum alterniflorum community (A13)																		0.5	0.5	
Myriophyllum alterniflorum community (A14)																		0.5	0.5	
Elodea canadensis community (A15)																		0.5	0.5	
Callitriche stagnalis community (A16)																		0.5	0.5	
Ranunculus aquatilis community (A!9)																		0.5	0.5	
Ranunculus peltatus community (A20)																		0.5	0.5	
Ranunculus baudotii community (A21)																		1		

Appendix Table A1.1 (continued)

BROAD HABITAT No.	1d	1e	3	4(i)	4(ii)	4(iii)	5	6a	6c	6e	11a	11b	11c	11d	11e	12(ii)	12(iii)	13	14	17
Juncus bulbosus community (A24)																		1		
Schoenus nigricans-Juncus subnodulosus (M13)													1							
Schoenus nigricans-Narthecium mire (M14)													1							
Erica tetralix-Sphagnum compactum wet heath (M16)																				
Narthecium-Sphagnum papillosum valley mire (M21)																	1			
J. subnodulosus-Cirsium palustre fen-meadow (M22)														1						
Juncus-Galium palustre rush-pasture (M23)														1						
Molinia-Cirsium dissectum fen-meadow (M24)														1						
Molinia caerulea-Potentilla erecta mire (M25)														0.5		0.5				
Filipendula ulmaria-Angelica tall-herb fen (M27)												1								
Carex elata swamp (S1)												1								
Cladium mariscus swamp (S2)												1								
Carex paniculata swamp (S3)												1								
Phragmites australis reedbed (S4)											1									
Glyceria maxima swamp (S5)												1								
Carex riparia swamp (S6)												1								
Carex acutiformis swamp (S7)												1								
Scirpus lacustris swamp (S8)												1								
Equisetum fluviatile swamp (S10)												1								
Carex vesicaria swamps (S11)												1								
Typha latifolia reedbed (S12)												1								
Typha angustifolia reedbed (S13)												1								
Sparganium erectum swamp (S14)												1								
Acorus calamus swamp (S15)												1								
Sagittaria sagittifolia swamp (S16)												1								
Carex pseudocyperus swamp (S17)												1								
Carex otrubae swamp (S18)												1								
Eleocharis palustris swamp (S19)												1								
Scirpus lacustris ssp. tabernaemontani swamp (S20)												0.5								
Scirpus maritimus swamp (S21)																				

Appendix Table 1.1 (continued)

BROAD HABITAT No.	1d	1e	3	4(i)	4(ii)	4(iii)	5	6a	6c	6e	11a	11b	11c	11d	11e	12(ii)	12(iii)	13	14	17
Glyceria fluitans swamp (S22)												1								
Other Glycerio-Sparganion (S23)												1								
Peucedanum palustris-Phramites australis fen (S24)												1								
Phragmites-Eupatorium cannabinum fen (S25)												1								
Phragmites australis-Urtica dioica fen (S26)												1								
Potentilla palustris-Carex rostrata fen (S27)												1								
Phalaris arundinacea fen (S28)												1								
Salix cinerea-Galium palustre woodland (W1)	1																			
Salix cinerea-Betula pub.-Phragmites woodland (W2)	1																			
Betula pubescens-Molinia caerulea woodland (W4)	1																			
Alnus glutinosa-Carex paniculata woodland (W5)	1																			
Alnus glutinosa-Urtica dioica woodland (W6)	1																			
Fraxinus-Acer campestre-Mercurialis woodland (W8)		1																		
Crataegus monogyna-Hedera helix scrub (W21)			1																	
Prunus spinosa-Rubus fruticosus scrub (W22)			1																	
Ulex europaeus-Rubus fruticosus scrub (W23)			1																	
Rubus fruticosus-Holcus lanatus underscrub (W24)			0.5							0.5										
Pteridium-Rubus fruticosus underscrub (W25)																				
Arrhenatherum elatius coarse grassland (MG1)										1										
Alopecurus pratensis-Sanguisorba meadow (MG4)								1												
Cynosurus cristatus-Centaurea nigra grassland (MG5)								1												
Lolium perenne-Cynosurus cristatus pasture (MG6)							0.5			0.5										
Lolium perenne improved grassland (MG7)							1													
Cynosurus cristatus-Caltha flood-pasture (MG8)									1											
Holcus lanatus-Desch. cespitosa grassland (MG9)										1										
Holcus lanatus-Juncus effusus rush-pasture (MG10)										1										
Festuca rubra-Agrostis stolonifera-Potentilla anserina inundation grassland (MG11)									1											
Festuca arundinacea coarse grassland (MG12)										1										
Agrostis stolonifera-Alopecurus geniculatus (MG13)									1											

Appendix Table A1.1 (continued)

BROAD HABITAT No.	1d	1e	3	4(i)	4(ii)	4(iii)	5	6a	6c	6e	11a	11b	11c	11d	11e	12(ii)	12(iii)	13	14	17
Papaver rhoeas-Viola arvensis community (OV3)				1																
Chrysanthemum segetum-Spergula arvensis (OV4)				1																
Veronica persica-Veronica polita community (OV7)				1																
Veronica persica-Alopecurus myosuroides (OV8)				1																
Matricaria perforata-Stellaria media community (OV9)				0.5		0.5														
Poa annua-Senecio vulgaris community (OV10)				0.5		0.5														
Poa annua-Stachys arvensis community (OV11)				1																
Poa annua-Myosotis arvensis community (OV12)							1													
Stellaria media-Capsella bursa-pastoris (OV13)				1																
Urtica urens-Lamium amplexicaule (OV14)				0.5	0.5															
Anagallis arvensis-Veronica persica (OV15)				1																
Papaver rhoeas-Silene noctiflora community (OV16)				1																
Reseda lutea-Polygonum aviculare community (OV17)				1																
Polygonum aviculare-Chamomila suaveolens (OV18)			0.5			0.5														
Poa annua-Matricaria maritima community (OV19)			0.5			0.5														
Poa annua-Sagina procumbens community OV20)																				1
Poa annua-Plantago major community (OV21)			0.5			0.5														
Poa annua-Taraxacum officinale community (OV22)			0.5			0.5														
Lolium perenne-Dactylis glomerata community (OV23)							0.5													0.5
Urtica dioica-Galium aparine community (OV24)			0.5																	0.5
Urtica dioica-Cirsium arvense community (OV25)			0.5				0.5													
Epilobium hirsutum community (OV26)												1								
Epilobium angustifolium community (OV27)			1																	
Agrostis stolonifera-Ranunculus repens (OV28)									0.5						0.5					
Alopecurus geniculatus-Rorippa palustris (OV29)															1					
Bidens tripartita-Polygonum amphibium (OV30)															1					
Rorippa palustris-Filaginella uliginosa (OV31)															1					
Myosotis scorpioides-Ranun. sceleratus (OV32)															1					
Polygonum persicaria-P. lapathifolium (OV33)															1					

Figure A1.1 *Species co-occurrence map: Biodiversity Broad Habitat – Broadleaved woodland*

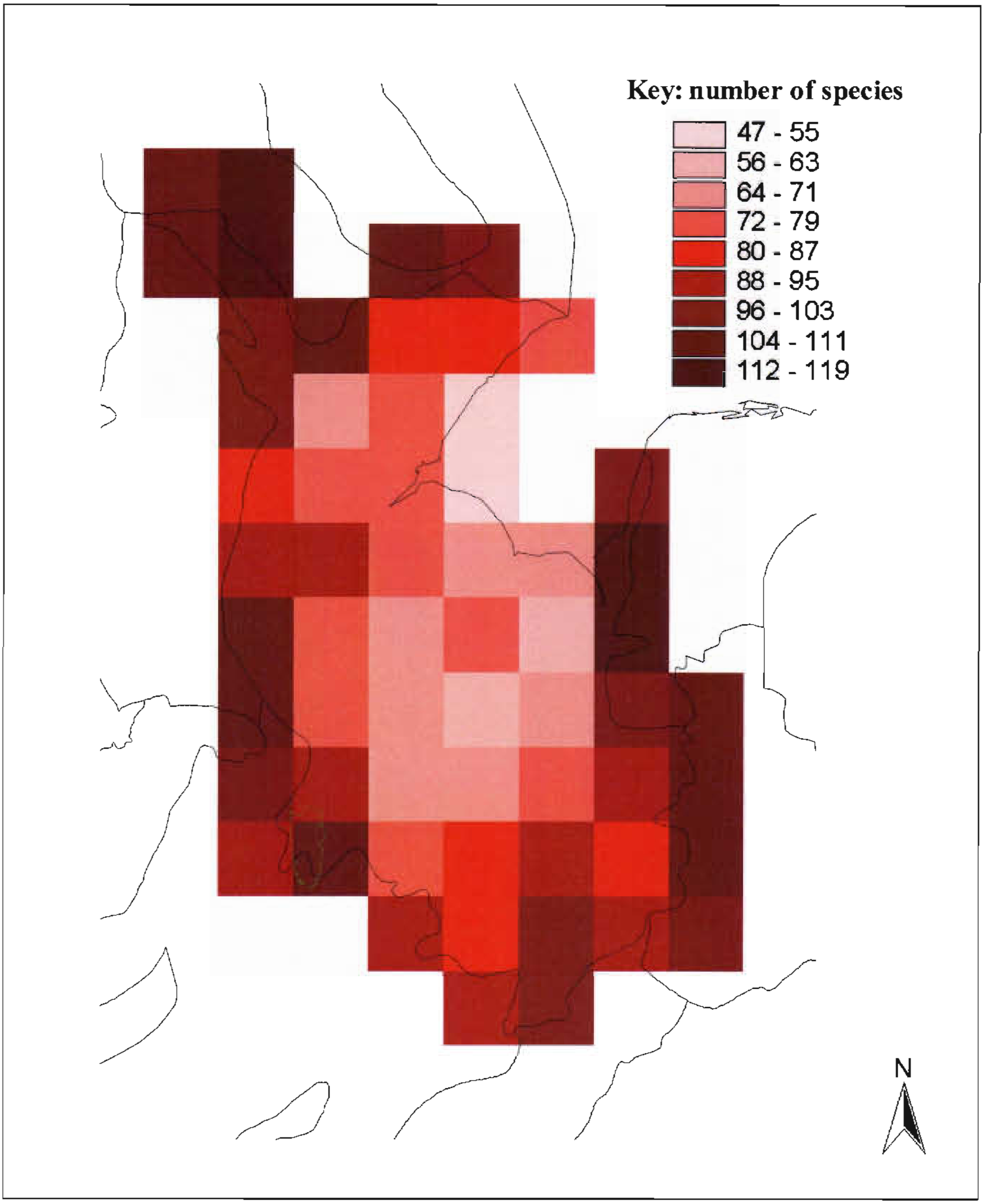


Figure A1.2 *Species co-occurrence map: Biodiversity Broad Habitat – Fen, marsh, swamp*

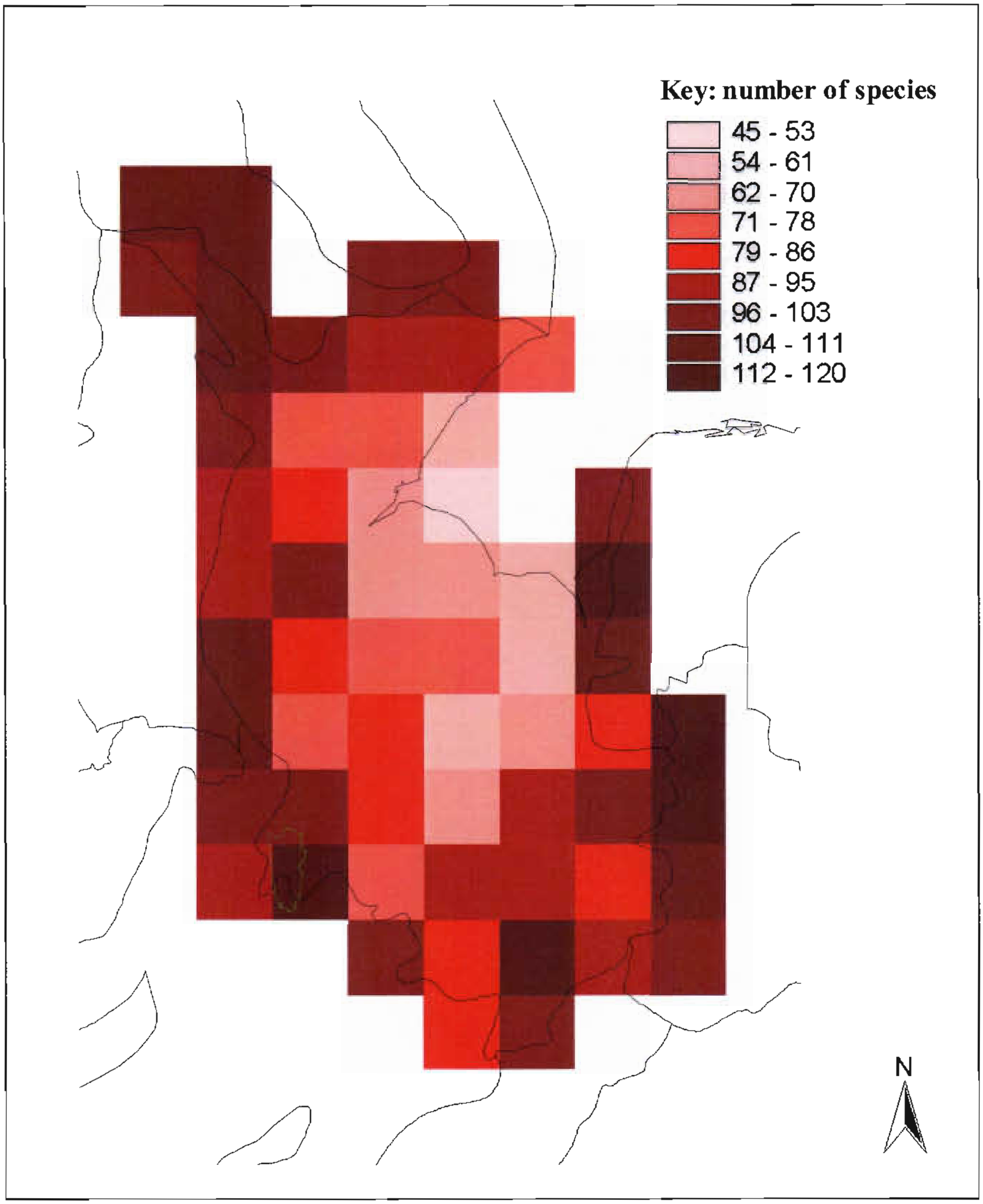


Figure A1.3 *Species co-occurrence map: Fen, marsh and swamp – constancy IV and V species*

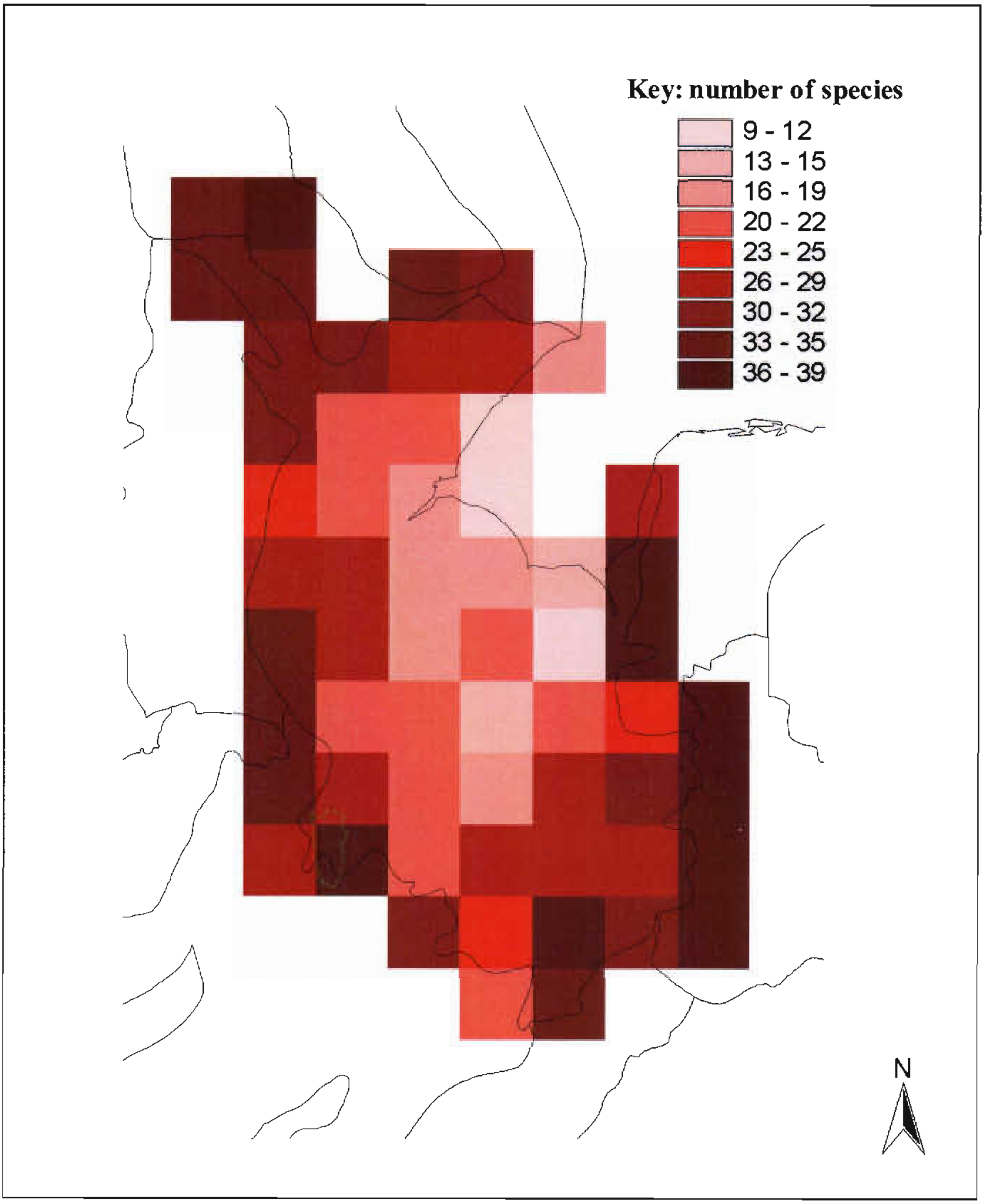


Figure A1.4 *Species co-occurrence map: National Vegetation Classification Community – **S24***

