A Guide to Management Strategies and Mitigation Measures for Achieving

Good Ecological Potential in Fenland Waterbodies

Representing Drainage Water Level & Flood Risk Management Authorities

IDB Bedford Group

Cambridgeshire ACRE

in partnership with Environment Agency

Middle Level Commissioners 1862

North Level District Internal Drainage Board

South Holland Drainage Board

Water Management Alliance

WITHAM FOURTH DISTRICT INTERNAL DRAINAGE BOARD

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A Guide to Management Strategies and Mitigation Measures for achieving **Good Ecological Potential in Fenland Waterbodies**

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Association of Drainage Authorities & Environment Agency

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Foreword

Since early settlers arrived on our shores our lowland landscapes, such as The Fens, have been progressively modified by man to meet changing needs. Fishing, wildfowling, peat-digging and reed cutting have given way to agriculture, permanent settlement, infrastructure and industry.

Although at first acquaintance the Fens can today appear desolate, its low-lying swathe of level terrain still contains a hidden wetland landscape of thousands of miles of ditches and drains that surround every field, road and settlement. These modifications by man over many hundreds of years have served to manage water and facilitate its passage from the land via drains and pumping stations into rivers and finally out to sea.

These water bodies are the part of The Fens that are not built on, ploughed, or harvested. As a result, they offer a refuge to nature just as hedgerows do in the rest of our landscape, creating strips of seasonal life. They are home to otters, warblers, dragonflies and rare aquatic plants. But just like hedges, the water bodies of The Fens must be cut, cleared and shaped every now and then so that they continue to function to manage water levels, reduce flood risk and provide suitable habitat for species such as the water vole.

Today, we rightly value our water environment and have developed targets to progressively improve their quality across England. The Water Framework Directive is an evolution of this approach to deliver a common standard of improvement across Europe. Whilst our future relationship with Europe will undoubtedly change in the coming years, our determination to deliver a better water environment will continue to be built upon this legislative approach.

Our challenge is to ensure that these continued improvements to the water environment work in tandem with the wider needs of society to manage the risk from flooding and drought, especially in a heavily modified landscape such as The Fens. This guide offers a key tool to considering how we can incorporate environmental enhancements into lowland water bodies whilst retaining these functions.

Ian Moodie
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May 2017

Introduction

Rivers, lakes and coastal waters are vital natural resources: they provide drinking water, important habitats for many different types of wildlife and are an essential resource for industry and recreation. However, a significant proportion of them are environmentally damaged or under threat from the pressures of urbanisation, water abstraction and climate change. The European Water Framework Directive (WFD), established in 2000, was transposed into national law in 2003 to reduce those pressures through a planning process to manage protection and enhancement of inland surface waters (lakes, rivers and drains), transitional waters (estuaries), coastal waters and groundwater. In effect, it puts the ecosystem at the heart of how we manage and protect the water environment, seeking more naturally functioning waterbodies, sustainable use of water resources, protection of water uses and high quality habitats for wildlife.

The WFD's objective is to ensure that all aquatic ecosystems meet 'Good Status', as well as the water needs of terrestrial ecosystems and wetlands. The WFD also prescribes that there should not be any deterioration in the state of the water environment, from a set baseline, and requires all waterbodies to be at Good Overall Status (or the best possible status). 'Overall Status' is comprised of a combination of 'Chemical Status' (the chemical quality of the water) and 'Ecological Status' (the condition of the wildlife habitat and the wildlife occupying it). Protecting and improving the environment is an important part of achieving sustainable development and is vital for the long-term health, well-being and prosperity of everyone.

To implement the WFD, Member States are required to establish River Basin Districts and for each of these a River Basin Management Plan which is prepared, implemented and reviewed on a six-year cycle. There are four distinct elements to the river basin planning cycle: characterisation and assessment of impacts on river basin districts; environmental monitoring; the setting of environmental objectives; and the design and implementation of the programme of measures needed to achieve them. Management authorities, such as Internal Drainage Boards (IDBs), Local Authorities (LAs) and the Environment Agency (EA), have a duty to implement measures to improve the ecology of water bodies where they are at a lower ecological status than they should be, and to ensure there is no deterioration.

The focus of this guide is the WFD classified waterbodies in the Fens of East Anglia, which are artificial and heavily modified watercourses often collectively known as 'drainage channels'. These channels usually contain slow-flowing water, retained behind sluices and pumped into Main Rivers or the sea; most have no 'natural' flow at all. The WFD sets out that the 'natural' condition of the water system should be used as the basis for determining the Good Ecological Status (GES) of each waterbody, ultimately seeking a return to as close to a natural condition as possible. However, the hydrology of the Fens is the result of millennia of environmental change and centuries of human intervention. Therefore there is no realistic comparative natural watercourse on which to base a reference condition. For cases like this, the WFD offers an alternate solution, whereby competent authorities must define both the highest achievable ecological status 'Maximum Ecological Potential' (MEP) and the ecological status they are going to try to achieve 'Good Ecological Potential' (GEP). In determining the MEP and GEP that a watercourse could achieve, assessors are faced with the challenge of deciding which watercourse characteristics are alterable, whilst still retaining its functions to provide, for example, flood defence and land drainage in Fenland, this is often a matter of expert judgement.

The GEP Working Group hopes that this guide will be a basis for education and consensus building whilst identifying the ecological potential of the Fenland waterbodies and complying with the WFD. The approach taken should also be useful for other IDBs and public authorities – the EA and LAs - across England. Additionally, it should help to explain the requirements of the relevant parts of the WFD for a wider audience including, landowners and rate payers, conservation organisations and the National Farmers' Union.

The guide sets out the following information:-

- As a context to the area, it describes the pre-history and modification history of Fenland, the contemporary landscape, types of drainage channel and their ecology and conservation.
- To interpret the relevant parts of the WFD, it explains hydromorphology, designation of highly modified and artificial waterbodies, WFD classification and assessment process, the importance of Mitigation Measures and a step-wise process to define and achieve GEP.
- For understanding and implementing Mitigation Measures, it presents case studies and management techniques.
- For defining the technical terms used in the text, there is a glossary.
- For sources of information, there is a section on references and further reading.

As the definition of GEP, and the selection of suitable combinations of cost effective measures is a relatively complex process, a step by step selection method is described. Following these steps and putting processes in place to define and realise the ecological potential, will not only lead to implementation of the WFD but also help to meet the 'Lawton principles' in Making Space for Nature 'more, bigger, better and joined' by enhancing the connections between wildlife sites through physical corridors (the drainage ditches) and reducing pressures on wildlife by improving the environment (such as implementing Mitigation Measures). Thus, the enhanced biodiversity of the drainage channels will create a more resilient and coherent ecological network. This will contribute to, and complement, the many landscape scale and local initiatives underway to maintain and enhance the biodiversity and hence the social benefits of the Fenland landscape.

This guide was commissioned by the Environment Agency (EA) principally for the staff and members of IDBs and the Environment Agency operating in the Fens of East Anglia to support the implementation of the Water Framework Directive (WFD) in their operational area. The task in producing this new guide has been greatly helped by the willing input of engineering and environmental staff of IDBs from Internal Drainage Boards and EA, who formed the Working Group to steer the Guide's content and its preparation.

We would particularly like to thank all the staff of The IDBs and EA who supported the working group with their willing input of knowledge and case studies, our illustrator and designer Coral Walton of Coral Design Management, and the coordinator of our later Working Group meetings Rachael Brown of Cambridgeshire ACRE, who were instrumental in bringing the content together and publishing the guide.

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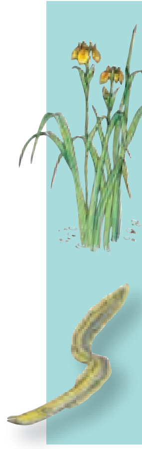


Introduction

This section sets the scene and context for the contribution made by the implementation of 'Mitigation Measures' to achieve GEP in Fenland waterbodies, and covers the:-

- pre-historic Fenland landscape;
- modification history over the last millennia;
- emergence of the present landscape since the large-scale drainage works that began in the seventeenth century;
- contemporary landscape;
- effective construction and maintenance of drainage channels; and
- ecology and biodiversity conservation of drainage channels.

The Fens are an area of low-lying land around The Wash embayment occupying large parts of Lincolnshire and Cambridgeshire with smaller areas in Norfolk and Suffolk; encompassing about 405,000ha (Figure 1.1).

This area was formerly England's largest wetland, a complex of waterbodies, wet woodlands, bogs, fens and marshes. The peat or black fens were formed under the influence of freshwater which drained into and flooded the Fenland basin, a process which started about 5000 Before Present (BP).