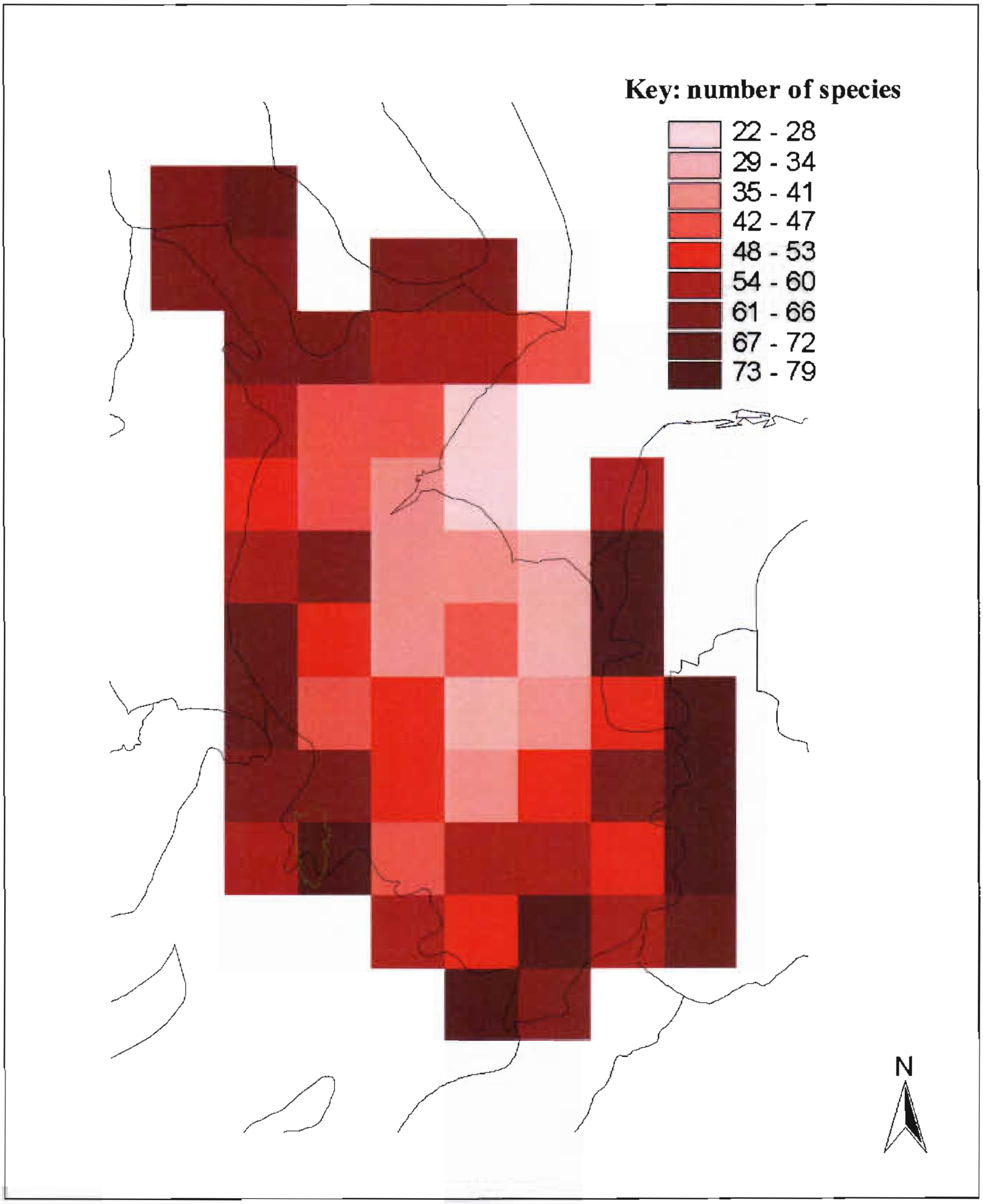


Figure A1.5 *Species co-occurrence map: National Vegetation Classification Community – **M24a***

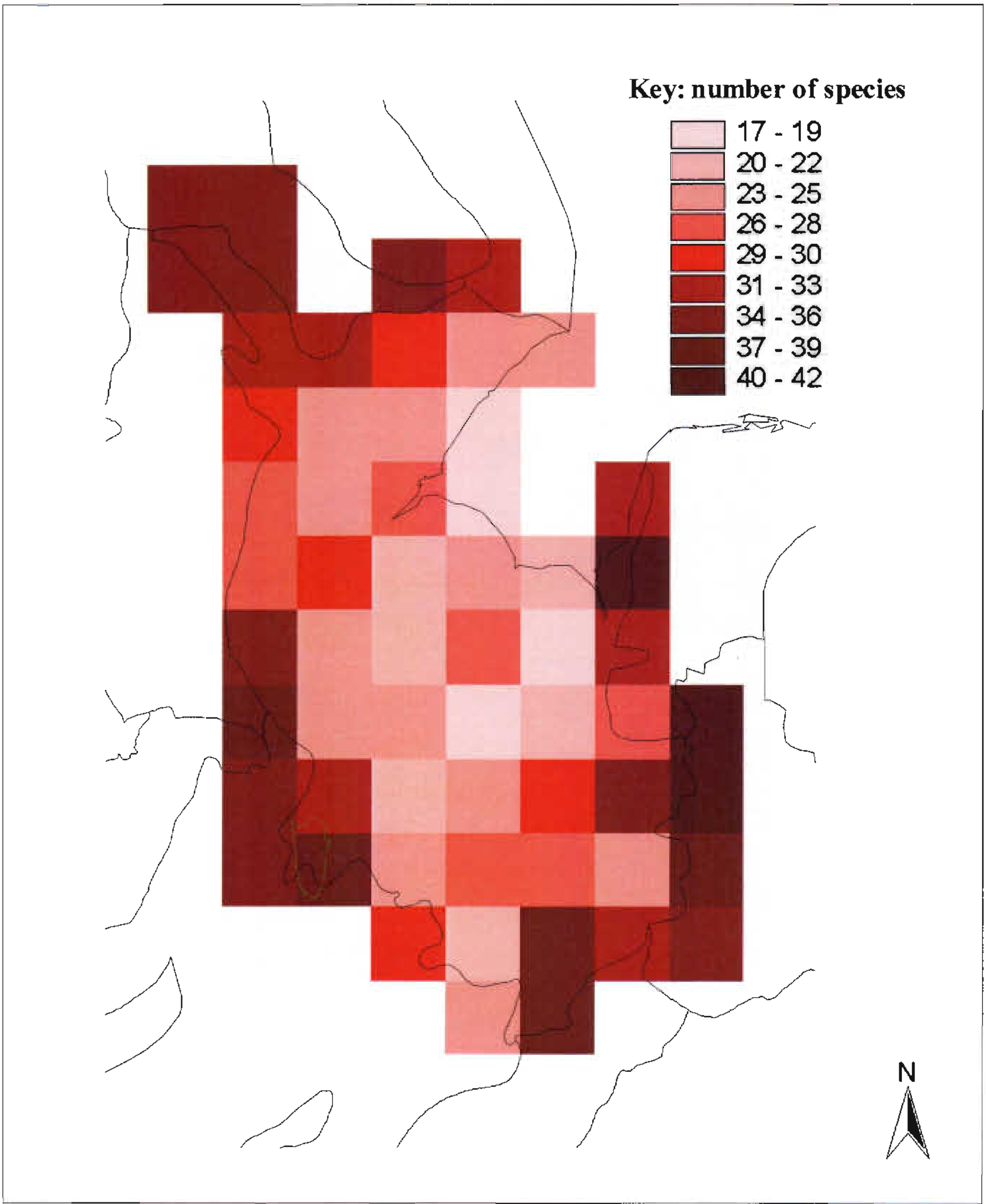


Figure A1.6 *Species co-occurrence map: Biodiversity Broad Habitat – Rivers and Streams*

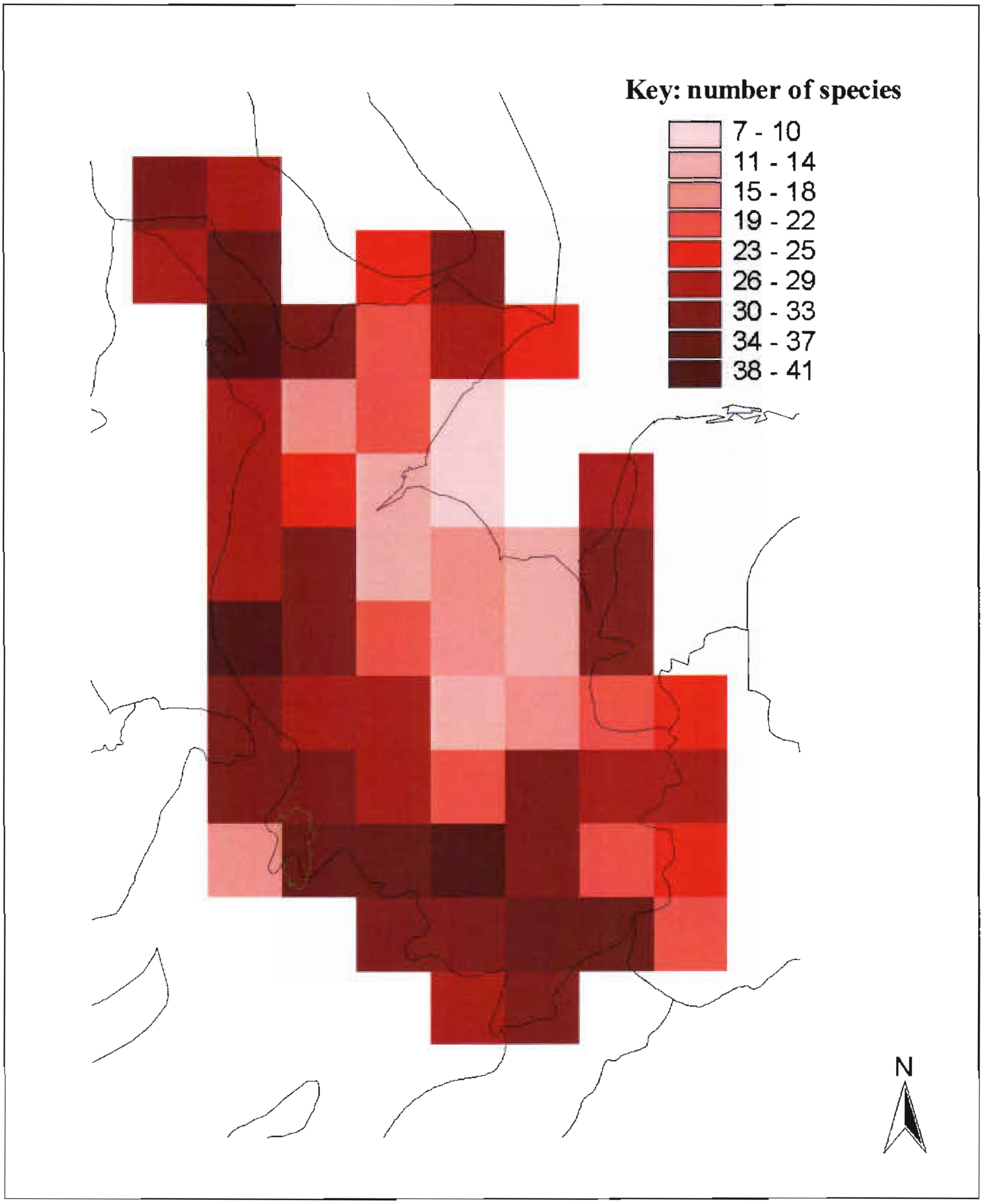


Figure A1.7 *Species co-occurrence map: Biodiversity Broad Habitat – Standing Water*

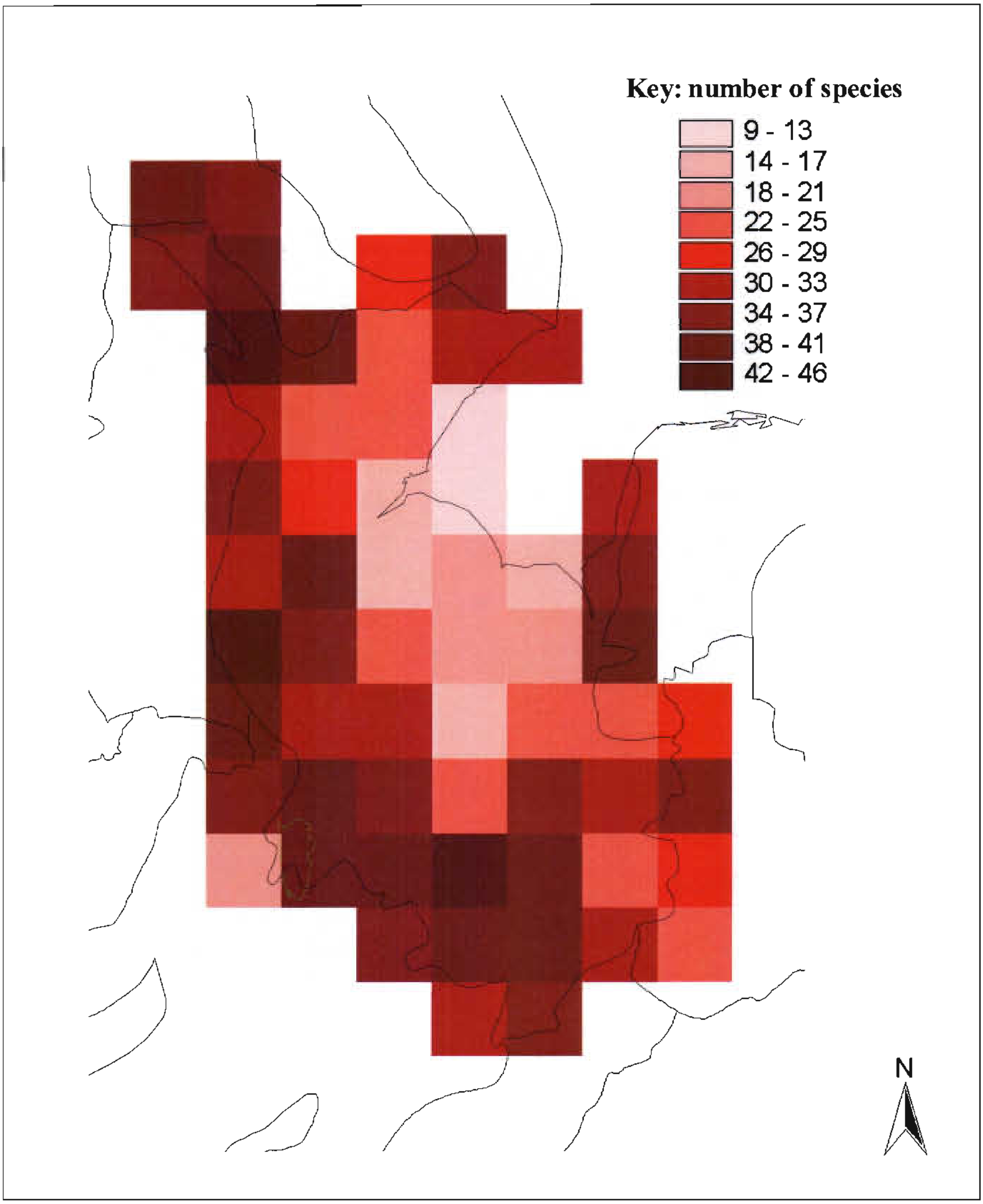
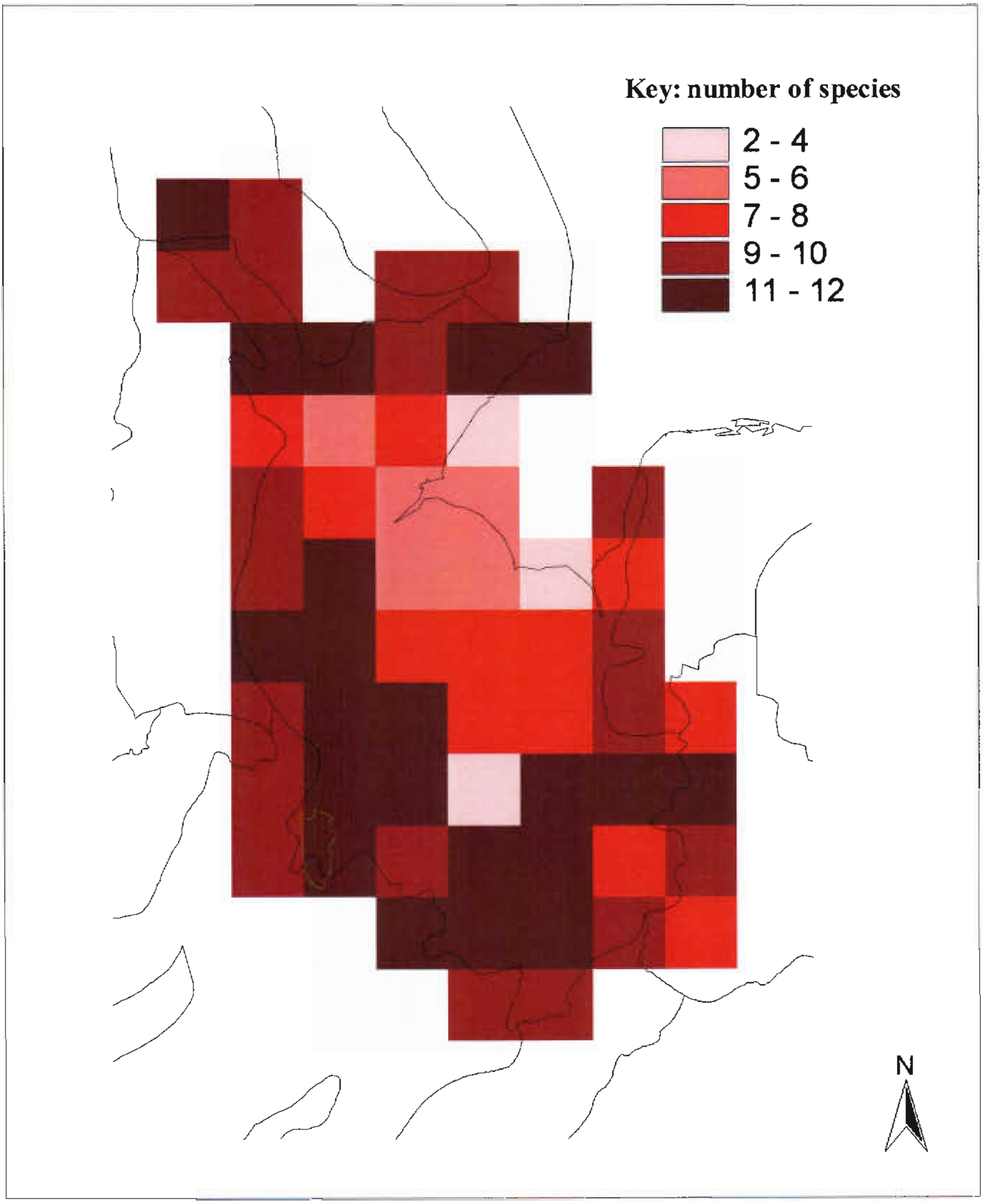