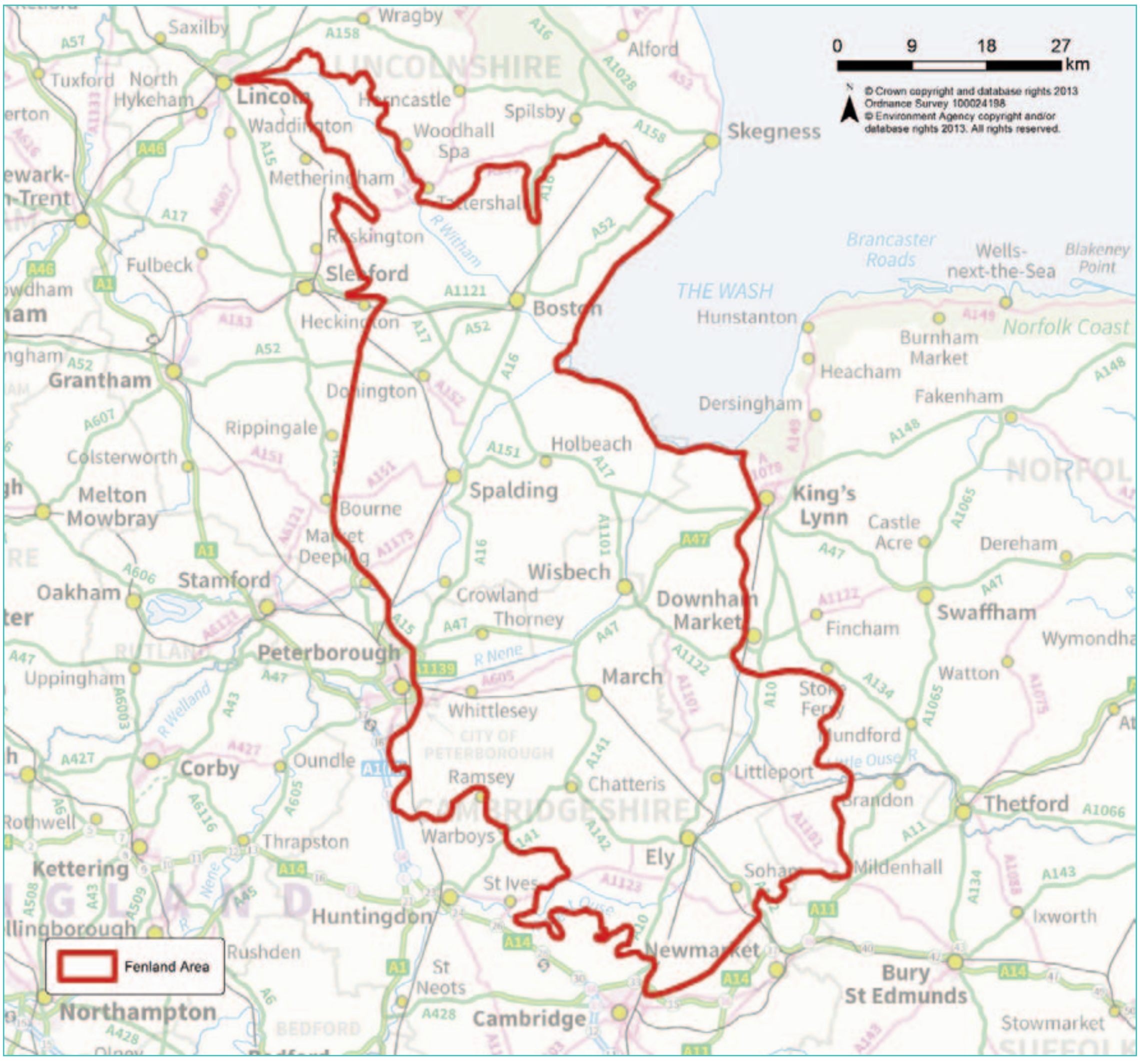
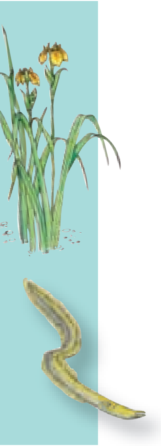


Figure 1.1 Map showing the Fenland area outlined in red

Closer to The Wash, the silt fens were formed of sediments deposited by wave and tidal action, and in recent times by land reclamation.



Drainage of the Fens began in early medieval times and accelerated in the seventeenth and eighteenth centuries. Now the remnants of this vast wetland are confined to a few nature reserves and old pits, along some of the drains and their banks in farmland which emerged from the drained fens. Less than 1% of the original wetland habitat remains. The present, drained Fens are notable for their large-scale, flat, open landscape. These blankets of silts and peats form some of the finest agricultural land in Britain. Except for the Isle of Ely, which rises above 20m, elevations rarely pass 10m and vary little over long distances. Much of the peat fen is below sea level, and relies on pumped water drainage and gravity discharge through sluices to the Fenland rivers at low tide. Peat wastage through shrinkage, oxidation and wind blow is a long-term issue affecting drainage and farming.

It is clear that, over this timeframe, there has not been a period during which a persistent habitat pattern has existed. In consequence, this continual change means that no realistic terrestrial or aquatic reference condition exists to which we might compare restoration attempts for Fenland waterbodies. Nevertheless, some waterbodies support a rich variety of wildlife including rare species plants and animals.

Pre-historic Fenland landscape

Fenland has a distinctive character governed by its complex geomorphological and occupational history. In the late Jurassic period (about 155 million years ago) the area was under a shallow sea in which marine Oxford, Ampthill and Kimmeridge Clays were deposited. These now form the base of the Fenland basin. Rocks that formed on top of this base and that surround the district, in the following 150 million years, such as chalk, were subsequently removed by uplift and erosion and more recently by about 2.5 million years of glacial erosion in the Pleistocene period. As ice advanced and retreated, ice sheets, outwash channels, paleo-rivers, such as the Trent and Bagington, and existing rivers, such as the Nene, Welland and Great Ouse, scoured a basin discharging through a fluvial network to The Wash. During the colder glacial periods, sea levels were possibly lower by up to 150m at times, causing the current coastline to be high ground adjacent to the vast plain of Doggerland which is now under the North Sea. As the ice retreated at the end of the Last Glacial Maximum (approximately 18000 BP), glacial till material (clay) and morraine (sand and gravel) was left behind over some parts of the eroded clay landscape, such as at March, Ely, Littleport, Sutton and Manea. It is believed that about this time 'Lake

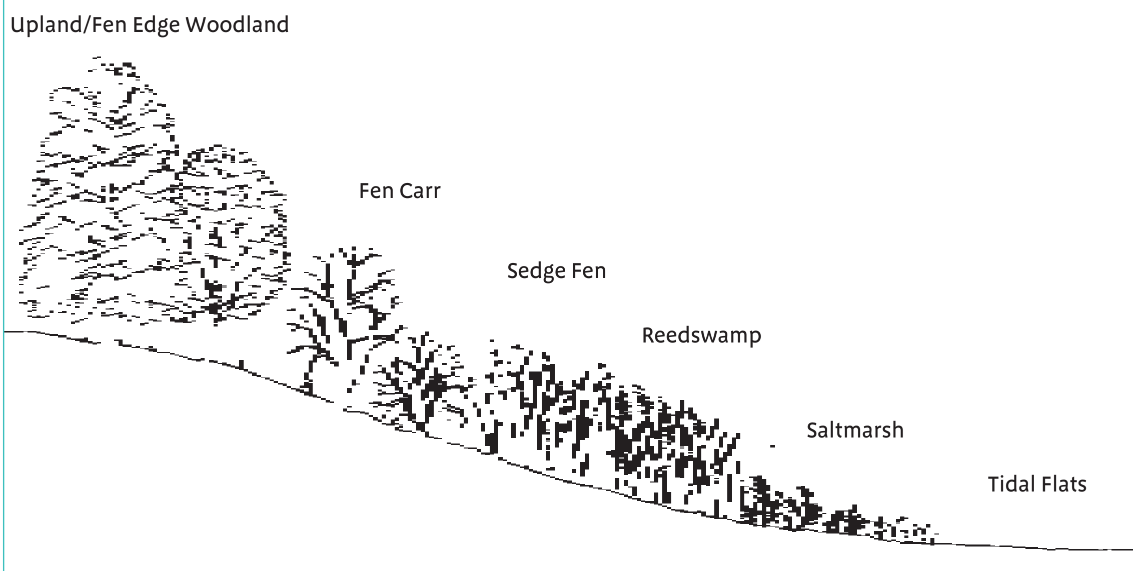


Figure 1.2 Vegetational zonation and succession in the post-glacial Fenland Landscape

Sparks', a melt-water lake adjacent to the snout of a glacier, existed over a large part of the Fenland landscape, dammed by the last ice sheet. As the ice receded, the swollen melt-water rivers deposited sand and gravel into the Fen basin on the way to a 'proto-North Sea', much smaller and distant than today. Some of these deposits still exist and form ridges and hills on which present settlements have been established such as Sutton, Witchford, Downham and Littleport.

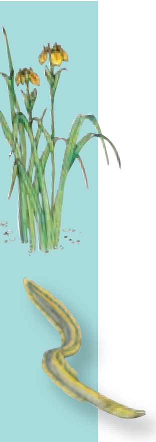
Following the glacial period, whilst the sea-level was still rising, the Fenland basin remained relatively dry. River systems draining the vast upland catchment crossed a post-glacial landscape dominated by woodland rooted directly on the Jurassic clays and glacial sand, gravel and till. During the 'pre-Boreal' (10000BP – 9000BP) and Boreal (9000BP – 7000BP) climatic periods, Mesolithic (middle stone-age) man lived a hunter-gatherer lifestyle in this primeval landscape and probably had a limited impact on the ecology.

The sea level gradually rose in this period, only affecting Fenland when it had reached close to its current position. The forest became waterlogged in the lowest valleys first and died back due to root anoxia. This created the first areas of peat development as the dead vegetation began a very slow decomposition. As the sea advanced inland (marine transgression), bringing with it an increasing zone of brackish marine deposition, the groundwater level rose and an area of fen and marsh developed ahead of this advance. A natural ecological succession occurred; a zone of salt-marsh existed at the estuarine margins growing on the higher fringes of the tidal flats, and these were tidally influenced and intermittently submerged. Upslope from this zone and into successively drier ground, there was a transition through reed-swamp, sedge fen, fen carr and to woodland at the Fen edge and on the higher ground and its hinterland (Figure 1.2).

Figure 1.3A Roddons, the fossilised watercourses which exhibit the characteristic, dendritic patterns of modern intertidal creeks

The area of reed swamp and sedge fen increased to its furthest inland extent up to the higher ground around King's Lynn, Cambridge, Peterborough and Lincoln (the Fen edge) and left the glacial highlands such as Ely, as islands. During the following 4000 years, the successive marine transgressions (sea incursions) and regressions (sea recessions) resulted in the habitat zones moving landward and seaward with this exchange between marine and freshwater conditions. Under this changing depositional environment, peats were formed under fresh-water conditions and silts and clays were deposited under marine conditions.

The material deposition by the sea and the river network dammed up the estuarine zone, causing the area of water-logged freshwater reed-swamp and sedge fen to increase in size to its maximum extent in the pre-Roman period. Through this tidally influenced wetland landscape, freshwater courses of



upland rivers meandered to discharge into The Wash in an interconnected tidal-creek network. These creeks, filled with river and marine sediment when their estuaries were choked, are now seen as curious modern landmarks known as 'Roddons', which are the fossilised remnants of these creeks. Because of desiccation and resulting shrinkage by surrounding peat and alluvium since drainage began, these meandering silt banks are now some 2-3m above the peat fen and may be 50m or wider. This caused significant changes in local micro-topography of the Fenland basin (Figures 1.3A & B). As Roddon silt is more stable than the fen peat, some Fenland settlements were built on them, such as Prickwillow and Wisbech St Mary.

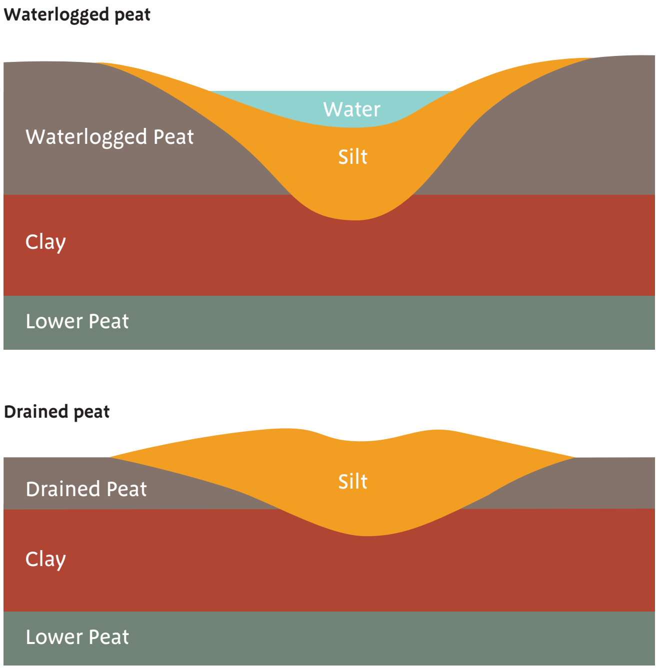


Figure 1.3B Schematic section to show the formation of a Roddon

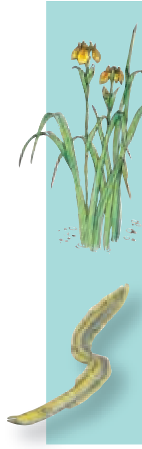
Modification History of Fenland watercourses

The first human influences around the Fens can be traced to Neolithic times, 6,000BP, when vegetation clearance for agriculture accelerated water runoff and sediment input. Evidence of Bronze age man causing localised modifications at the Fen Edge through building causeways and villages, as well as developing ditched fields and droveways, comes from the archaeological investigations at Flag Fen (4500BP) and Must Farm (3000BP). Major direct modification caused by drainage, diversion and channelization began during the Roman occupation in the 1st century and continued into the late 20th century. These changes have resulted in direct alteration of river shape and flow. By connecting areas of land, rivers have also been indirectly affected by catchment-scale land use changes, such as urban development, forestry and intensive agriculture. Rivers haves often been altered with the best of intentions but without knowledge of the potential repercussions. Population growth and technological advance since the Industrial Revolution resulted in extensive alteration of aquatic, wetland and terrestrial habitat within river corridors. Truly natural environments that have escaped both direct and indirect alteration by man no longer exist in Fenland.

The drainage of The Fens is believed to have begun with the Roman occupation of Britain. Examples of Romano-British waterways include Foss Dyke, Bourne-Morton Canal and Car Dyke. The Foss Dyke bridged the gap between the River Trent from Torksey to Lincoln, and connected to the Car Dyke and River Witham. This enabled navigation between Nottingham, in the heart of the East Midlands, to the Humber Estuary and the contemporary waterways in the wider Fenland.

Late Saxon and Medieval canals are also known in The Fens. Most are confined to the southern Cambridgeshire and Huntingdonshire fens and termed 'Leam', 'Lode' or 'Reach'. In the Middle Ages, the lush fertile fens yielded natural resources (fish, waterfowl, peat and reed) and rich grazing for animals. Artificial waterways or canals would have provided an ideal method of getting to and from the remote fens and for commuting between settlements, markets, fairs, larger towns and the ports of Lincoln and Boston, possibly transporting goods by fen lighter or similar. During the Middle Ages, large areas of undrained fen were owned by Fenland Monasteries and wool export to the UK and the continent brought considerable monastic wealth. Waterway construction was therefore often commissioned by the Church facilitating the transport of Fen produce as well as stone for building. The church also maintained the waterways until the dissolution of the monasteries in 1537.

Land drainage was begun on a large scale during the 1630s by the various investors who had contracts with King Charles I. The initial drainage was based on a proposal by John Hunt to construct a new river, 34 km long, from Earith to Denver, shortening the length of the River Great Ouse by many miles. It was eventually named the Bedford River (subsequently Old Bedford River) after Francis, Earl of Bedford, who was the chief financier (known as an 'Adventurer'). The project created or improved eight other channels and was judged as substantially complete in 1637. However, it was criticised for its limited goal to provide 'summer lands', leaving the land subject to winter flooding.



Later, Charles I appointed the Dutch engineer Cornelius Vermuyden as his agent to be involved with the second phase of construction in the 1650s. Vermuyden wrote a 'Discourse Touching the Draining of the Great Fennes' for the King. In this, he proposed two innovations to the drainage scheme: 'Washes' – areas of land allowed to flood in periods of bad weather to absorb the extra water that cannot drain to the sea – and a 'Catch-drain' around the eastern edge of the fen. The Washes were constructed as part of the second phase of drainage in the 1650s, but the Catch-drain was not developed until the early 1960s. The scheme was imposed despite huge opposition from locals who were losing their livelihoods based on fishing, wildfowling and peat digging.