Figure A1.8 *Species co-occurrence map: Standing water – constancy IV and V species*



2 Protected areas and BAPs for the Fens Natural Area

Appendix Table A2.1 *National and Local Nature Reserves, SSSIs and other designated areas on peat within the Fens Natural Areas (or **P** in peaty valleys immediately adjacent to the Natural Area). Sites within the Great Fen Project Area are indicated *.*
Note certain RSPB reserves are presented in more detail in Appendix Table 2.2

Site Name	Grid Reference	Area (ha)	Wetland Broad Habitats Represented	BAP species present *etc*
Chippenham Fen NNR ***P***	TL648695 *etc*	117	BH1, BH6, BH11 and BH13	*Selinum carvifolia*
Holme Fen NNR *	TL208888 *etc*	266	BH1, BH11, (BH12 relic) and BH13	*Luzula pallescens*
Wicken Fen NNR	TL555700 *etc*	255	BH1, BH6, BH11 and BH13	*Peucedanum palustre, Viola persicifolia*
Woodwalton Fen NNR *	TL230845 *etc*	208	BH1, BH6, BH11 and BH13	*Lathyrus palustris, Viola persicifolia*
Bassenhally Pit LNR	TL285985	4.1	BH1, BH6, BH11 and BH13	*Sium latifolium*
Baston Fen LNR	TF145176	33	BH1, BH6, BH11 and BH13	
Boughton Fen SSSI ***P***	TF718013		BH1 and BH11	
Berry Fen SSSI	TL378745	18	BH6 and BH11	
Cam Washes	TL538732		BH6, BH11 and BH13	
The Chasm & Northorpe Slipe	TR151185 and 129170	13.9	BH11 and BH13	*Sium latifolium*
Conington Fen Drains CWS *	TL20.86.			
Cross Drain (Deeping Fen)	TF147131		BH13	
Deeping Gravel Pits	TF177080		BH13	
Friskney Decoy Wood	TF464571	5.9	BH1	
Kingfisher Bridge LNR	TL542732		BH6, BH11, BH13 and BH14	
Lakenheath Poors Fen LNR	TL701827	4.9	BH6, BH11 and BH13	*Lathyrus palustris*

Appendix Table 2.1 (continued)

Site Name	Grid Reference	Area (ha)	Wetland Broad Habitats Represented	BAP species present *etc*
Nene Washes SSSI	TL200977-395029	1310	BH6, BH11 and BH13	Birds: waders & wintering wildfowl
Norwood Road LNR	TL417980	2	BH1, BH6, BH11 and BH13	
Ouse Washes SSSI	TL393747-571987	2403	BH6, BH11 and BH13	Birds: waders & wintering wildfowl Water Vole, Otter Spined Loach Compressed River-mussel *Sium latifolium*
Pashford Poors Fen SSSI, Lakenheath	TL732835	12.2	BH1, BH6 and BH11	
Snailwell Meadows SSSI ***P***	TL678638	14.7	BH6 and BH11	*Selinum carvifolia*
Soham Wet Horse Fen	TL612725, 605723 and 612729	35.7	BH3, BH6 and BH11	
Stallode Wash, Lakenheath	TL675853	33.95	BH6, BH11 and BH13	*Lathyrus palustris* and *Teucrium scordium*
Stow-cum-Quy Fen SSSI	TL515627	29.6	BH6 and BH13	
Stretham Ponds SSSI	TL501722	9.7	BH13	
Thurlby Fen Slipe	TF119164	7.8	BH1, BH6, BH11 and BH13	
Upware North Pit	TL544728		BH1, BH11 and BH13	*Teucrium scordium*
Wilde Street Meadow SSSI	TL710791	10.9	BH1, BH6, BH11 and BH13 (and calcareous grassland)	

Note: The following LNRs and SSSIs occur on fringes (or clay islands within) immediately adjacent to the peat

Barnwell	Chettisham Meadows	Dernford Fen	Dogsthorpe Star Pit	Eye Green
Fulbourn Fen	Lattersey Field	Mare Fen	Roswell Pits	Wilbraham Fen

Appendix Table A2.2 RSPB reserves within the Fens Natural Area, with Phase 1 and BAP habitats [*P* = Sites on peat]

Reserve	Phase One Habitat	Description	BAP Broad Habitat	BAP Priority habitat	Area (ha)
FREISTON SHORE	H.2		littoral sediment	saltmarsh	100
Lincolnshire	H.1.1		littoral sediment	mudflats	583
	J.1		arable		78
	H.7		inshore sublittoral sediment	saline lagoons	12
FRAMPTON MARSH	H.2.2.1		littoral sediment	coastal saltmarsh	281.6
Lincolnshire	H.1.1	Coastland: intertidal, mud/sand	littoral sediment	mudflats	74.1
Total area: 390 ha	J.2.8.1		boundary and linear features		
	J.2-5	Other: artificial habitats	undefined		9.6
LAKENHEATH FEN *P*	A.1.1.1	Woodland: broadleaved, semi-natural	broadleaved		2
Suffolk	A.1.1.2	Woodland: broadleaved, plantation	broadleaved		38
Total area: 298 ha	A.1.1.2.5	Woodland: broadleaved, plantation, under planted	broadleaved		2
	A.2.2.2	Scrub: scattered, neutral	neutral grassland		1
	C.3.1	Tall herb and fern: other tall herb and fern, ruderal	arable		185
	F.1.1	Swamp: single-species dominant	fen, marsh, and swamp	reedbeds	9
	F.1.2	Swamp: tall fen vegetation	fen, marsh, and swamp		31
	F.2.1	Inundation communities: fragmentary marginal	standing water		8
	G.1.1	Standing water: eutrophic	standing water		11
	G.1.1.3	Standing water: eutrophic, lakes 0.5-5ha	standing water	eutrophic standing waters	8
	G.1.2.5	Standing water: mesotrophic, canals and ditches	standing water		3
NENE WASHES *P*	A.1.1.2	Woodland: broadleaved, plantation	broadleaved		2.0
Cambridgeshire	B.2.0.2	Grassland: neutral, lowland	neutral grassland	coastal/floodplain grazing marsh	17.1
Total area: 328 ha	B.4.2	Grassland: improved/reseeded, lowland	improved grassland	coastal/floodplain grazing marsh	236.48
	F.1	Swamp	fen, marsh, and swamp	reedbeds	15.10
	F.1.2	Swamp: tall fen vegetation	fen, marsh, and swamp		23.84

Appendix Table A2.2 (continued)

Reserve	Phase One Habitat	Description	BAP Broad Habitat	BAP Priority Habitat	Area (ha)
NENE WASHES *P*					
(continued)	F.2.1	Inundation communities: fragmentary marginal	standing water		10.10
	G.1	Standing water	standing water		16.10
	G.2.1	Running water: eutrophic	rivers		
	J.1.1	Arable	arable		1.55
	J.2.2.2		boundary and linear features		
	J.5	Other	undefined		1.08
OUSE WASHES *P*	A.1.1.2.2	Woodland: broadleaved, plantation, coppice	broadleaved		10.5
Cambs/Norfolk	B.2.1.2	Grassland: neutral, unimproved, lowland	neutral grassland	coastal/floodplain grazing marsh	900.1
Total area: 1046 ha	F.1.1	Swamp: single-species dominant	fen, marsh, and swamp		30.0
	F.2.1	Inundation communities: fragmentary marginal	standing water		19.0
	G.1.1.1	Standing water: eutrophic, small ponds	standing water		5.67
	G.1.1.5	Standing water: eutrophic, canals and ditches	standing water	eutrophic standing waters	
	J.2.2.2		boundary and linear features		1.2
SNETTISHAM	A.2.2.3	Scrub: scattered, basic/calcareous	broadleaved		6
Norfolk	B.3.1.2	Grassland: basic/calcareous, unimproved, lowland	calcareous grassland		14
Total area: 1830 ha	H.1.1.1	Coastland: intertidal, mud/sand, Zostera beds	littoral sediment	seagrass beds	1136
	H.2.3.1/H.2.3.2		littoral sediment	coastal saltmarsh	112
	H.3/H.5		supralittoral sediment	coastal vegetated shingle	12
	H.7.1		inshore sublittoral sediment	saline lagoons	20

Appendix Table A2.3: *Summary of Invertebrate Site Register sites for Cambridgeshire - table of sites and location map*

Note: Three Ouse valley sites (Brampton Flood Meadow, Hemingford Grey Pits and Portholme omitted from map)

Site name	Grid Reference	Lowland Pond/lake	Quarry	Stream or river	Reedbed, fen, carr or grazing marsh
Ailsworth Stream Paddock	TL123998			1	1
Bassenhally Pit	TL286985	1			1
Bassenhally Pond	TL288984	1			
Brampton Flood Meadow	TL219700				1
Castor Flood Meadow	TL124970	1			1
Farcet Brick Pits	TL195945	1	1		
Fletton Brick Pits	TL185965	1	1		1
Hemingford Grey Pits	TL297709	1			
Holme Fen	TL205895			1	1
Holy Well	TL168981			1	
Lady's Wood	TL243826				
Lattersey Hill	TL283965	1	1		1
Monks Wood	TL200800				
Nene Park	TL146977	1		1	1
Nene Washes	TL200977			1	1
Old River Nene, Holme	TL244884			1	
Portholme	TL238708			1	1
Ramsey Heights Clay Pits	TL245848	1			1
River Nene, Water Newton	TL104977			1	
Upwood Meadows	TL251825	1			
Woodwalton Fen	TL223835	1			1
Yaxley Brickpits	TL181934	1	1		

Appendix Table A2.4: *Summary of BAP targets for UK and Fenland counties - Wet Woodland* (No plan for Norfolk)

Scale	National	Cambridgeshire	Lincolnshire	Suffolk
Targets	Maintain the total extent (50,000-70,000 ha) and distribution of wet woodland	Identify all wet woodland sites by 2005	Identify current resource	Improve knowledge of distribution extent and quality of wet woodlands
	By 2015, complete establishment of a further 3,375 ha on unwooded sites or by conversion of plantations	Develop a small suite of demonstration wet woodland sites where detailed structure, process and species monitoring is carried out, by 2005	Maintain the current area of wet woodland	Identify wet woodlands that may be cleared to restore higher priority habitats
	Maintain current area (estimated at 24,000-30,000 ha) of ancient semi-natural wet woodlands	Initiate measures intended to achieve favourable condition in 100% of wet woodlands within SSSI and in 70% of the total resource by 2010	Achieve favourable condition of all wet woodland SSSIs by 2005 and all identified wet woodland sites by 2010	Improve the targeting of the *Woodland Grant Scheme* to assist in wet woodland habitats
	Initiate measures intended to achieve favourable condition in 100% of wet woodlands within SSSI/ASSIs by 2004	Initiate restoration of 20 ha to native wet woodland. Complete restoration to site-native species over half of this area by 2010 (and all of it by 2015).	By 2002, where water resources allow, investigate opportunities for restoration and creation of wet woodland.	Maintain the existing extent of high quality wet woodland
	Initiate measures intended to achieve favourable condition in 80% of wet woodlands of the total resource by 2004	Establishment of 100 ha of wet woodland by 2010 (and 200ha by 2015).		Initiate measures to achieve favourable condition in 100% of wet woodlands within SSSIs and SACs, and in 80% of total resource by 2004. Achieve favourable conservation condition over 70% of designated sites and 50% of total resource by 2020 where appropriate
	Achieve favourable condition over 50% of the total resource by 2010			Fully restore to site native species 50% of the sub-optimal wet woodlands by 2010 and complete this by 2015 where appropriate

Appendix Table A2.4 (continued)

Scale	National	Cambridgeshire	Lincolnshire	Suffolk
Targets	Achieve favourable condition over 70% of the designated sites by 2010			Maintain and strengthen populations of key BAP species associated with wet woodlands including: a) *Melanapion* minimum (weevil) and b) *Rhynchaenus testaceus* (a jumping weevil)
	Complete restoration to site-native species of 1,600 ha of former native wet woodland that has been converted to non-native plantations on ancient woodland sites by 2010			Achieve favourable management of 25% of wet woodlands by 2005 and 50% by 2010.
	Complete restoration to site-native species of a further 1,600 ha of former native wet woodland that has been converted to non-native plantations on ancient woodland sites by 2015			Develop new wet woodlands
	Complete establishment of 3,375 ha of wet woodland on unwooded sites or by conversion of plantations by 2010			Develop favourable conservation status guidance.

Appendix Table A2.5: *Summary of BAP targets for UK and Fenland counties - Neutral grasslands*
(No specific targets for Lincolnshire and Norfolk)

Plan	National	Cambridgeshire	Suffolk
Habitat	**Lowland meadows**	**Meadows and pastures**	**Lowland hay meadows**
Targets	Arrest the depletion of unimproved lowland meadows throughout the UK	Recreate and rehabilitate meadows/pastures. By 2010: (I) Bring 100% of SSSIs with unimproved neutral grassland into favourable management (II) Bring 20ha of second tier County Wildlife meadow and pasture sites into favourable management (III) Create 50ha of meadow/pasture on suitable sites.	1
	In SSSI/ASSIs, begin rehabilitation management for all significant stands of unimproved lowland meadow in unfavourable condition by 2005	Create 20ha of new meadows and pastures on suitable sites (by 2005)	Secure favourable condition on unimproved grassland sites wherever feasible.
	Wherever biologically feasible achieve favourable status of all significant stands of unimproved lowland meadow within SSSI/ASSIs by 2010	Bring all current (1999) SSSIs with meadows and pastures into favourable management (2005).	Re-establish 20 hectares of flower rich grassland by 2010.
	For stands outside SSSIs and ASSIs, wherever biologically feasible, secure favourable condition over 100% of the resource by 2015		
	Attempt to re-establish 500 ha of lowland meadow of wildlife value at carefully targeted sites by 2010		

Appendix Table A2.6: *Summary of BAP targets for UK and Fenland counties - Coastal and floodplain grazing marsh* (Floodplain only in Cambridgeshire)

Scale	National	Cambridgeshire	Lincolnshire	Norfolk	Suffolk
Targets	Maintain the existing habitat extent (300,000ha) and quality	Maintain existing habitat area and quality: By 2005 (I) All SSSI wet grassland in positive conservation management (II) Define specific nature conservation objectives for all sites. Take necessary action to ensure that these objectives are met	Maintain the existing habitat extent and biodiversity	Maintain the existing habitat extent (29,500 ha) and its quality	Improve knowledge of extent and quality of coastal and floodplain grazing marsh
	Rehabilitate10,000 ha that has become too dry, or is intensively managed by 2000 (inc. 5,000ha already targeted in ESAs)		Restore 200 ha of former grazing marsh by 2005.	Rehabilitate 640 ha by year 2000 (320 ha already targeted in ESAs, with additional 320 ha).	Maintain the existing extent of high quality grazing marsh
	Begin creating 2,500 ha from arable land in targeted areas, in <u>addition</u> to that to be achieved by existing ESA schemes, with the aim of completing as much as possible by year 2000	Create 200 ha (by 2005) and 400 ha (by 2010) of wet grassland from arable land in targeted areas	Create 100ha of grazing marsh from arable land in targeted areas by 2010	Aim to create 350 ha of grazing marsh from arable land on the North Norfolk Coast	Increase ecological quality of 5% of grasslands entered into Suffolk River Valleys ESA (Tier 1) by altering management to meet Tier 2 criteria. Emphasise permanent grassland in sensitive areas, such as those adjacent to estuaries
			Ensure appropriate regimes of management for coastal grazing land through the production of management plans		Encourage the restoration of 200 ha of grazing marsh from arable land by 2018

Appendix Table A2.6: (continued)

Scale	National	Cambridgeshire	Lincolnshire	Norfolk	Suffolk
Targets			Ensure that appropriate water levels are maintained as agreed in management plans		Integrate grazing marsh restoration into initiatives for reedbed and fens creation
			Promote retention of surviving meadow and pasture, and restoration of viable areas by long-term set-aside and Countryside Stewardship		
			Establish database relating to grazing marsh in Lincs by 2001		
			Promote the schemes for restoration of river flood plains and wet grassland		

Appendix Table A2.7: *Summary of BAP targets for UK and Fenland counties - Reedbeds*

Scale	National	Cambridgeshire	Lincolnshire	Norfolk	Suffolk
Targets	By 2000, rehabilitate the priority areas of existing reedbed (targeting those of 2ha or more)	Rehabilitate existing priority areas (targeting those ≥2ha) and maintain this thereafter by active management	Maintain and enhance the current area and quality of reedbeds and halt further loss	Maintain existing area/quality as a minimum. By 2000, identify and rehabilitate priority areas of existing reedbed that are not at favourable conservation status	Maintain existing overall area and quality as a minimum
	Maintain priority areas of existing reedbed by active management	Create new beds on land of low nature conservation interest (100 ha by 2005). Ideally create in blocks of >20ha with priority near to existing reedbeds (with linkage). By 2010, create 400 ha on land of low conservation interest including reedbed as a component of ≥1 major wetland creation project (*i.e.* >200ha).	Increase by 100% the area of reedbed on a) existing nature reserves and b) as part of habitat restoration schemes by 2010, providing in so doing there is no conflict with other habitats and species.	Create 100 ha of new reedbed to replace reedbeds likely to be lost to rising sea levels in advance of loss. These should be located as near as possible to existing sites on areas of current low nature conservation interest	Enhance by managing for key species where requirements are known
	Create 1,200 ha of new reedbed on land of low nature conservation interest by 2010.	Encourage smaller scale reedbed creation *e.g.* as part of water purification systems		Create an additional 600 ha of new reedbed safe from future threat of sea level rise within Norfolk and Suffolk by 2010. This will be on areas of current low nature conservation interest.	Audit existing reedbed resource, particularly for priority species
					Research habitat requirements for priority species

Appendix Table A2.7: (continued)

Scale	National	Cambridgeshire	Lincolnshire	Norfolk	Suffolk
Targets					Recreate, in advance of losses through coastal erosion, 200 ha to maintain the current area. This will be as near as possible to existing sites on areas of low current nature conservation interest
					Recreate a further 600 ha of new reedbed safe from future threat of sea level rise with Norfolk and Suffolk. This will be on areas of low current nature conservation interest

Appendix Table A2.8: *Summary of BAP targets for UK and Fenland counties - Fens*

Scale	National	Cambridgeshire	Norfolk	Suffolk
Targets	Initiate restoration of priority fen sites in critical need of rehabilitation by 2005	Rehabilitate priority sites. The aim of rehabilitation should be to recreate the habitat/species quality found in the late 19th century. Plans produced by 2005. All priority sites rehabilitated by 2010.	Identify Norfolk fen sites in critical need of rehabilitation, and initiate restoration by the year 2005. All rich fen and other sites with rare communities should be considered	Ensure by 2010 the long-term sustainable management (including water resources) of all fens that are currently in favourable condition or will be brought into favourable condition following restoration
	Ensure appropriate water quality and quantity for the continued existence of all SSSI/ASSI fens by 2005.	Create fens on land of low conservation interest, especially in areas close to or abutting present fens. Create at least one large wetland (>200ha) including a major fen component by 2010.	Ensure appropriate water quality and water quantity for continued existence of all Norfolk SSSI fens by 2005	Promote rehabilitation of degraded or declining fens, providing environmental conditions to allow for the development of target fen communities or species
		Maintain and strengthen populations of key BAP species associated with fens		Encourage the re-creation of 100 ha of fen communities where suitable hydrology can be ensured and where the fen species are likely to recolonise, preferably abutting Priority 1 (CSPA, SPA, RAMSAR, SAC or sites with significant populations of species) sites and within its hydrological unit
		Ensure appropriate groundwater quality and quantity for all groundwater dependent fen sites by 2005		

Appendix Table A2.9: *Summary of BAP targets for UK and Fenland counties - Rivers, streams, drainage channels and canals* (Two plans for Cambridgeshire, one for Lincolnshire, none for Norfolk and Suffolk)

Scale	National	Cambridgeshire	Cambridgeshire	Lincolnshire
Habitat	**Rivers and streams**	**Rivers and streams**	**Drainage ditches**	**Rivers, canals and drains**
Targets	Maintain and improve the quality, state and structure of all UK rivers and streams and their associated floodplains	To manage all catchments in a condition which respects and supports their diverse range of flora and fauna	Favourable wildlife management of ditches but with respect for their important land drainage and flood defence functions	Locate the best botanical watercourses, by checking earlier records. Resurvey to see if diversity is still good or in decline. Restore water quality, flows and habitat diversity where they have deteriorated.
	Restore degraded river and streams taking account of water quality and quantity, structure and hydraulic connection with the floodplain	To ensure that there is no deterioration and where necessary improve water quality and quantity in all catchments. With respect to water quality ensure that all water quality targets are achieved in accordance with relevant legislation and the Agency's remit	Increase use of buffer zones beside ditches	Maintain and enhance the characteristic flora and fauna of Lincolnshire's rivers, canals and drains and drainage ditches.
		No net reduction in the number of headwaters or length of watercourse except by natural processes (by 2005)	Raise awareness/value of the wildlife importance of ditches	Encourage sympathetic management of wildlife on all watercourses.
		Respect and where possible restore the dynamic nature of rivers, their micro-habitats and their associated flood plains taking into account the constraints imposed by flood defence and land drainage	Improve water quality within ditches following National EA and EC Freshwater Fish Directive guidance	

Appendix Table A2.10: *Summary of BAP targets for UK & Fenland counties - Standing water and canals* (Drainage ditches -Table A2.9)

	National	Cambridgeshire[6]	Lincolnshire	Suffolk
Habitat	**Eutrophic standing waters**	**Lakes and irrigation reservoirs**	**Ponds, lakes and reservoirs**	**Eutrophic standing water**
Targets	Maintain condition of all important sites judged as in favourable condition (typical plant and animal communities present)	Maintain the conservation status of all Tier 1 sites (in line with the National Action Plan objectives)	Determine extent, status and distribution of all standing open water-bodies >25m^2 and improve knowledge of distribution and status of small ponds by 2005.	Await national classification by EA by 2002 of eutrophic water bodies in Suffolk into three tiers according to naturalness, biodiversity and restoration potential.
	By 2005 initiate action to restore to favourable condition other important sites damaged by human activity	Improved to favourable condition those Tier 2 eutrophic standing waters that have been damaged by human activity	Maintain current area of standing open water (ensuring water-bodies are not cleared to create open water to the detriment of good fen/swamp/marsh). Offset any loss of water-bodies and fringing vegetation by habitat creation.	Ensure protection and continuation of favourable condition of eutrophic standing waters classified in Suffolk as Tier 1 by 2005.
	Ensure that no further deterioration occurs in the water quality and wildlife of the remaining sites	Ensure that no further deterioration occurs in the water quality and wildlife of the remaining Tier 3 eutrophic standing water resource	Enhance conservation value of ponds, lakes and reservoirs through appropriate management, especially sites supporting species/communities of conservation importance.	Restore 50% of Tier 2 sites damaged by human activity to favourable condition by 2020.
		Promote incorporation of conservation enhancements into all new reservoir schemes	Create 100 new ponds (use pond guidance leaflet) on Lincs. land of low conservation importance by 2010.	Ensure no further deterioration in water quality and wildlife of Tier 3 resource.
		Create appropriate habitats associated with open water where opportunities arise	Control exotic species such as *Elodea canadensis* and *E. nuttallii* to prevent choking of water-bodies.	Set up a pilot community pond initiative involving a network of volunteer wardens.

[6] In CAMBS, by 2005: 1) Identify all open water sites over 1ha and classify their Tier status; 2) Develop monitoring criteria and methodology for evaluating the favourable conservation status of open water; 3) Maintain the conservation status of all Tier 1 sites; 4) Provide advice to owners of all Tier 2 sites designated as County Wildlife Sites; 5) Determine the conservation status of all Tier 3 sites; and 6) Develop environmental enhancement section of the EA's document on the creation of open water. By 2010: 1) Maintain the conservation status of all Tier 1 sites; 2) Provide advice to owners of all Tier 2 sites not designated as County Wildlife Sites; 3) Improve the condition of 25% (by number) of Tier 2 sites; 4) Agree and implement the criteria and methodology for evaluating the favourable conservation status of open water; and 5) Maintain the conservation status of all Tier 3 sites

A3 Other background information

Table A3.1 Habitat requirements of selected *NVC* communities important to the Great Fen Project (Derived from Newbold and Mountford 1997; Rodwell 1991-2000; and Wheeler and Shaw 1987)

NVC Type	Occurrence (habitat)	Soil type *etc*	Water-regime	Management
A1	Mainly in SE England in standing or sluggish water	Eutrophic and base-rich water on a range of soils	Since free-floating, to some extent independent of depth provided that the surface is sheltered (though not shaded)	Favoured by fertiliser/sewage runoff and regular ditch clearance
A2	Throughout lowlands in standing to slow-moving water	Meso- to eutrophic, circum-neutral to rather base-poor water (varied substrate)	As latter (more tolerant of shading). Will tolerate brief periods of stranding	As latter, but les strictly confined to polluted sites
A3	Lowland SE Britain in standing water of ditches	Mesotrophic-eutrophic water, often calcareous sites	As **A1**	Superseded by emergent swamp unless ditch cleaned frequently - intolerant of pollution
A5	Still to slow-moving water in SE lowlands	Eutrophic water on a range of circumneutral substrates	As **A1**	Favoured by regular ditch cleaning
A11	Clear standing (or flowing) water in the lowlands	Mesotrophic-eutrophic water that is base-rich (pH 7-8.5) and 30-125 mg l^{-1} $CaCO_3$, on a range of soil textures	Normally in moderately deep water	Favoured by occasional cleaning of drainage channel
A12	Throughout lowlands in still to quite fast-flowing water	Eutrophic or brackish water often on silts, but over a range of parent soils	As **A11**	Favoured by occasional cleaning of channel, and tolerant of pollution
A16	Throughout Britain in a range of wet or aquatic situations	Wide range of water pH and underlying substrate	From moderately deep water to seasonally-exposed wet mud	Favoured by ditch clearing or (in terrestrial situations) by trampling
MG5	Widespread in lowland Britain, often on ridges of ridge-and-furrow	Circumneutral brown soils - but over a wide range	Soils moist - where soil particles finer, drainage may be impeded (local water-logging). Normally no flooding	Minimal improvement for farming. Shut up for hay April-June, then cut, aftermath grazed
MG11	Probably frequent in flood-plains, shores and upper salt-marsh	Brown earths and alluvial soils. Circumneutral (often brackish)	Soils moist to damp, but free-draining. Inundated by fresh or brackish water, but also prone to periods of drying out	Regularly grazed but rarely mown. Locally treated with artificial fertilisers.
MG13	Widespread washes floodplains and seasonally wet hollows	Circumneutral silts	Soils damp, and sometimes waterlogged. Regularly flooded by fresh water - sometimes for long periods.	Naturally fertile sites are summer grazed (occasional hay-cut)

Table A3.1 (continued)

NVC Type	Occurrence (habitat)	Soil type *etc*	Water-regime	Management
M24	Local where mires have been affected by cutting and/or grazing	Peats and peaty mineral soil, neutral to mildly acidic	From fairly moist to quite dry (especially in summer) with little fluctuation in water-table or throughput. Very seldom flooded	Derived from drier fringes of mires by regularly cutting but now often maintained by grazing alone. No fertiliser, herbicide or reseeding
S2	Pure *Cladium* stands in East Anglia and NW England	Calcareous and base-rich fen peat	Open water transition, floodplain and basin fen situations. Standing water-table, tolerant of range between -15cm & +40cm	Annual summer cutting
S4	*Phragmites* dominated sites throughout Britain	No strict soil preferences	Open water transition and floodplain situations (hydroseres). Can tolerate range between 100cm below soil surface and+50cm above - very variable	Annual winter cutting
S5	Regularly inundated flood-plain washland and fringes	Nutrient-rich, circumneutral or basic alluvium, or organic soil with regular inputs of mineral-rich water (pH >6.0) and high phosphate levels	Usually in waterlogged sites - with water at soil surface for most of the summer. Regular very prolonged winter-flooding and may occur as a floating raft	Tolerant of fertiliser use, as well as summer mowing and grazing
S12	Great Reedmace stands occur throughout Britain	Mesotrophic to eutrophic situations on a wide range of soil types.	Can occur in shallow water (or recently exposed wet mud/peat) with little annual fluctuation, or in deeper water to 1m	Usual in uncut sites, but intolerant of severe wave-action
S24	Largely confined to East Anglia	Fen peat with moderate bicarbonate, calcium and pH (5.5-6.9). Fertility moderate	Occupies intermediate seral zone between swamp and carr, where mean water-levels are low, but with some winter flooding	Often subject to mowing at 1-few year intervals
S25	Mainly East Anglia, southern England and Anglesey	Calcareous fen peat, base-rich and moderately eutrophic	Mean water-levels generally low, but higher than **S24**	Occasionally managed as **S24** but not grazed, and not maintained by cutting. Often disturbed.
W2	Mainly East Anglia and the plain of Cheshire/Shropshire	Fen peat with calcium of 60-120 mg l^{-1} and pH5.5-7.5	Floodplain mires with low incidence of winter flooding	Normally unmanaged
W4	Throughout lowlands	Moderately acid peat (including some soligenous fens) - base/nutrient poor	Margins of mires rarely subject to any flooding	Normally unmanaged, though it occurs where mires have been previously disturbed
W6	Local but widespread in the lowlands	Eutrophic soils enriched by silts	Margins of topogenous (often floodplain) mires	Uncut, but often subject to grazing

Table A3.2 ***Ecological requirements of major aquatic species and those of high conservation status (after Newbold and Mountford 1997)***

Species	Trophic status/pH	Water-level: "Dry" limit	Water-level: Preferred	Water-level: "Wet" limit	Preferred Management
Callitriche stagnalis	Mesotrophic to Eu/hypertrophic pH especially 6.5-7.5	-20	Very catholic	+40(+50)	Annual cleaning and marginal grazing
Ceratophyllum demersum	Mesotrophic to Eu/hypertrophic pH >6.0		Submerged floating		Frequent cleaning
Elodea canadensis	Oligo/mesotrophic to Eutrophic pH especially *ca* 7	+20	+50 to +150	+300	Frequent cleaning
Equisetum fluviatile	Oligotrophic to eutrophic PH 5.2-6.4	-30	*ca* +60	+100	Regular, but not annual cleaning
Hydrocharis morsus-ranae	Mesotrophic to Meso/eutrophic pH >5.5	0	Floating species		Cleaning at >3 year intervals, and marginal grazing
Lemna gibba	Meso- to Eutrophic pH >6.0		Floating species		Annual cleaning - tolerant of disturbance/pollution
Lemna minor	Oligotrophic to Eu/hypertrophic pH especially >4.5		Floating species		Tolerant of many regimes, provided open waters maintained.
Myriophyllum spicatum	Mesotrophic to Hypertrophic pH >5.5	+10		+200	Frequent cleaning - tolerant of disturbance
Phragmites australis	Oligotrophic to Eu/hypertrophic pH >4.5	-100	-20-0	+50	No marginal grazing, infrequent cleaning (>5 years)
Potamogeton compressus	Oligotrophic to mesotrophic	+2	+10 to +100	+150	Frequent to occasional cleaning
Potamogeton pectinatus	Mesotrophic to Hypertrophic pH >5.5		+20+100	+150	Frequent cleaning - tolerant of pollution
Spirodela polyrhiza	Mesotrophic to Eutrophic pH >5.5		Floating species		Annual cleaning
Stratiotes aloides	Meso/eutrophic to Eutrophic pH >6.0		+20 to +75	+100	Cleaning at >3 year intervals, and marginal grazing
Typha latifolia	Mesotrophic to Eu/hypertrophic pH >5.5	-20	+10 to +75	+100	Infrequent cleaning/grazing, but maintain moderately deep water

Table A3.3 Ecological requirements of major terrestrial species (After Benstead *et al.* 1997 and Hill *et al.* 1999)

Species	Soil type	Soil pH	Soil Water-table and flooding	Grazing & cutting	Fertiliser
Agrostis stolonifera	Fertile soil	5.5->8.0 *etc*	Moist to damp soils; and tolerant of flooding (will grow floating in still water)	Favoured by mowing, but eaten by stock	Somewhat favoured
Alnus glutinosa	Fertile alluvium/peat	5-6	Damp to wet soils, tolerating flooding	Intolerant of grazing when young	N/A
Alopecurus geniculatus	Fertile alluvial soil	5.5-7.0	Intolerant of long drought, typical of wet soils. Prefers winter flooded sites - tolerant of poor aeration	Favoured by late mowing	Favoured by moderate application of nitrogen
Anthoxanthum odoratum	Widespread at lower fertility	4.5-6.0	Widespread, but commoner in moist sites. Intolerant of flooding	Favoured by late mowing and aftermath grazing	Suppressed by inorganic fertilisers, but favoured by manure
Betula pubescens	Oligotrophic soils including peat	4-5.5	Moist to damp sites. Suppressed by regular flooding	Intolerant of grazing when young	N/A
Calliergon cuspidatum	Widespread except on oligotrophic soils	4.5->7.0	Damp-wet sites - suppressed by prolonged flooding	Tolerant	Suppressed by inorganic fertilisers
Carex panicea	Mainly on organic soil	(4-)5.0-6.0(-7.5)	Typical of damp sites, intolerant of prolonged drought, but tolerant of flooding	Favoured by defoliation	Suppressed by high levels of fertiliser
Centaurea nigra	Mainly of moderately fertile mineral soil	Esp. >5.0	Typical of moist sites, tolerant of drought and intolerant of flooding	Favoured by (late) mowing but suppressed by intense grazing	Strongly suppressed by moderate to high levels of fertilizer
Cirsium dissectum	Infertile organic soil	Esp<7.0	Typical of damp to wet, often waterlogged sites, that are prone to moderate flooding	Favoured	Suppressed by high levels of fertiliser
Cladium mariscus	Infertile peat soils	*ca* 6-7.5	Typical of wet sites, liable to winter flooding	Avoided by stock - tolerates regular mowing	Intolerant
Cynosurus cristatus	Mainly on moderately fertile mineral soil	Esp. 5.0-7.5	In moist sites, tolerant of long drought, but intolerant of very prolonged flooding	Strongly favoured by grazing	Strongly suppressed by inorganic fertilizer
Dactylis glomerata	Especially in moderately fertile mineral soil	Esp. 5.0-8.0	In moist sites, tolerant of drought and intolerant of prolonged flooding	Favoured by occasional defoliation, tolerant of summer grazing	Favoured by lower applications of nitrogen
Eupatorium cannabinum	Fertile soil	5.0-7.0	Damp-wet sites - will tolerate brief winter flooding	Intolerant	Tolerant of light dressings

Table A3.3 (continued)

Species	Soil type	Soil pH	Soil Water-table and flooding	Grazing & cutting	Fertiliser
Festuca rubra	Commonest on mineral soil - widespread	Esp. >5.0	Widespread and tolerates moderate flooding	Found over a wide range of management	Suppressed by even low levels of fertiliser
Filipendula ulmaria	Mineral and organic soil	>4.5	Damp to wet sites, not in permanent waterlogging (nor prolonged flooding); tolerates some drought	Prefers an annual cut and light grazing	Suppressed by moderate rate of inorganic fertiliser
Galium palustre	Organic and mineral soil	Esp. 5.0-7.0	Wet, waterlogged sites, intolerant of prolonged drought and will grow in shallow water (inc. winter flooding)	Prefers annual cut and light grazing	Suppressed by higher fertiliser rates
Glyceria fluitans	Fertile, organic and mineral soil	Esp. 5.0-7.0	Typical of wet sites, intolerant of drought. Often aquatic, preferring prolonged flooding	Prefers annual cut and light grazing	Probably favoured by low rates of fertiliser
Glyceria maxima	Fertile, organic and mineral soil	5.0-7.5	Waterlogged sites, intolerant of longer drought. Often aquatic, prefers sites that are regularly inundated	Prefers annual cut and light grazing	Favoured by fertiliser application
Holcus lanatus	Widespread, but esp. on quite fertile soil	Esp. 5.0-6.0	Moist-damp sites, tolerant of moderate droughts, but intolerant of very prolonged floods	Limited by very intense grazing, but otherwise widespread	Strongly favoured in short term by fertiliser application
Juncus subnodulosus	Relatively fertile organic soils	6.5-8.0	Damp to wet sites, intolerant of prolonged droughts and tolerant of winter flooding (occasional as aquatic)	Favoured by defoliation, avoided by stock at light grazing pressures	Possibly suppressed by heavy rates of inorganic fertiliser
Lathyrus palustris	Fen peat soils	6-7.5	Wet sites, liable to shallow winter flooding	Tolerant of regular mowing and light grazing	Intolerant
Lotus corniculatus	Widespread	4.0-8.0	Dry-moist sites. Suppressed by waterlogging and prolonged floods	Favoured	Suppressed by heavy applications
Lotus pedunculatus	Organic and mineral soils	Esp. 4.5-6.5	Damp to wet sites, but relatively drought-tolerant. Will tolerate regular (usually not prolonged) flooding. Rare as an emergent in aquatic sites	Prefers lightly grazed and/or annually mown sites	Suppressed by heavy, but possibly favoured by light inorganic fertiliser.
Luzula pallescens	Oligotrophic peats	4-5.5	Damp sites. Will tolerate some drought, but not floods	May tolerate light mowing	Intolerant
Lysimachia vulgaris	Moderately fertile peat and mineral soils	5-7.0	Wet sites - will tolerate regular winter flooding	Tolerant of regular mowing, but not grazing	Intolerant
Lythrum salicaria	Moderately fertile peat and mineral soils	5-7.0	Wet sites - will tolerate regular winter flooding	Tolerates light mowing., but not intense grazing	Intolerant
Mentha aquatica	Organic and mineral soil	>5.0, esp. 6.0	In wet sites, intolerant of drought. Flood-tolerant, often found as an emergent	Suppressed by frequent grazing or cutting	Probably suppressed by heavy fertiliser rates