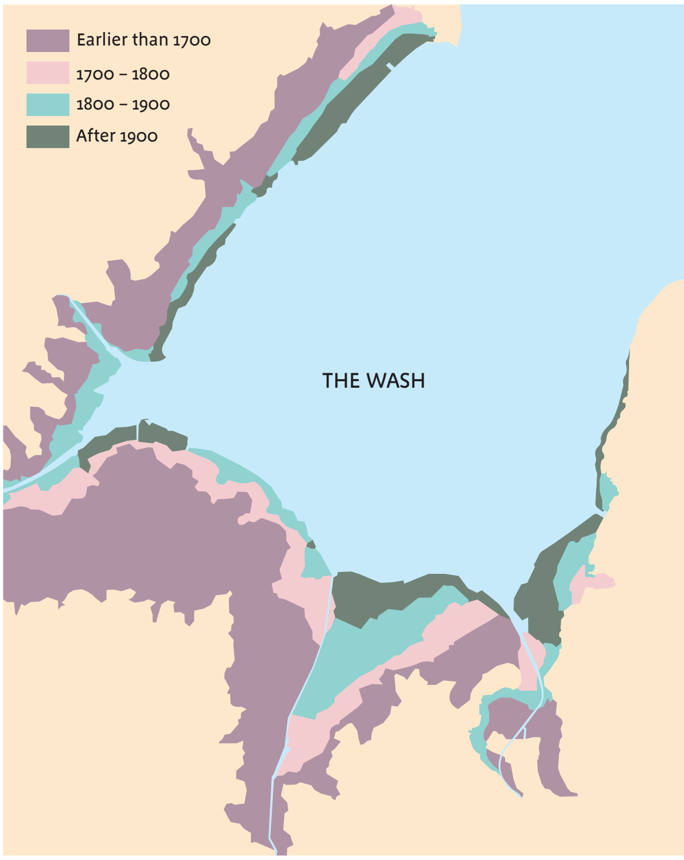


Figure 1.4 Sequential reclamation of land around The Wash

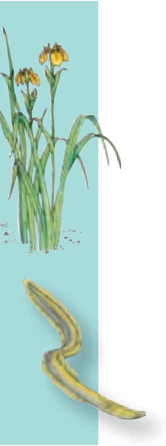
Despite the initial success of the reclamation, the engineers did not understand enough about the geomorphology of The Fens. The drying of the land caused peat to shrink greatly, lowering the remaining land below the height of the drainage channels and rivers. This caused the reclaimed farmland to become vulnerable to flooding again. By the end of the 17th century, much of the reclaimed land was regularly flooded.

Further work to drain the Fens took place in the late 18th and early 19th century, involving fierce local rioting again. The final phase came in the 1820s when wind-pumps were replaced with powerful coal-powered steam engines, which were themselves replaced with diesel-powered pumps, and more recently by electric pumps that are still used today.

As well as reclaiming peat fens and coastal salt marshes, building new sea walls around The Wash has added a significant area of agricultural land extending the silt fens seawards (Figure 1.4).

Although most of the literature on the The Fens and its subsequent history has focused on drainage aspects, there is good evidence that commercial waterways traffic continued after the drainage works were completed. Fenland navigation remained viable from the mid-seventeenth century until the coming of the railways two centuries later. And even after that there was still some commercial traffic into the mid-1960s, with grain from across the North Sea through The Wash up the River Nene to the flour mill at Peterborough and with limestone transported by barge back down that river.

Contemporary Fenland landscape



The huge scale of the Fenland landscape with its level horizons, open panoramas and enormous skies, with their changing weather patterns has a strong influence on the observer: a strong sense of isolation, tranquillity and a distinctive sense of place.

Water from much of the East Midlands drains to The Wash through four major rivers: the Witham, Welland, Nene and Great Ouse. When the spring tides flood into The Wash and run up the embanked lower courses of these rivers, more than 3,100 km2 of Fenland lie below this water level. All these rivers now have artificial, canalised sections that run straight for long distances and are bounded by high banks to contain and separate them from the lower adjacent fields. To maintain a functional, agricultural landscape and to protect settlements and associated infrastructure from flooding, water must be pumped from the lower drains and dykes into the rivers. Nevertheless, these waterways and their associated and connected drainage ditches provide ecological networks and functional connections to and across other natural features in this landscape. Remnants of the original fen, such as at Wicken and Woodwalton, are rare.

As cultivation techniques have become more intensive, the soil resource is increasingly diminished through desiccation and erosion. Clays and silts laid down by marine incursions dominate the area abutting The Wash and extend inland along the rivers, forming the fertile horticultural soils of the silt fens (See Figure 1.5). This area is now marginally higher in altitude than the inland peatlands which have shrunk and 'wasted'.

Fertile peat soils have been historically drained and managed to support national food production at the expense of other Ecosystem Services. Drained peat is more vulnerable to loss, particularly where the deposits are deep and the water table is kept artificially low. Peat wastage through shrinkage, oxidation and wind erosion at 1.5cm/year is a long-term issue affecting the Natural Capital of The Fens; the carbon emissions from Fenland peat wastage is estimated at approximately 3.8 x 108kg C/year!

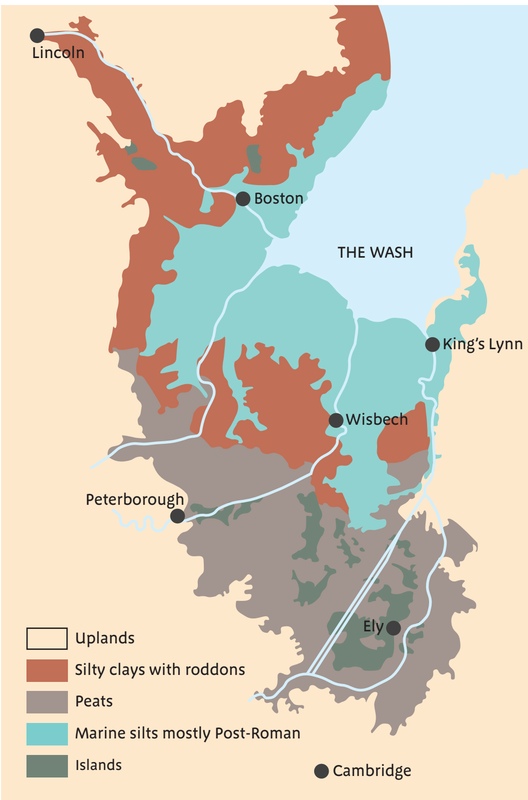


Figure 1.5 Surface deposits in modern Fenland

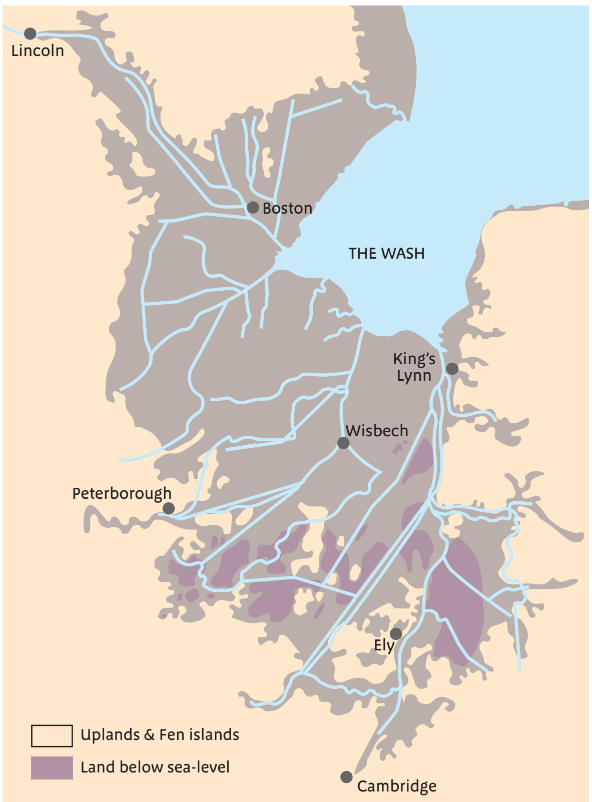


Figure 1.6A Fenland showing islands and land below sea level

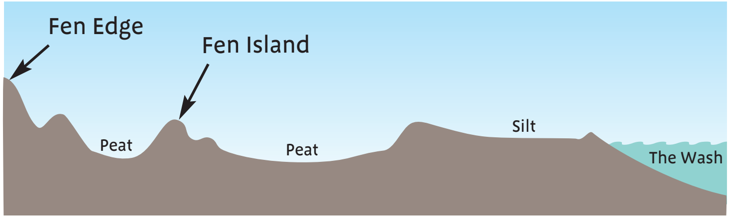
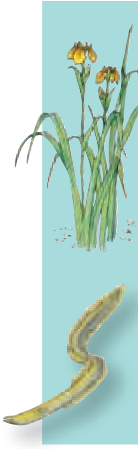


Figure 1.6B Schematic section through Fenland with exaggerated elevations to show islands and land below sea level

Elevations in The Fens typically vary by little more than one or two metres over long distances (Figures 1.6A & 1.6B) relying on pumped drainage and control of sluices at high and low tides. The Fens are protected by 97 km of embankments defending against the sea and 154 km of river embankments. Thirty-four IDBs maintain 286 pumping stations and 6,100 km of drainage watercourses to ensure Fenland's agricultural viability and protect urban and industrial areas and other infrastructure against flooding.



Groundwater Influence on the drains at the Fen Edge

Although most of the flow in drainage channels is regulated and pumped around the Fen Edge and islands, there is at times be some natural flow from groundwater seepage. A succession of geological units means a variety of bedrock aquifers contribute baseflow to the streams and ditches on the Fen Edge. These include Lincolnshire, Cornbrash and Blisworth limestones to the north and central 'western edge', Sandringham Sands and chalk to the eastern and southern edges see (Figure 1.7).