Table A3.3 (continued)

Species	Soil type	Soil pH	Soil Water-table and flooding	Grazing & cutting	Fertiliser
Molinia caerulea	Mainly in infertile organic soils	Often <4.0 & >7.0	Damp sites, typical of fluctuating water-table. Intolerant of prolonged flooding and waterlogging	Favoured by annual cutting, but suppressed by intense grazing	Probably suppressed by heavy rates of inorganic fertiliser
Peucedanum palustre	Infertile peat soils	*ca* 6-7.5	Typical of wet sites, liable to winter flooding	Tolerates regular mowing	Intolerant
Phragmites australis	Widespread	General	In up to 50cm of water, but also in wet sites	Favoured by regular mowing, but suppressed by grazing	Intolerant of heavy dressings
Potentilla anserina	Fertile mineral and organic soils	Esp. >5.5	Moist to damp sites, but tolerant of prolonged drought. Tolerates regular (including tidal or prolonged) flooding	Tolerant of (light) mowing and grazing	Possibly favoured by light applications of fertiliser
Potentilla erecta	Relatively infertile organic & mineral soils	Esp. <6.0	Wide tolerance, including brief flooding	Tolerant of mowing and grazing	Probably suppressed by heavy rates of fertiliser
Salix cinerea	Widespread, esp. in less fertile situations	General	Damp-wet sites, tolerant of some winter flooding	Tolerant of trimming and some browsing	N/A
Sium latifolium	Moderately fertile peat and alluvium	6-8.0	Usually in shallow water (to 40cm) - will tolerate some exposure, or on waterlogged ditch banks	Intolerant	Tolerates lighter applications
Succisa pratensis	Infertile situations on peat and mineral soils	General	Moist-damp sites, with some winter waterlogging. Generally suppressed by prolonged flooding	Favoured by defoliation	Intolerant
Teucrium scordium	Infertile base-rich peat and sands	6.5-8.0	Damp-wet sites, and will tolerate prolonged flooding (even in summer)	Tolerant of light grazing	Intolerant
Thelypteris palustris	Infertile peats	44.5-7.0	Damp-wet sites, with prolonged waterlogging and some winter flooding	Intolerant	Intolerant
Trifolium pratense	Widespread, esp. on fertile soils	Esp. 5.0-6.0	Commonest on moist soils, but tolerant of short-term drought and waterlogging (absent under long flooding)	Favoured by mowing and grazing	Strongly suppressed by applications of fertilizer
Trifolium repens	Mainly on fertile soils	Esp. 5.0-8.0	Wide tolerance, but intolerant of severe drought. Suppressed where flooding is regular and prolonged	Strongly favoured by () mowing and grazing	Strongly suppressed by applications of fertiliser
Urtica dioica	Widespread on fertile to very fertile soils	General	Damp sites. Will occur under frequent flooding by eutrophic water.	Tolerant	Favoured by manuring
Viola persicifolia	Infertile base-rich soils, especially peat	6-8.0	Damp-wet sites. Often in winter-flooded sites	Tolerant	Intolerant - suppressed

Figure A3.1 **Derivation of Sum Exceedence Values (SEV):** from a hydrograph as generated by a hydrological model. The horizontal lines represent threshold depths for the particular soil type. The upper line is the waterlogging threshold, with the blue shaded area above it representing the SEV (waterlogging). The lower line is the soil drying threshold and the red shaded area blow represents the SEV (soil drying). After Gowing *et al.*2002.

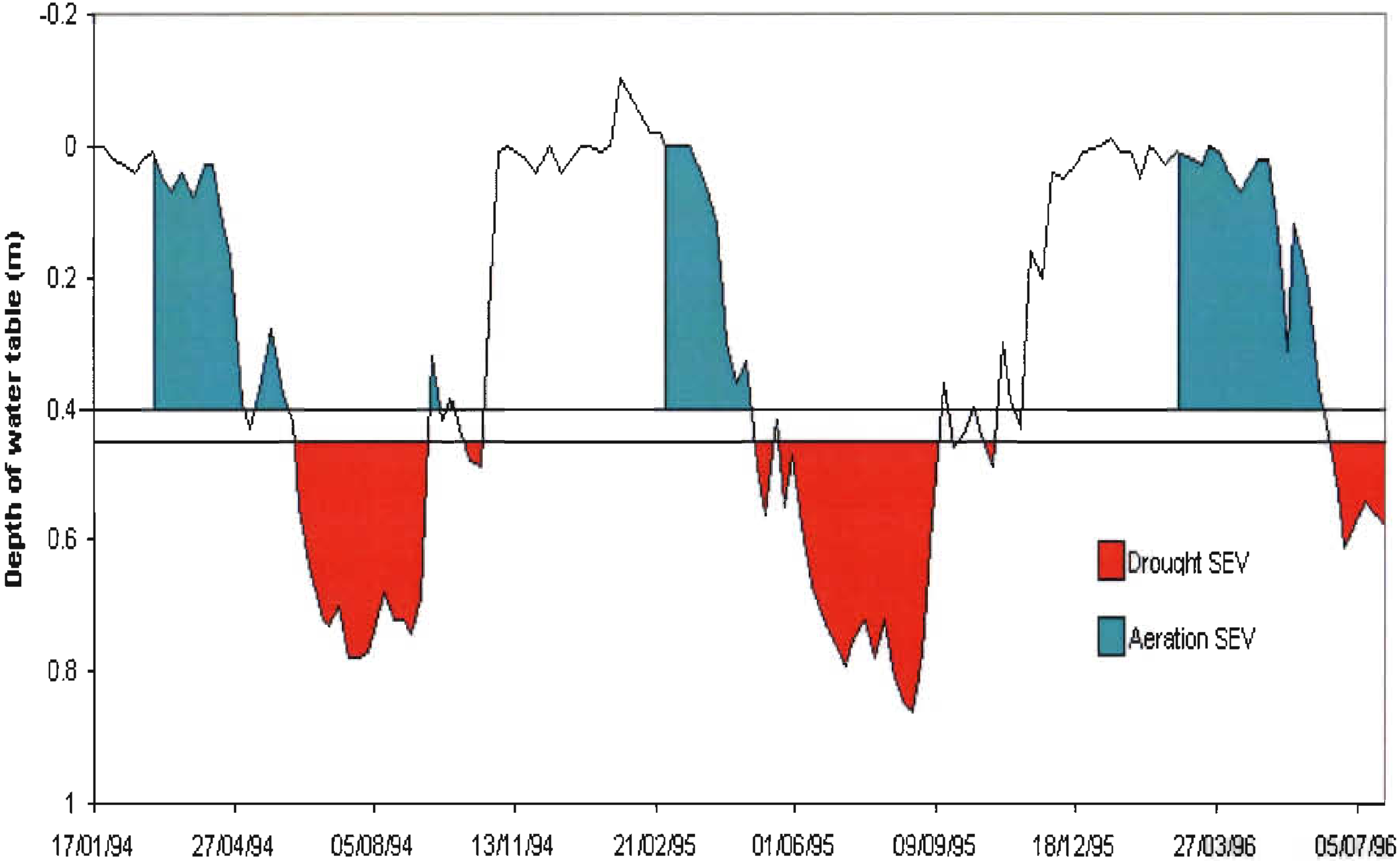


Figure A3.2 Water-regime tolerance of *NVC* lowland wet grassland communities in terms of Sum Exceedence Values (SEV) to drought and aeration (waterlogging) stress (after Gowing 2000). Bars represent inter-quartile ranges.

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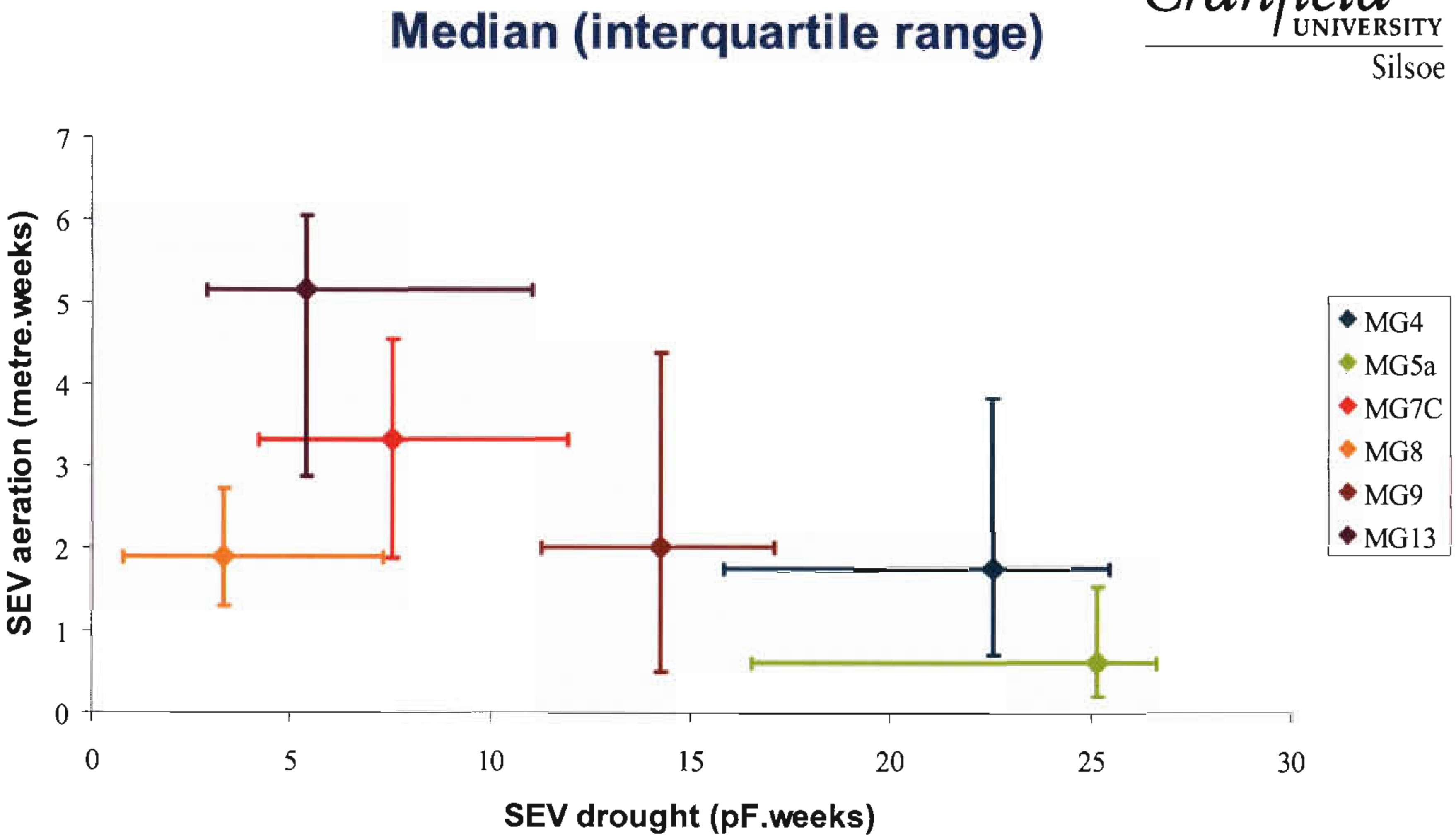


Derivation and meaning of Sum Exceedence Values (SEV)[7]

The level of water-stress tolerated by plants can be calculated using the concept of Sum Exceedence Values (SEV), derived from Dutch work and developed extensively for the British situation through the work of Gowing *et al.* (2002). The approach uses the output of hydrological models of water-table elevation for each sampled location over a period of years. The method relies on threshold depths being specified for each site and soil type. One of these thresholds defines the water-depth at which the zone of densest rooting (taken to be 0-10cm depth) begins to become waterlogged, whilst the second defines when drying of the surface soil becomes detectable by plants. Hence, two stresses can be calculated for each micro-site (quadrat *etc*):

a) "aeration stress" (***Aeration SEV***) represents the extent to which high soil water-tables prevent aeration of plant roots. A threshold water-table depth is calculated based on the critical depth given by the Gardner equation. When this is exceeded, the length of time (in weeks) and extent to which it is exceeded (in metres) were multiplied together to give the SEV measure of plant stress.
b) "drought stress" (***Drought SEV***) represents the level of soil drying experienced; and may be calculated using soil water-tension instead of water-table depths, thus enabling sites with different soil moisture characteristics to be compared. A threshold value of 0.5 m tension at the surface has been used by Mountford *et al.* (1999) for the summation of drought SEV.

Thus for each threshold, the SEV represents the degree to which water-tables exceed it (Figure A3.1). Note that for the example of grasslands, waterlogging is only cumulated during the period of active grass growth (March-September), when the plants are most sensitive to the oxygen status in their root zone. The water regime at a given point may then be characterised by taking a long-term mean (over a period of years) of the annual SEV (waterlogging) and the annual SEV (soil drying). The advantage of using the SEV approach with site-specific thresholds is that the resultant information is transferable between sites holding similar species and vegetation types.

Estimation of parameters

The parameters required at each site to run the hydrological models and hence to generate the two

types of SEV were:

Hydraulic conductivity (k)
Unsaturated hydraulic conductivity exponent (c)
Depth of ditch base
Depth of impermeable layer
Drainable porosity (S)
Water content at threshold tensions

Hydrological Model Validation

Validation for each site can be undertaken by running the model for all available dipwell locations over the period for which dipwell water-table data had been collected. Predicted water-table heights, calculated by the model, can then be compared with the field observations.

[7] Derived from two earlier accounts: Mountford *et al.* 1999 and Gowing *et al.* 2002

Figure A3.3A methodological structure for wetland management planning: the example of the EU-LIFE project "*Development of Integrated Management Plans for Catchment Areas: the River Dommell*" (after Pieterse *et al.* 1998).

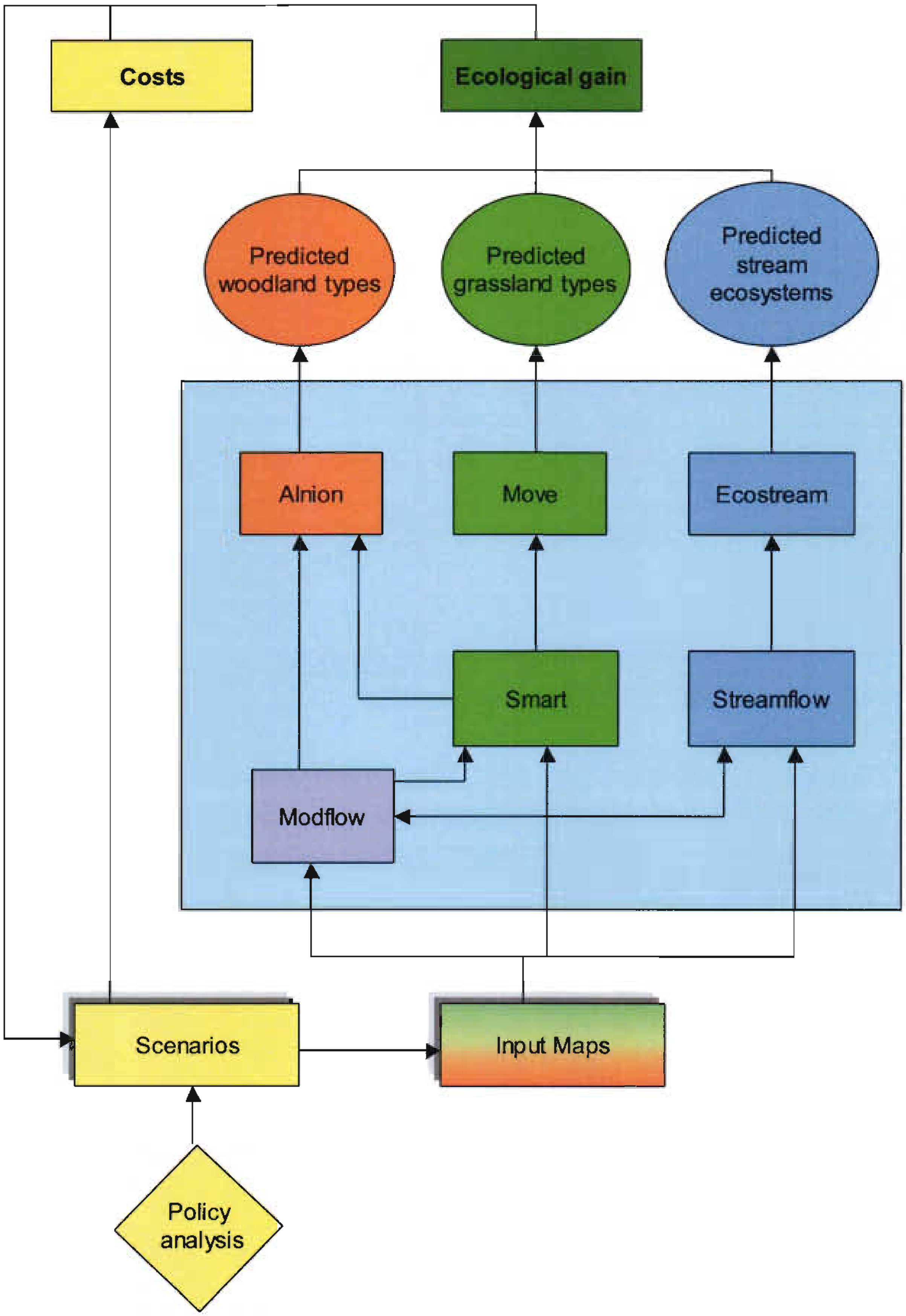


Figure A3.4 Example of an eco-hydrological model for wet grassland management and restoration: the example of the Smart/Move model (after Pieterse *et al.* 1998).