Rainfall recharge percolates through these aquifers to reach the water table. On the western Fen Edge, limestone dips gently eastward; where topography falls away it can intersect the water table and springs can emerge. This happens not just at discrete points but also at seepages along stretches of a watercourse, for example parts of the upper East and West Glens, the head of Dunston Beck and stretches of Holywell Brook a tributary of the West Glen. The location and volume of groundwater from a spring will be governed by the amount of rainfall in the preceding days, weeks or months, as well as the effect of artificial influences such as nearby groundwater abstraction. Along the eastern edge of The Fens in north west Norfolk there may be seepage from the Sandringham Sands into the surface watercourses such as the Babingley, Gaywood and Mintlyn. However, most river flow here is a result of chalk baseflow from further east.

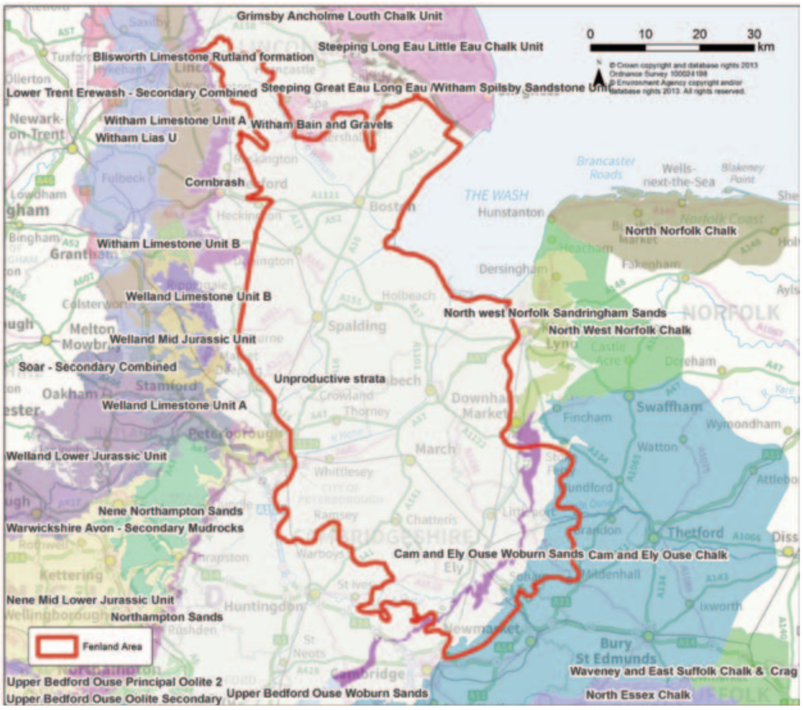
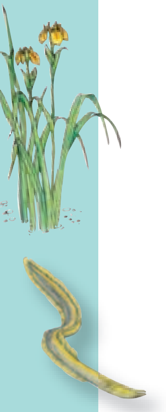


Figure 1.7 Groundwater geology around the Fenland basin

Springs can also emerge when an aquifer becomes confined (covered) by other geology. This confinement often marks the point at which groundwater rises naturally to form springs. Sometimes they are fault controlled such as at Scopwick, Billingborough or Horbling or they can be artificial as witnessed by the numerous leaking wildbores of the low lying fen area to the north-east and east of Bourne which then feed into the South Forty Foot system. Upward seepage from limestone into overlying deposits east of Bourne is believed to contribute to baseflow in ditches and watercourses of this area. Along the eastern and southern edge of The Fens area the chalk becomes thinner and the water table closer to the surface. At these locations, there may be groundwater dependant wetlands, such as meres, spring flow and groundwater seepage to surface watercourses. The extent of these features is influenced by numerous factors such as local geology, seasonal variation in rainfall, and human impact like land drainage. Some areas along the south-western edge are largely surface water fed due to the presence of low permeability bedrock geology.



Modification and construction of channels for land drainage

Efficient water conveyance Land drainage channels have usually been constructed to provide efficient water conveyance at lowest possible cost. Cost effective maintenance, stability and modification of channels are important considerations in achieving this.

There are various types of watercourses in Fenland which are used as drainage channels (Figure 1.8). Whilst a few are modified from relict, natural watercourses, most lowland drainage channels are artificial structures, designed to cater for given flows with a certain roughness co-efficient (Mannings n), to achieve a set freeboard to the lowest land (between 300mm to 900mm), which varies on a return period from a 1-in-100 year, to a 1-in-10 year flood event.

Most of the current drainage infrastructure dates from the land drainage 'peak' in the period from the early 1940s through to the 1970s, and was therefore designed at a time when environmental considerations were given a lower priority. These channels were designed with a relatively low roughness coefficient as, at that time, there were no restrictions to keep watercourses free from obstructions and vegetation growth. Certainly, any drainage channel constructed over 25 years ago will not have much additional capacity for environmental features, which is why most IDB drains are weed-cut annually to ensure the conveyance standard is maintained. Historically IDB's would weed-cut 2 or 3 times per annum starting during the spring through to Christmas (Figures 1.9 and 1.10). In some IDB areas, this practice has been modified over the years to accommodate environmental gain, but possibly at an increased flood risk. In addition to weed cutting, silt deposits are routinely removed from all watercourses in an operation usually referred to as 'mudding out', 'de-silting' or 'cleansing' watercourses – on cycles of 5 to 20 years. This usually involves removing about 300mm of silt from the watercourse bed to return it to the original design profile.

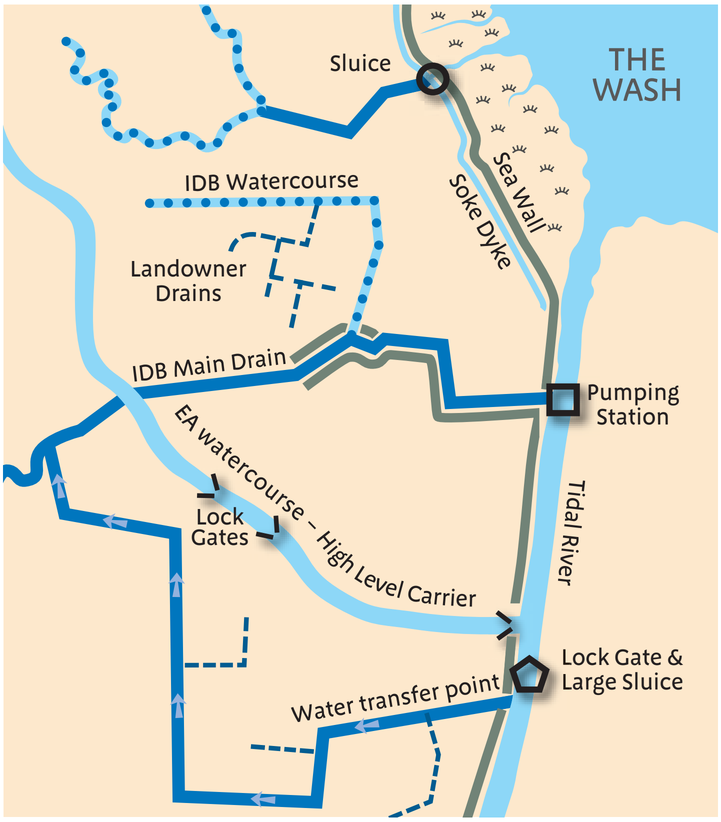


Figure 1.8 Watercourse types in Fenland

In typical IDB areas, often reliant upon pumped drainage, it becomes even more essential to maintain a clear, obstacle free channel. For this reason, incorporating woody material into a lowland drainage channel, seen as an ecological benefit in many watercourses, would not usually be appropriate. Also, as IDBs do not own most of the watercourses, creating features such as additional storage and reed margins, for example, require the land owner's agreement.

Cost Effective Maintenance A trapezoidal channel profile is the most economic to manage. Any deviation from that profile increases maintenance costs with no gain in water conveyance. For example, the addition of a berm will give environmental gain and additional storage, but will increase maintenance costs without necessarily increasing conveyance. However, it will probably also incur capital expenditure to acquire additional land on which to construct berms.

If margins are left with reed and weed growth, conveyance is adversely affected. Also, if trees and bushes are present on the drain side, these become obstacles to maintenance as they inhibit access for machinery. Margins can ultimately increase the amount of maintenance required as shading the watercourse does not inhibit all weed growth and deposits of leaf and woody debris into the watercourse must often be removed to maintain drainage capacity. In consequence, most IDBs operate byelaws which prevent any obstacle within 9m of the brink of their watercourses.