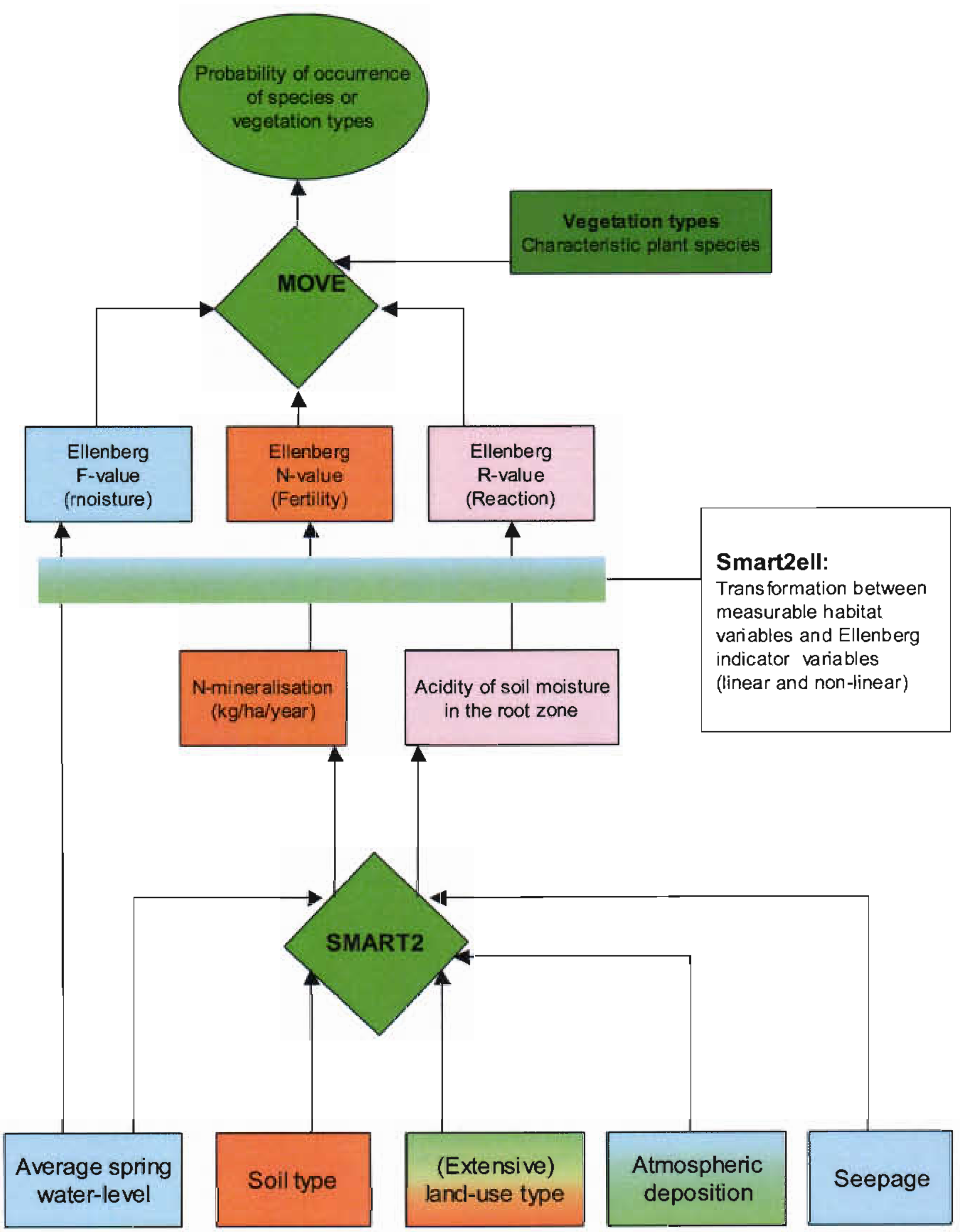


Figure A3.5 *Decision Support Tree* for restoration of wet grassland (Mountford (ed.) in press). See section 3.3. Yellow boxes represent a situation where a decision or action is required by the practitioner.

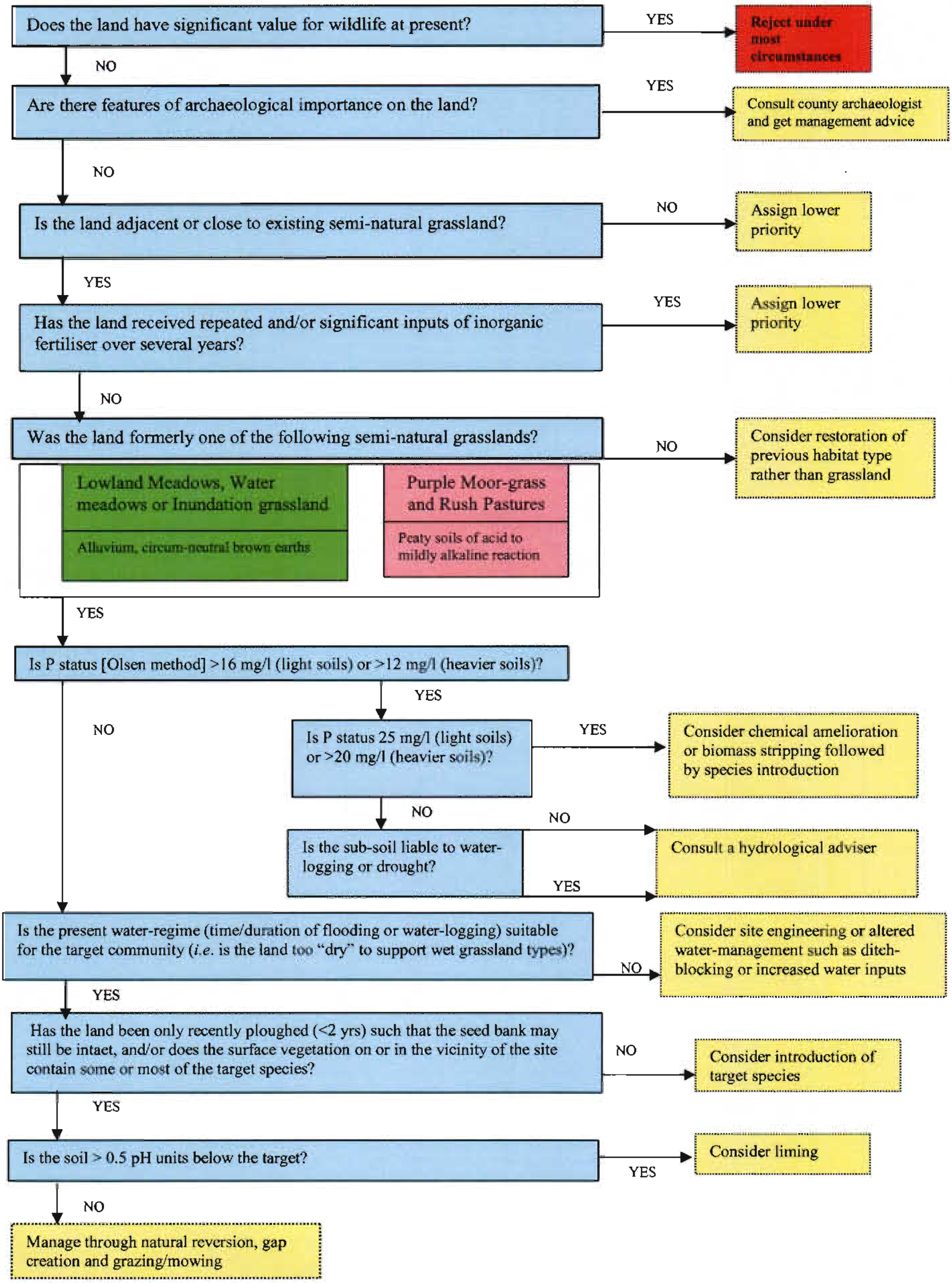


Table A3.3 Suggested water-depth requirements for wetland restoration options. After Somerset County Council (2000)

	Suggested depth (in metres) for first 10 years following restoration			
Year and quarter	Wet grass	Commercial Reed	Fen	Open Water
Year 0 March	0	0	0	0
June	0	0	0	0
Sept	0.3	0.3	0.3	0.3
Year 1 Jan	0.2	1.2	0.7	1.2
Mar	0.025	0.75	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 2 Jan	0.2	0.5	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 3 Jan	0.2	0.75	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 4 Jan	0.2	1	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 5 Jan	0.2	1	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 6 Jan	0.2	0	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 7 Jan	0.2	1	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 8 Jan	0.2	0	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 9 Jan	0.2	1	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 10 Jan	0.2	0	0.2	1.2
Mar	0.025	0.3	0.0	1.2
Jun	0	0.05	-0.1	1
Sept	0	0.05	-0.1	1
Year 11 Jan	0.2	1	0.2	1.2

APPENDIX 4: The Great Fen Project – the "No Diversion" Scenario

A4.1 Background and Introduction

Following discussion with the Steering Group (see main report section 5.3.2), other potential scenarios were identified that the Group believed should be addressed. It was agreed that an assessment of the potential habitat distribution be made under the following conditions:

3) Summer abstractions not to exceed the average of what is presently taken (*i.e.* allowing for no input via runoff from the uplands) or additional diversion from Stanground).
4) With the further limitation that there also be no winter diversion into storage (*i.e.* into the reed beds)

Appendix 4 includes maps and explanatory text that respond to this request. This scenario is demonstrated both under present climatic conditions **(F1)** and those described under the *UKCIP98* medium-high climatic change forecast **(F2)** - see section 4.2.3.2 of the main report.

A4.2 Assumptions

In running the scenarios described below, assumptions were made that:

a) Once water is in a High Level Drain (HLD) it is no longer available for use within the Great Fen project.
b) Within each of the three Great Fen sections ("blocks" - each separated from the others by HLDs), water can be moved from high- to low-lying areas through the existing Low Level Drain (LLD) network.
c) There is no competing demand for water in each block.
d) No spray irrigation is practised.
e) No storage ponds are created.
f) Water that enters the reedbed/pond (open water) habitat is not available for other uses.
g) There is no land shaping (digging or scraping out hollows for ponds or bunds).
h) There is no restriction on the upper area that can be flooded.
i) There are no aesthetic considerations on the expanse of bare mud that might be exposed during periods of severe drawdown.
j) There is no constraint that a pond (of open water) must be present in every year.
k) Active management of encroaching reeds will maintain open water habitats within the complex of reedbed and pond.
l) Carr and scrub encroachment will be controlled.

A4.3 Limitations

Similarly, there are certain clear limitations to the approach as reported here:

a) No allowance was made for enhanced evaporative rate from shallow water.
b) No account was made of any water quality issues.
c) Volume area relationships within a block were unsubtle.
d) The model assumes that groundwater flow/losses were not significant.

A4.4 Results and discussion

A4.4.1 Degree of submergence in reedbed/pond complex

Clearly, the deeper the "pond" the more likely is it to persist through dry periods. However, without land shaping the very flat nature of the landscapes in the Great Fen Core Area means that a deep pond must also have a very large surface area. An additional problem of the flat topography is that even small fluctuations in water level generate very large changes in surface area. It is the opinion of the CEH team that, except over the existing ditch networks, it is not possible to have a pond deep enough to stay naturally clear of *Phragmites* without some land shaping.

A4.4.2 Micro-topography

Years of "slubbing out" the drains and dumping the spoil material on the banks means that many fields are slightly "dished" with lower elevations in the middle and slightly higher elevations (resembling levées) around the margins. LiDAR can measure these differences so that predicted ponds are often discontinuous square-shaped blocks - this can be observed most clearly in the Southern and Middle sections. It should be noted that most of these "square" ponds will only be a few centimetres deep in their centre.

A4.4.3 Proportion of reedbed/pond habitat

The most critical factor in the simulations is the relative area of reedbed/pond habitat that is desired. Figure A4.1 shows (for the Southern Section and scenario **F1**) the difference in the amount of submergence (depth of the pond) for a reedbed/pond covering 20% of the total area compared to one covering 30% of the total area. For the smaller reedbed/pond area, there is some submergence for 97% of the time and the average maximum depth over the lowest-lying field would be *ca* 716mm (ignoring water depths over the old ditch network). For the larger reedbed/pond there is some submergence for 85% of the time but the average maximum depth of water is only 466mm. A pond occupying less than 20% of the total area is obviously not much more reliable than the "20%" pond, since it is the sequence of dry years with no appreciable winter run-off that is the key factor that causes the pond to dry out. If winter topping up were permitted, the surface level of the reedbed/pond can be kept within closer bounds.

Under the *UKCIP98* medium-high climate change scenario (**F2:** Figure A4.2) the average maximum depth of water in the "20%" reedbed/pond declines to 563mm (from 716mm) and the reliability drops just below 90%. A "30%" fen/pond becomes very unreliable under the climate change scenario since it is dry 27% of the time and has an average maximum depth of water of only 164mm. Over the whole simulation period a "30%" pond under a revised climate never reaches the level of the weir.

A4.4.4 Harvesting runoff

The existence of the reedbed/pond requires that any run-off from the dry grassland areas within the block be diverted into the fen. Runoff is only available when the soil reaches saturation. Hence this is a conservative estimate due to the very low gradients within the area. It is assumed that this "upland" runoff can be harvested with insignificant losses *en route* to the reedbed/pond complex. However, there are no data to confirm whether this is actually possible.

Wetter winters under a climate change scenario should increase the amount of winter runoff that is available from an average of 71mm to 92mm. The proportion of runoff occurring during the winter increases from 84% of the annual total to 89% of the annual total, and in about 20% of years there will be no runoff at all.

A4.4.5 Soil moisture deficits and stress.

Under the current climate the "wet" and "dry" grassland habitat dry out to a similar degree with the soil moisture content close to the PWP (permanent wilting point) about 12-13% of the time. The wet grassland is however frequently submerged (38% of the time). This alternation between being submerged and being desiccated may produce a difficult environment for some plants. Soil moisture in the reedbed/pond complex stays above the PWP all the time even when there is no standing water. Under the climate change scenario **(F2)** the wet and dry grassland desiccate more often, 21% and 20% of the time respectively. The wet grassland is inundated less frequently (*ca* 23% of the time). The reedbed/pond complex will occasionally (during 4 months) dry out to the PWP.

A4.4.6 Spatial Coherence and Visual Impact

With no land shaping and no diversion of water from the HLDs the proposed restoration does not achieve spatial coherence, the land between Woodwalton and Holme Fens will still contain an extensive area of dry grassland within the Northern Section (see Figure A4.11). This means that the road crossing the Great Fen will Core Area will only provide at best fleeting views of wetland. Views from the East Coast mainline (providing many travellers with a panorama over the Great Fen), will not be very impressive - only a small part of the Northern Section will register as having changed.

A4.5 Individual Sections of the Great Fen Core Area

A4.5.1 Southern Section

Due to the tongue of higher land that stretches into this section, there are two areas where the topography may be suitable for wetland habitats, despite the land being higher than average for the section. These patches are identified on Figure A4.3 and have been allocated to a wet grassland habitat. Figure A4.4 is a hill shading of the topography to aid visualisation.

The lowest fields have an average elevation of about –2.1m ODN. Setting a weir one metre above this level means that all land below –1.1m ODN is liable to flood. Land above –1.2m is allocated to the dry grassland habitat with the exception of the two topographic depressions described above.

The average, maximum and minimum extent of submergence is indicated on Figures A4.5, A4.6 and A4.7. Note that the dish shape cross section to the fields is particularly noticeable in Figure A4.5.

A4.5.2 Middle Section

The centres of the lowest fields are about half a metre above the level in the southern section. There are no topographic "anomalies" like those found in the Southern Section, however it is not clear whether the northeastern corner is isolated from the rest of the block.

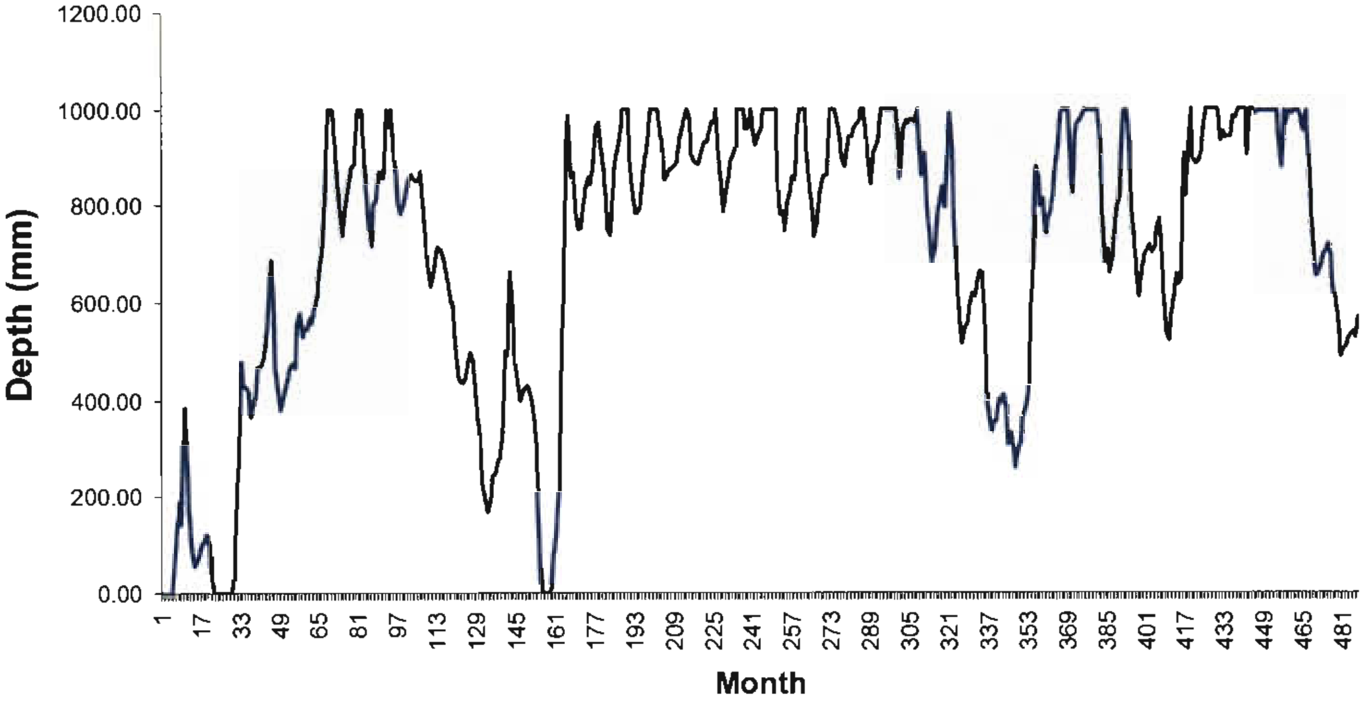
Figure A4.8 illustrates the topography as a hill shade image. Figures A4.9 and A4.10 show the restored land cover and the maximum flood level using the same parameters as the Southern Section (20% of the area to reedbed/pond and a weir approximately one metre above the lowest fields).

A4.5.3 North Section

The influence of Whittlesey Mere can still be detected in the topography (Figure A4.11), and in particular the extensive network of roddons that led out of the mere is clearly apparent. The lowest fields are around –1.6m ODN. Figure A4.12 indicates the restored land cover and Figure A4.13 the maximum flood.

Figure A4.1: Great Fen Restoration Scenario **F1** - no diversion and current climate

A) Assuming reed/open water habitat as 20% of Core Area southern section



B) Assuming reed/open water habitat as 30% of Core Area southern section

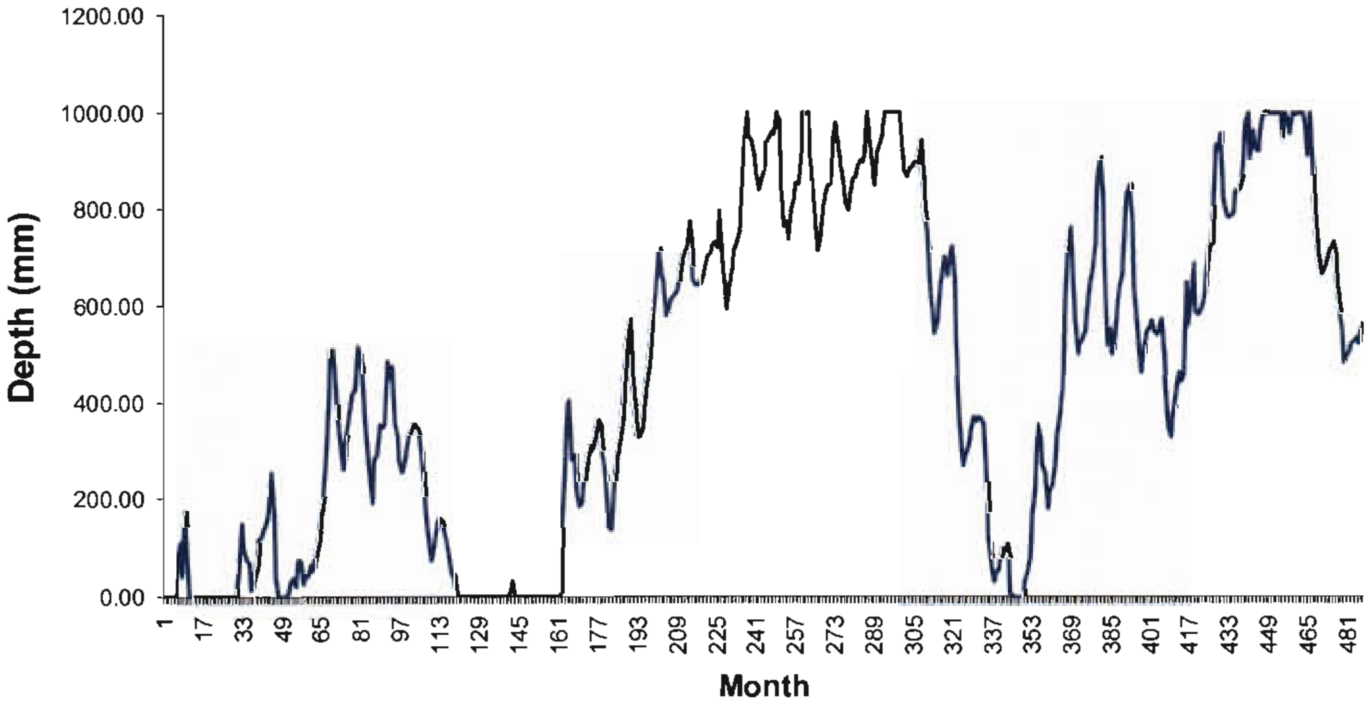
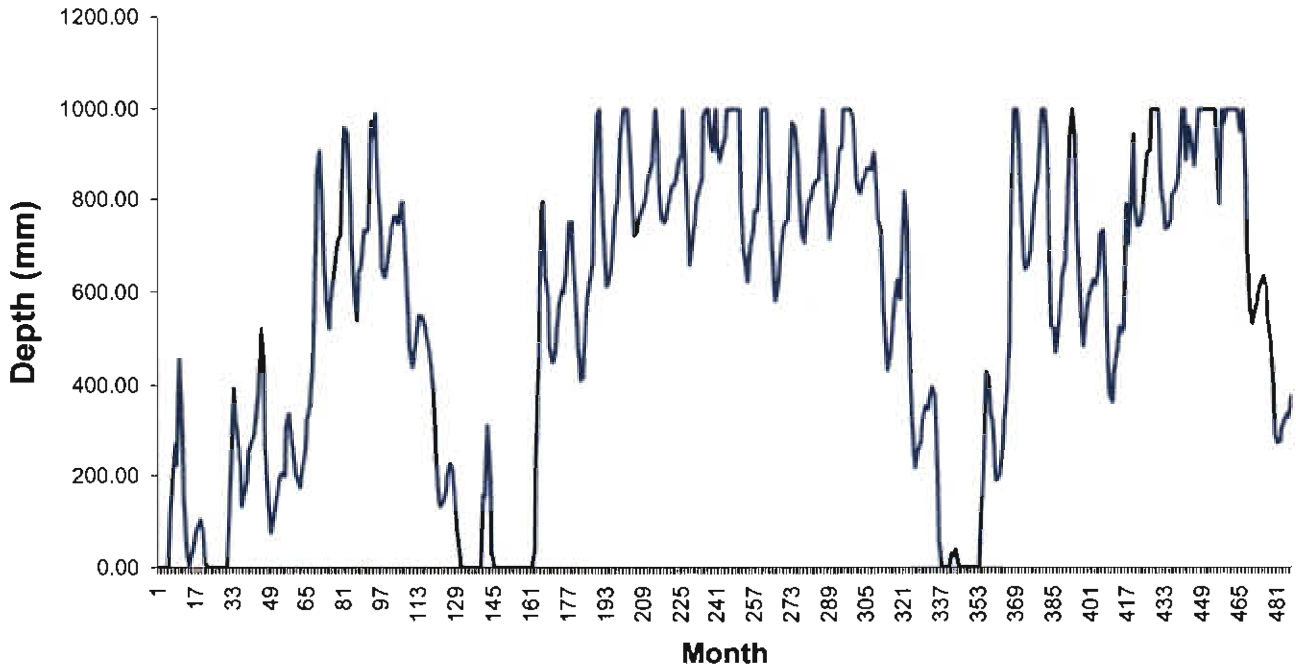


Figure A4.2: Great Fen Restoration Scenario **F2** - no diversion and new climate

A) Assuming reed/open water habitat as 20% of Core Area southern section



B) Assuming reed/open water habitat as 30% of Core Area southern section

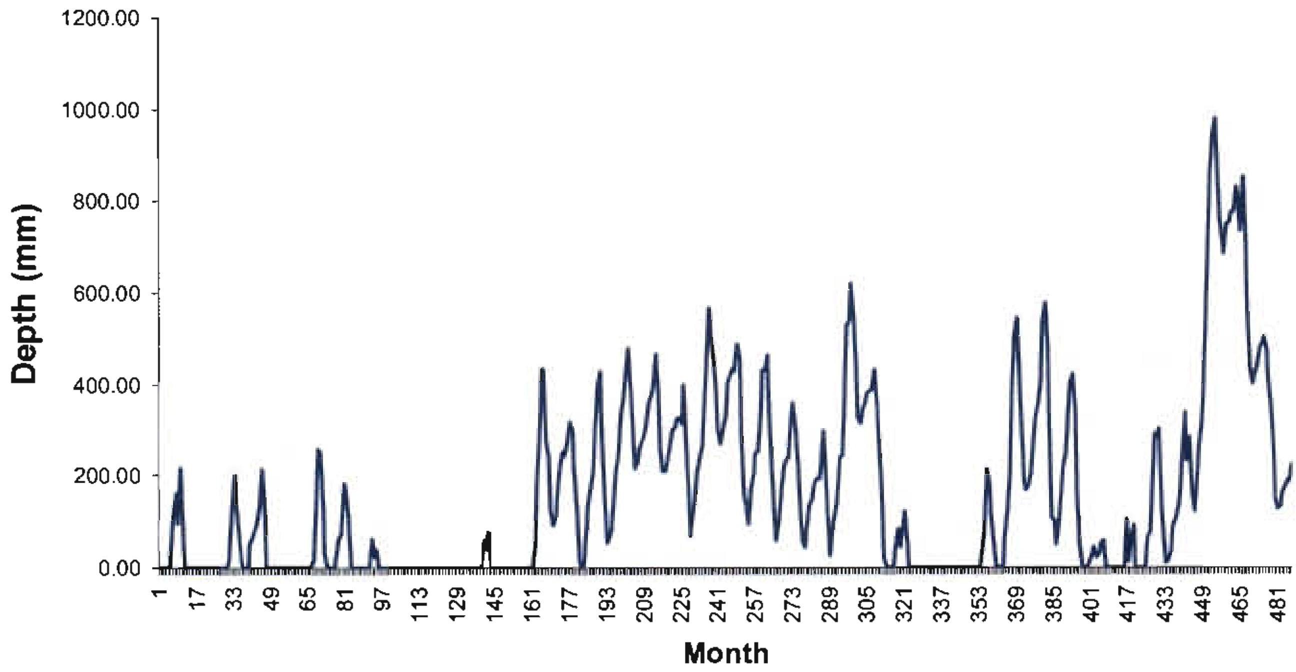


Figure A4.3: Great Fen Core Area - Southern Section Topography (omitting Woodwalton Fen NNR)

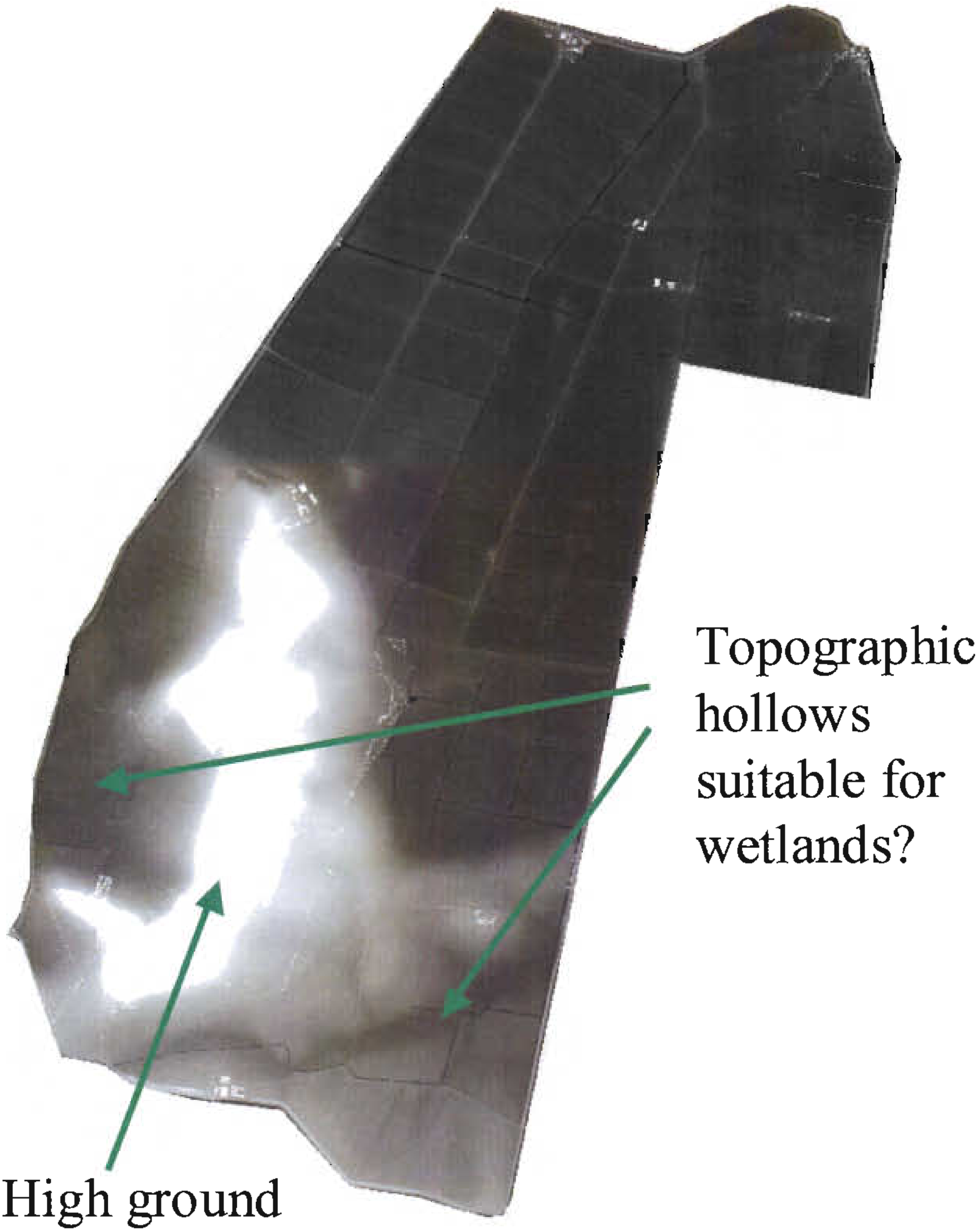


Figure A4.4: Great Fen Core Area - Southern Section
Hill-shaded Topography

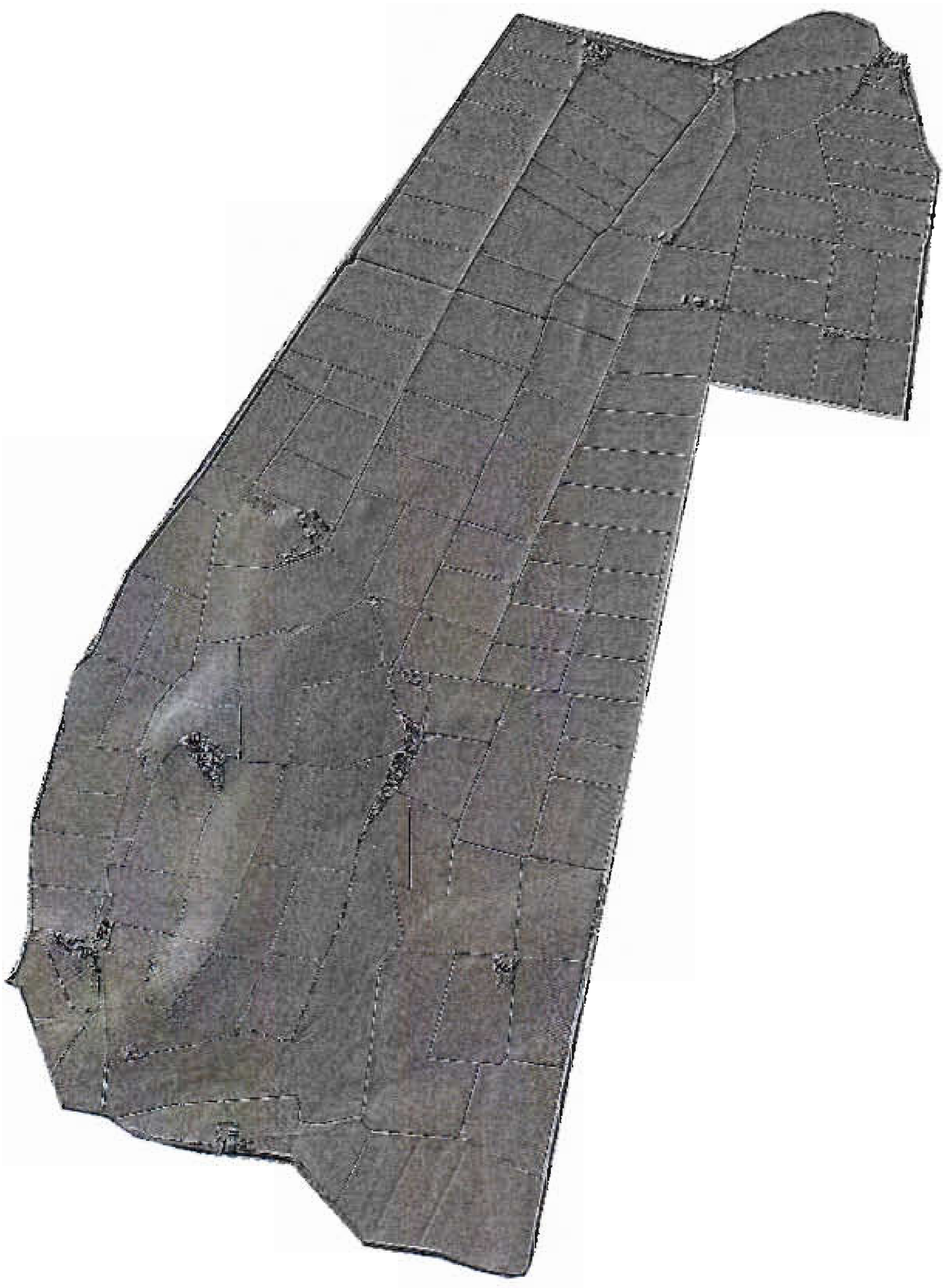


Figure A4.5: Great Fen Core Area - Southern Section
No diversion scenario **(F1)** - average conditions