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Figure 1.9 Drainage channel before weed cutting

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Figure 1.10 Drainage channel after weed cutting

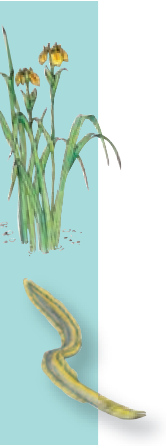
IDB drains are typically straight, which reflects the man-made and artificial nature of the lowland catchment. Also, a straight drain being shorter in length and requiring less land take than a meandering stream, is therefore the most economical method of transferring or conveying water.

Channel Stability Trapezoidal channels are excavated according to soil type and can vary from 1:1 batters in heavy ground conditions to 2:1 in sandy silts. The aim is to create a stable drain batter which will not slip causing potential blocking. However, during and following periods of high flows and high water level, slips do still occur and various methods are then employed to stabilise these watercourses. These methods depending on ground conditions, but typically involve using timber faggots, coir rolls or stone revetments. Repairs are always carried out to return the channel to its former state, to prevent unacceptable conveyance and land loss, or increased Health and Safety risks.

Channel Modification It may be necessary to modify a length of watercourse by piping a section. IDBs consent this work on a case by case basis under the Land Drainage Act 1991, Section 23. Most IDBs try to avoid piping unless absolutely necessary as it results in loss of storage capacity, increased maintenance costs in the long term and loss of wildlife habitat.

Future improvement schemes may offer the chance to incorporate environmental gain by widening drains to allow fringe vegetation to be retained or berms to be constructed. However, it is recognised that this does bring additional financial burden both in construction, land take and maintenance costs.

Ecology and biodiversity conservation of Fenland watercourses



This section summarises the habitats and species associated with Fenland watercourses and describes their protection and conservation.

Ecology of Fenland watercourses

Many plants have become associated with ditches, both aquatic and emergent, as well as invertebrates (such as dragonflies, water beetles, snails and mussels), amphibians (such as frogs, toads and newts), fish (such as eels), birds (such as warblers and kingfishers) and mammals (such as otters and water voles). The banks beside ditches can support a range of species-rich wet and dry grassland as well as stands of sedges, reed and willow scrub. The plants and animals associated with these watercourses include rare and red-listed species, most of which are priorities under Biodiversity Action Plans.

A Fens Biodiversity Audit, published in 2012, revealed that over 500 rare species had not been seen in the last 25 years and 100 species had been lost to the area altogether. However, Fenland still has 25% of Britain's rarest wildlife, 3 globally rare species, and 20 species found virtually nowhere else in the UK amongst the 13,500 species of plants and animals found. Drainage channels provide refuge habitats for many of these species within the farmed landscape. Although an artificial habitat, they are of high value for a broad range of wildlife; drainage channels with a groundwater connection being particularly good. They also form corridors that connect important conservation areas, facilitating species movement through the landscape. Sympathetic management can enhance both the richness of wildlife and the connectivity provided by the watercourses.

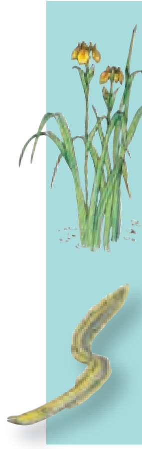
Comprehensive studies of aquatic plants in arable ditches has produced a consistent view of what constitutes a 'good arable ditch' in terms of its floristic diversity. The factors determining which are high quality ditches include water quality, soils and substrate, location and water supply, ditch dimensions and management. Using these criteria, it is possible to predict which ditches are likely to have the richest aquatic flora and then categorize them as Excellent, Good, Moderate or Poor – based on the indicator plants present. These studies and other biodiversity audits have shown the importance of Fenland and have confirmed that the drains are amongst the most important refugia for aquatic plants in lowland Britain.

However, management to suit aquatic plants may not necessarily be the best for aquatic invertebrates, amphibians, fish, mammals and birds. Studies of ditch management requirements in terms of bankside vegetation cutting and channel dredging have indicated which ditches should be targeted for biodiversity enhancement and which management options best suits which groups of species.

The survey of Fenland, its drainage channels and associated habitats continues. Amongst others, an ambitious project is underway to compile a Fenland Flora, the systematic collection of field data for which is due for completion in 2018.

Part of the WFD process for determining Good Ecological Potential is to find the most closely comparable natural waterbody as a reference condition for high ecological status (see Section 2). However, as the Fenland drainage channels are mostly artificial in origin or highly modified, there is no real equivalent 'natural' waterbody to use for comparison. Nevertheless, because of great deal of survey work on Fenland watercourses, there are now good descriptions of their ecology and the recognition that some are biodiversity rich. And, also for reference, there are the dykes in Wicken and Woodwalton Fen as well as the paleo-ecological record of the pre-drained Fenland. So, although the ecological status of these watercourses cannot be used as a 'reference condition' in the strict sense of the WFD, they can give some indication of the enhanced biodiversity that might result if the ecological potential is realized.

Biodiversity conservation of Fenland watercourses



The importance of The Fens for biodiversity is recognised by various conservation designations. The Ouse Washes and Nene Washes are designated as Special Protection Areas (SPA) and Ramsar sites; they are areas of seasonally flooded grassland important for their diversity of plant and animal life, particularly national and international populations of breeding and overwintering waders and wildfowl. Their associated watercourses are designated for important spined loach populations. In the Welland catchment, the Counter Drain in Baston Fen Special Area of Conservation (SAC) also contains high densities of spined loach. Fenland SAC holds large areas of calcareous fen and is also important for populations of spined loach and great crested newt. In terms of biodiversity, Wicken Fen is the richest site in the UK; Holme and Woodwalton Fens are also important relict fenland habitats. All three are National Nature Reserves. There are also 41 Sites of Special Scientific Interest (SSSI) in The Fens covering 8,939 ha.

Both the EA and the IDBs have a statutory duty to further the conservation of wildlife in performing their duties; in consequence, the IDBs are implementing Biodiversity Action Plans. In the context of the Fenland area, the ecological enhancement of the connected network of drainage channels by a programme to achieve GEP contributes to the improvement of the habitat for wildlife associated with these watercourses by putting in place processes which lead to enhanced communities of plants and animals.

An important publication in promoting the active conservation of drainage systems is 'The Drainage Channel Biodiversity Manual' which points out that IDBs are uniquely equipped to make a vital contribution to the conservation of wetland wildlife as custodians of wetlands and watercourses. This practical guide to channel management techniques that are sympathetic or beneficial to wildlife complements Section 3 of this guide where, in some cases, there are cross references to appropriate management interventions. Another useful guide is 'The Middle Level Internal Drainage Board Biodiversity Manual' which provides a range of techniques and initiatives to inform the implementation of the Biodiversity Action Plans, as well as dealing with invasive plants and animals, and sets out advice to help ensure that the IDBs comply with current wildlife protection legislation.

There have been recent efforts to re-create Fenland to provide important habitat for rarer species and there has been focused activity on re-creating areas of wet grassland and fen. Particularly important initiatives are The Great Fen Project, which is creating an important link between Woodwalton Fen and Holme Fen and extending fenland restoration into the surrounding fen landscape; the Wicken Vision to extend Wicken Fen; and at Lakenheath Fen where the Royal Society for the Protection of Birds (RSPB) have created a large wetland from agricultural land. Partnership working elsewhere is also focusing efforts to re-create fenland to provide important habitat for rare species. The Fens for the Future Partnership has a mission statement to make The Fens one of the main UK landscape-scale wetland complexes within a matrix of sustainable agriculture. The implementation of GEP in Fenland waterbodies will directly contribute to the Partnership's aim to increase connectivity by enhancing Main Rivers, waterways and riverside habitats to create a web of habitats that help species disperse and increase resilience, building on existing work by the EA the IDBs.

Recent national policy documents relating to biodiversity such as the Lawton Report, Making Space for Nature: A review of England's Wildlife Sites and Ecological Network and the subsequent White Paper The Natural Choice: securing the value of nature, provide the strategic steer for this Plan's approach. Lawton sets out the actions needed to enhance the resilience and coherence of England's ecological network in four words: more, bigger, better and joined. Improving the ecology of the Fenland drainage channels and the many other conservation initiatives underway in the Fenland to maintain and enhance its biodiversity, certainly contribute to this.

Designating Fenland waterbodies and defining Good Ecological Potential

Introduction

This section introduces 'Hydromorphology' as the key concept to understand Fenland waterbody designation as 'Artificial' or 'Heavily Modified' and explains how GEP may be achieved in these waterbodies. It covers:-

- introducing the concept and importance of hydromorphology;
- designating Artificial (AWB)and Heavily Modified waterbodies (HMWB);
- defining GEP in AWB and HMWB;
- understanding the WFD classification and assessment of waterbodies based on their biological, physico-chemical and hydromorphological attributes;
- implementing Mitigation Measures to alleviate the effects of altering the hydromorphology by;
- detecting and avoiding Hydromorphological Harm; and
- understanding the importance of 'Mitigation Measures' and the set selected that are relevant to drainage and flood protection.