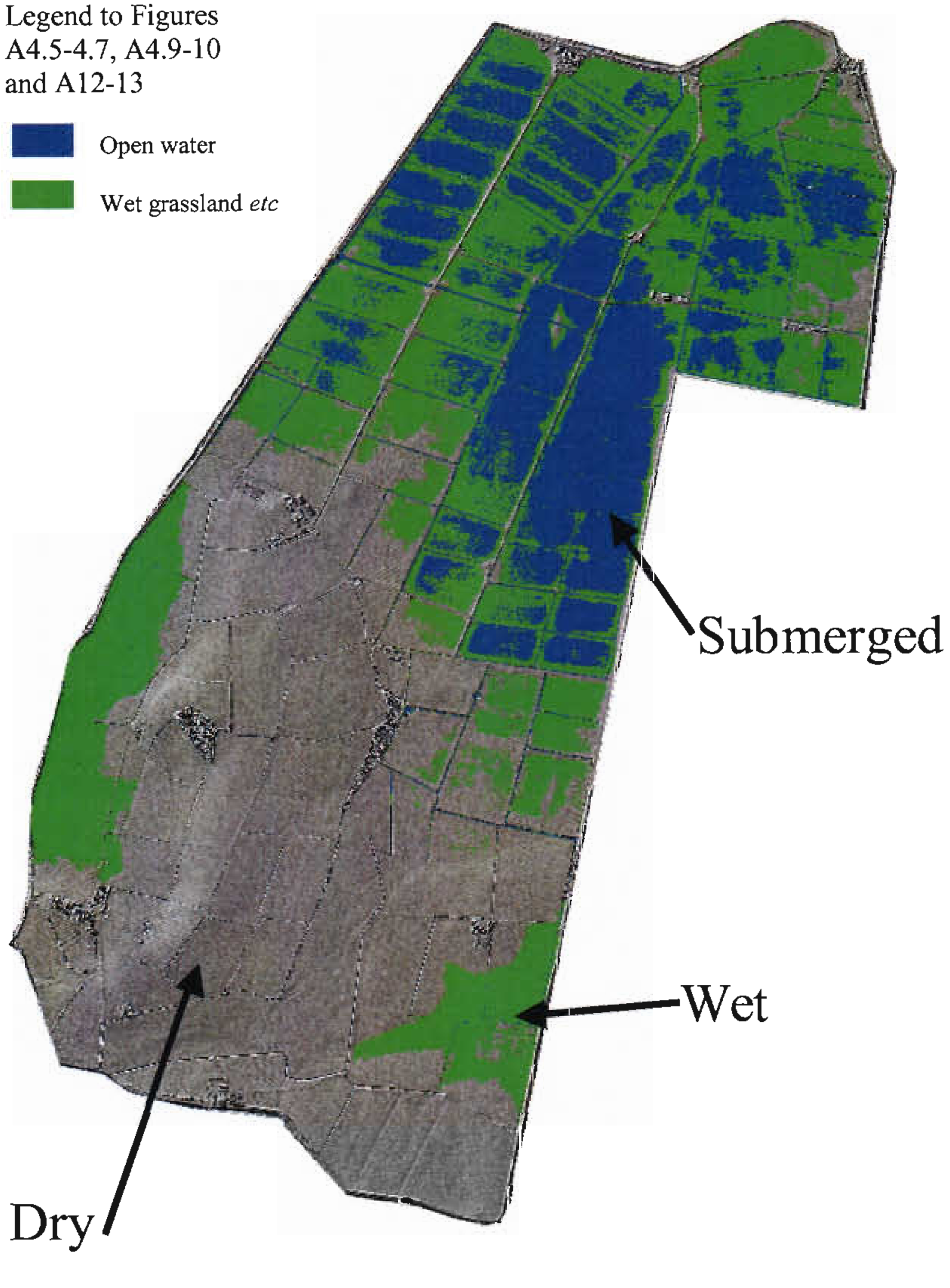


Figure A4.6: Great Fen Core Area - Southern Section
No diversion scenario (**F1**) - maximum flood

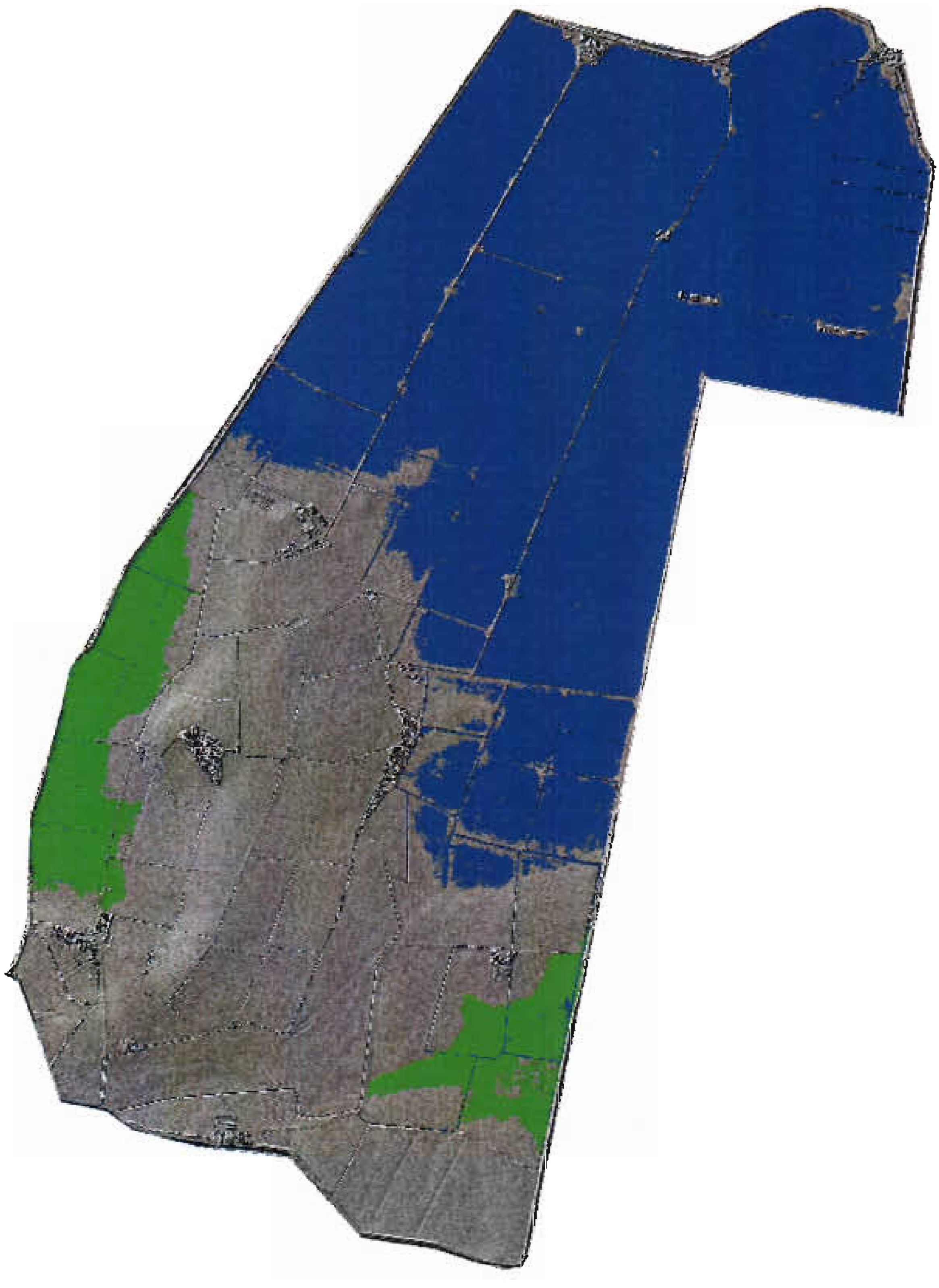


Figure A4.7: Great Fen Core Area - Southern Section
No diversion scenario (**F1**) - minimum submergence

Figure A4.8: Great Fen Core Area - West Section
Hill-shaded Topography

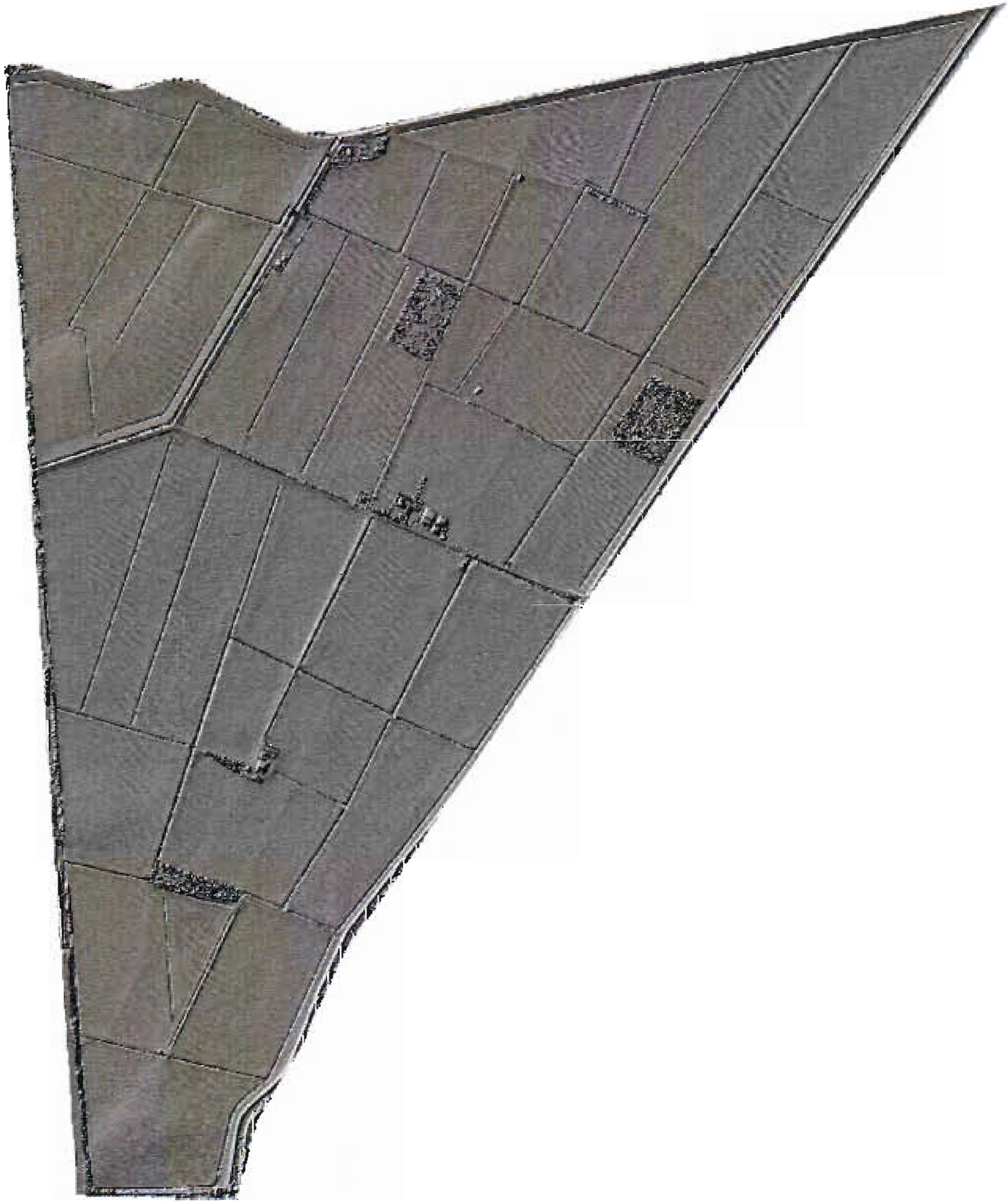


Figure A4.9: Great Fen Core Area - West Section
No diversion scenario (**F1**) - average conditions

Figure A4.10: Great Fen Core Area - West Section
No diversion scenario **(F1)** - maximum flood

Figure A4.11: Great Fen Core Area - Northern Section Topography (omitting Holme Fen NNR)

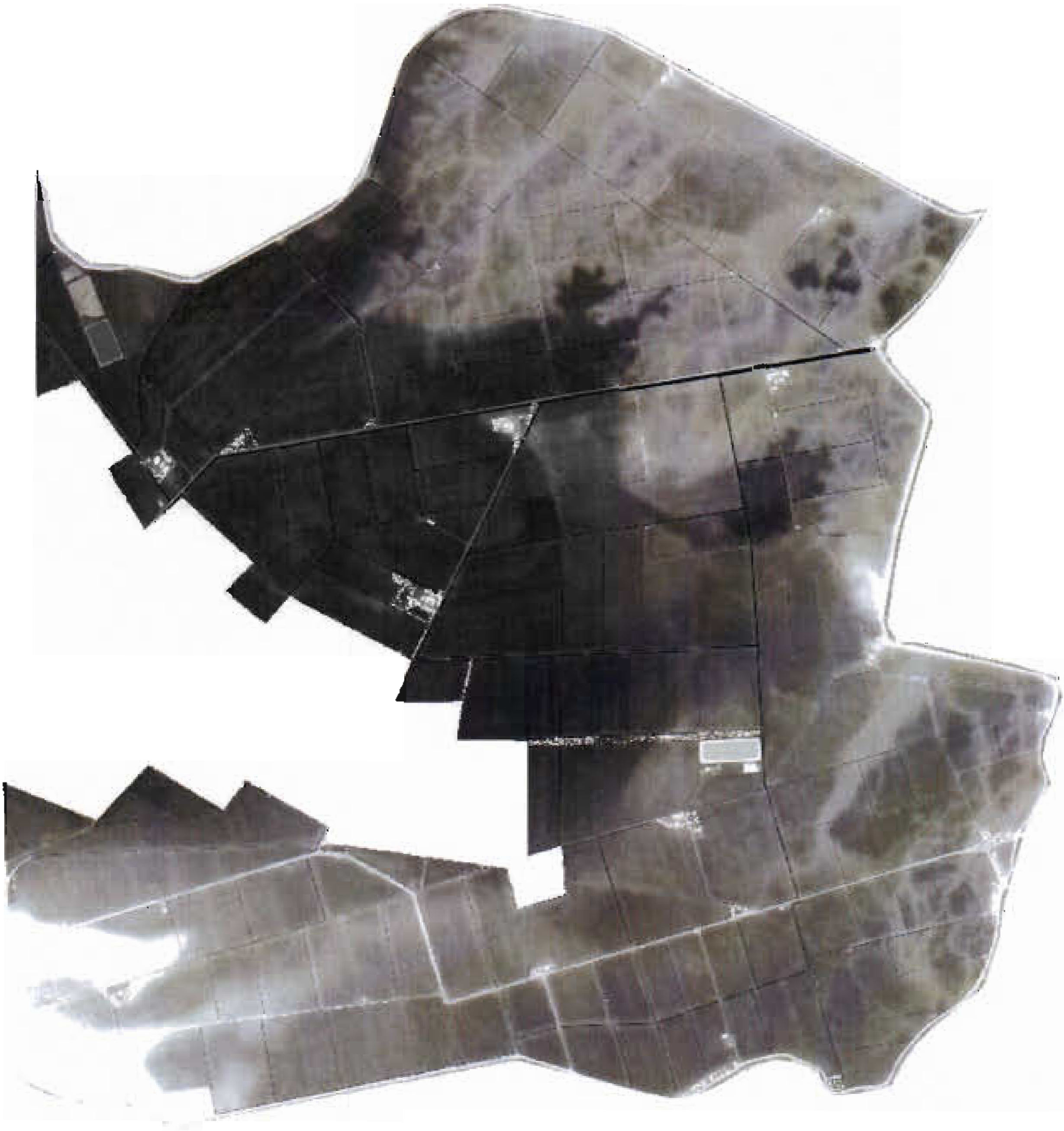


Figure A4.12: Great Fen Core Area - Northern Section
No diversion scenario (**F1**) - average conditions

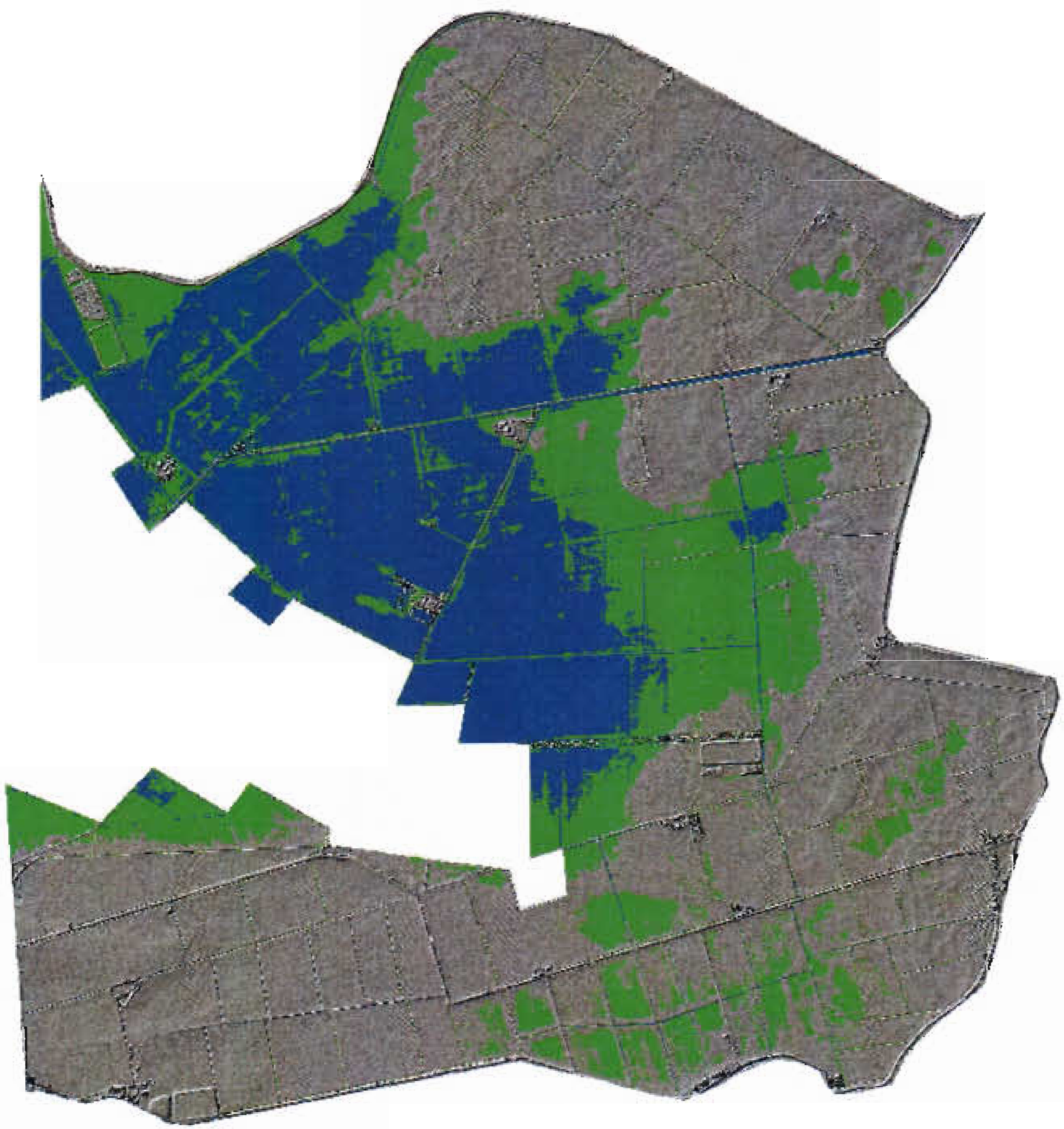


Figure A4.13: Great Fen Core Area - Northern Section
No diversion scenario **(F1)** - maximum flood