If physical alterations have changed the hydromorphology of a waterbody, then this may impact negatively on the ecological status and reduce its ecological potential. To alleviate this effect, the operating authority must look at Mitigation Measures that can be put in place to restore hydromorphology, but without having a significant adverse effect on the designated use and functions of that waterbody (for example drainage and flood protection) or at excessive cost. To do this, a step by step decision making process is described together with a set of relevant Mitigation Measures that should be considered.

Hydromorphology

The term 'Hydromorphology' is a new concept introduced by the WFD to describe physical waterbody characteristics. It is key to understanding waterbody designation and achieving GEP. It is a

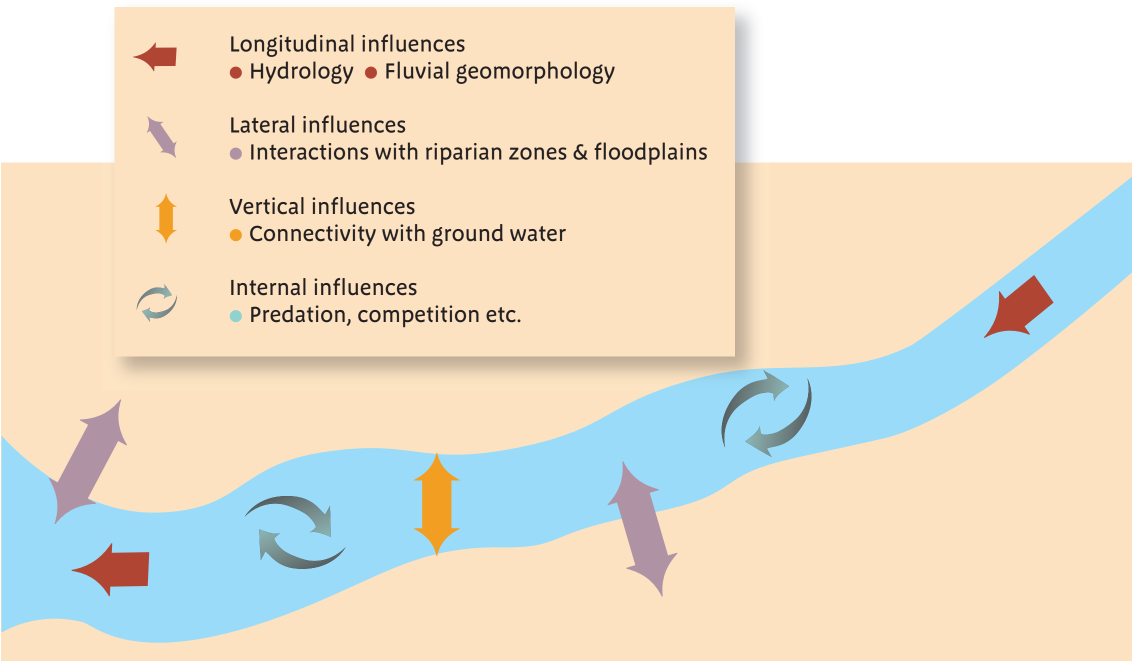


Figure 2.1 How hydromorphology influences ecology

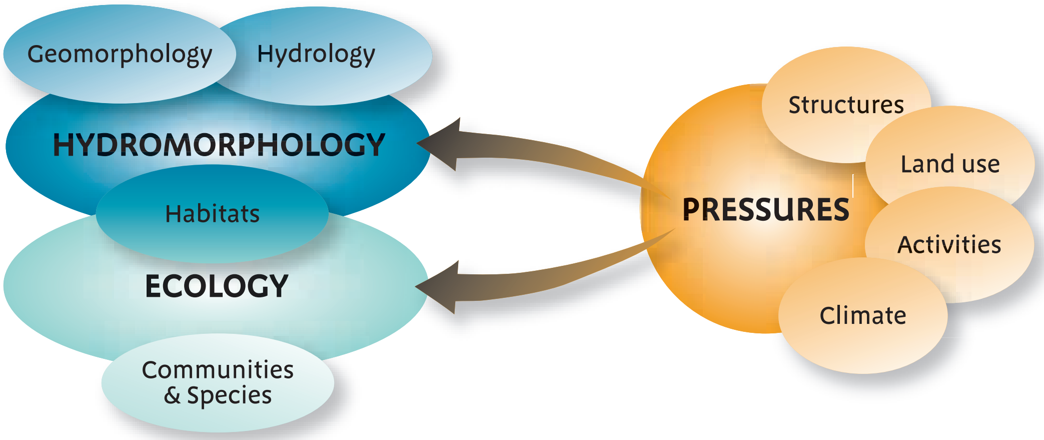
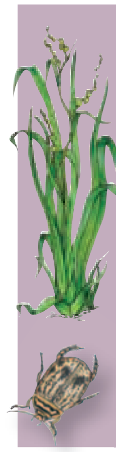


Figure 2.2 Pressures impacting the hydromorphology and ecology

combination of hydrology and geomorphology and includes elements taken from both, such as water flow discharge and dynamics, river continuity, channel shape and substratum. These features and processes support the biological features of a waterbody (Figure 2.1). An ecologist would consider the hydromorphology of a waterbody to be the 'habitat', and the biological features to be the 'communities of species of plants and animals'. A habitat and its associated species is known as an 'ecosystem' and often also referred to as 'the ecology'.

Pressures, such as land use, engineering structures (weirs, dams, revetments) will influence waterbody hydromorphology and, therefore, often have a negative impact on its habitats, species and communities (Figure 2.2).



Waterbody designation and defining Good Ecological Potential

The hydromorphology of the water environment has often been changed to provide certain functions or uses. For example, artificial reservoirs have been built and used for drinking water supply, and rivers have been altered to reduce the risk of flooding, provide navigation and to ensure

Article 4.3

Member States may designate a body of surface water as artificial or heavily modified, when:

(a) the changes to the hydromorphological characteristics of that body which would be necessary for achieving good ecological status would have significant adverse effects on:
(i) the wider environment;
(ii) navigation, including port facilities, or recreation;
(iii) activities for the purposes of which water is stored, such as drinking-water supply, power generation or irrigation;
(iv) water regulation, flood protection, land drainage, or
(v) other equally important sustainable human development activities;

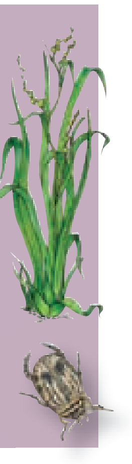
(b) the beneficial objectives served by the artificial or modified characteristics of the water body cannot, for reasons of technical feasibility or disproportionate costs, reasonably be achieved by other means, which are a significantly better environmental option.

Such designation and the reasons for it shall be specifically mentioned in the river basin management plans required under Article 13 and reviewed every six years.

Figure 2.3 Water Framework Directive - Article 4.3

farmers have enough water to irrigate their crops. Restoring the hydromorphology of such waterbodies to GEP, as defined in the WFD, may have a significant impact on these uses. If this is the case, the Article 4.3 of the WFD allows waterbodies to be designated as a HMWB or AWB (Figure 2.3). A HMWB is a body of surface water that has been modified by physical alterations to such a degree that the Good Ecological Status (GES) is no longer achievable, for example a river highly modified for drainage and/or navigation purposes. An AWB is a waterbody that has been constructed for a specific purpose, usually where no substantial waterbody existed before, for example drainage ditches and canals.

Once a waterbody has been designated as a HMWB or AWB, the next step is to determine its GES and GEP. To derive the GES for a HMWB, first the reference condition (that of the most closely comparable type of natural waterbody) should be determined. After that, the physical alterations that have taken place are recorded and those that are irreversible are identified.



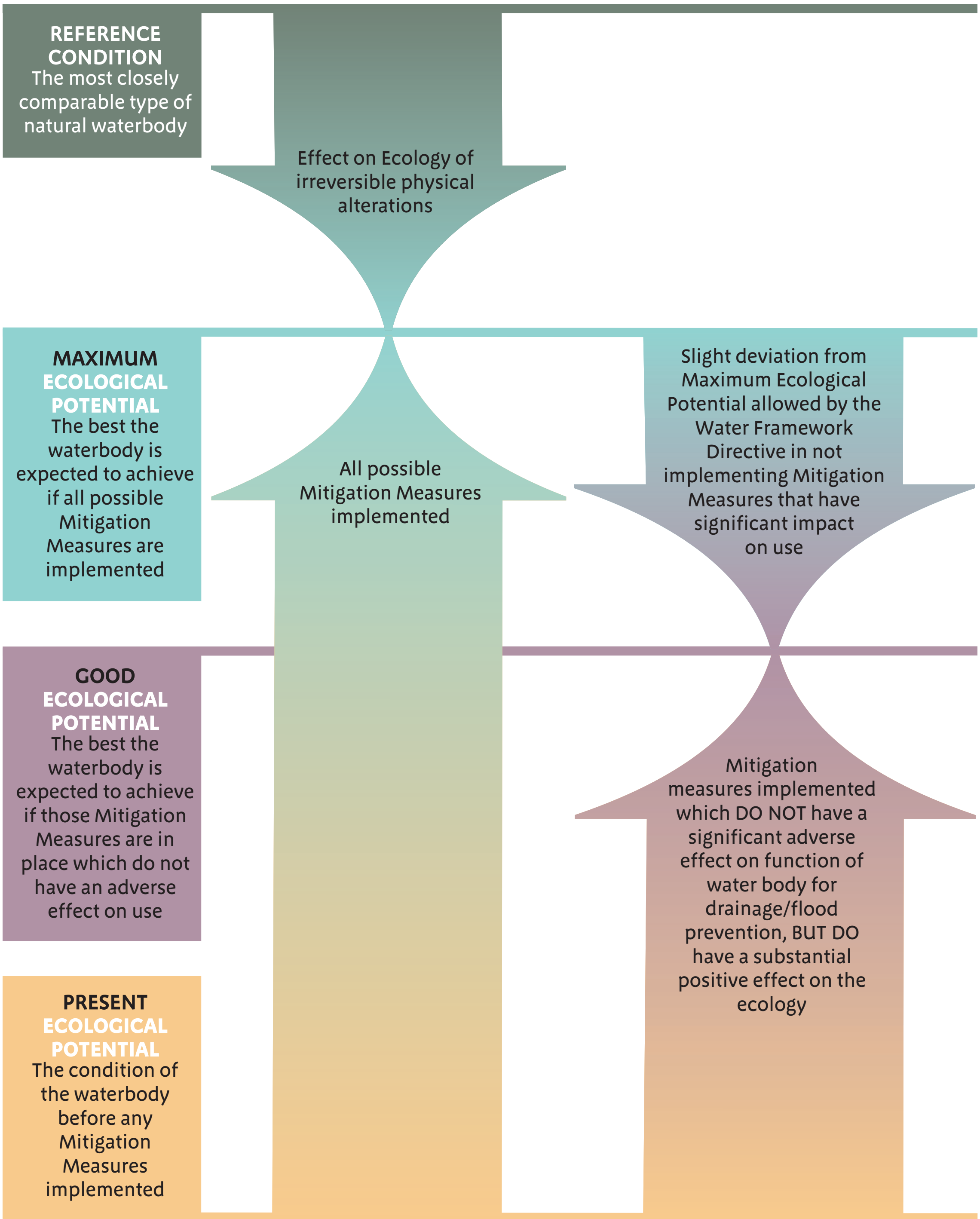


Figure 2.4 How Reference Condition is used in determining Good Ecological Potential

The Maximum Ecological Potential (MEP) is the best that a waterbody is expected to achieve if all possible Mitigation Measures were implemented to offset the physical alterations. Where some of these Mitigation Measures would significantly adversely impact on a designated use under article 4.3 (e.g. flood protection), then they are not implemented. When the remaining Mitigation Measures that improve ecology and do not significantly adversely impact on use are implemented, the waterbody achieves GEP, the best it can achieve whilst still serving its' designated function.

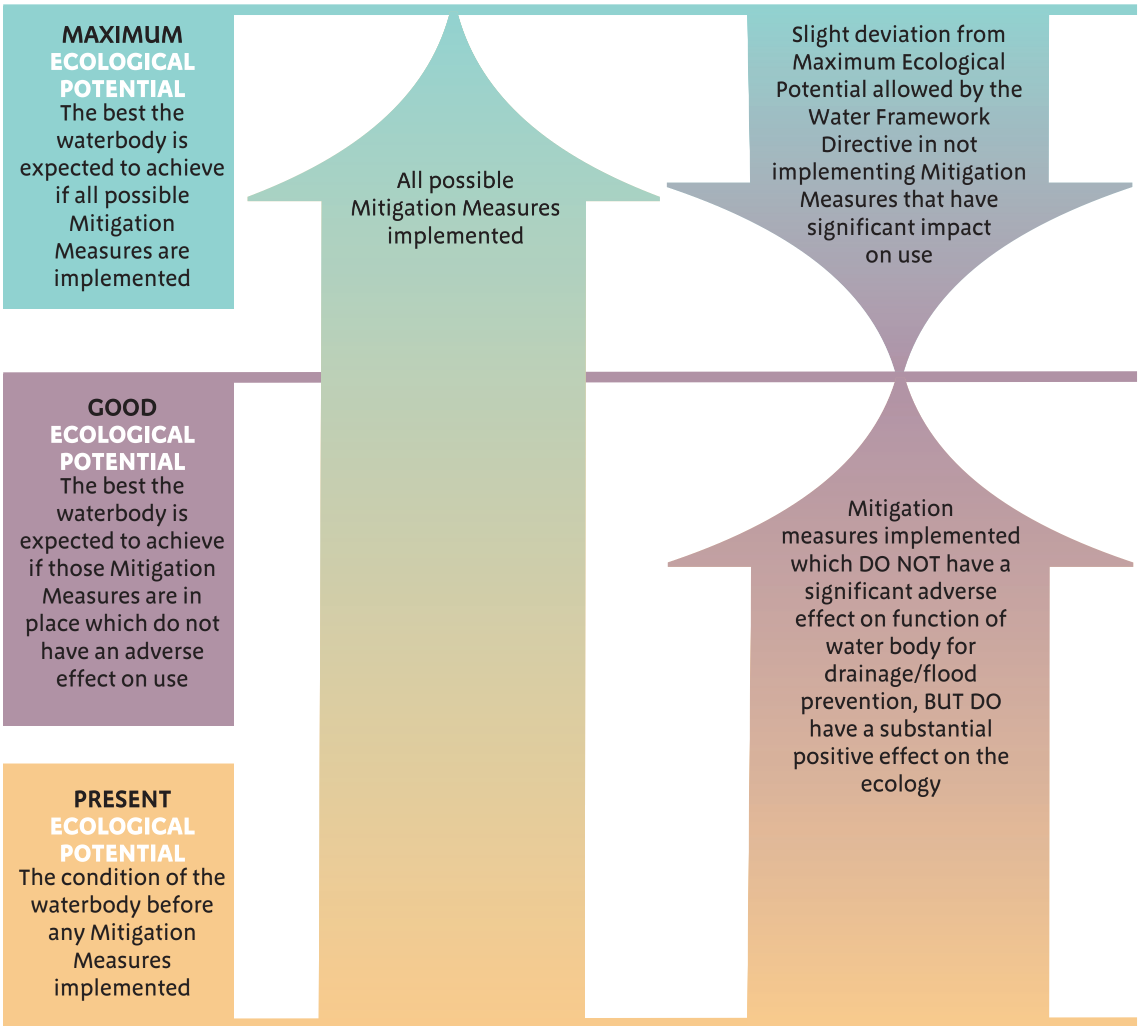
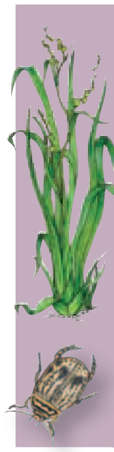


Figure 2.5 Establishing Good Ecological Potential in Heavily Modified & Artificial Waterbodies where there is no Reference Condition

However, as the hydrology of the Fens is the result of centuries of human intervention, it would clearly be unrealistic to base the determination of ecological objectives for HMWB on a set terrestrial or aquatic reference conditions that have been in continual geomorphological change prior to human intervention. For cases like this, the WFD offers an alternative solution whereby competent authorities must define both the highest achievable ecological status (MEP) and the ecological status they are going to try and achieve GEP.

An AWB is a man-made construction and thus there is no natural condition to which it might be restored i.e. reversing any alterations will not restore it to its natural condition. So, the concept of 'physical alterations' is irrelevant. Nevertheless, the fact that a physical alteration is irreversible does not mean that the water management authority should resign itself to its adverse effects. The WFD requires that, wherever possible, measures should be taken to mitigate such impacts to achieve GEP. The cost of implementing a Mitigation Measure will not play an immediate role in the decision i.e. the potential for taking measures must be identified first and the pros and cons weighed up later. In effect, both HMWB and AWB are treated in the same way to establish GEP (Figure 2.5).



Water Framework Directive classification and assessment

All waterbodies have an Ecological Status or Classification which is expressed in terms of five classes: High, Good, Moderate, Poor or Bad (Figure 2.6).

These classes are established based on specific criteria and boundaries defined against:

Biological
- Fish, plants and invertebrates

Physico-chemical
- Ammonia, nutrients (phosphate), heavy metals or pesticides

Hydromorphological elements
- Quantity of water or hydrology and whether this is influenced by human use such as abstraction
- Physical structure or morphology, whether the natural form has been changed for human use

High Near natural conditions. No restriction on the beneficial uses of the waterbody. No impacts on amenity, wildlife or fisheries.

Good Slight change from natural conditions as a result of human activity. No restriction on the beneficial uses of the waterbody. No impact on amenity or fisheries. Protects all but the most sensitive wildlife.

Moderate Moderate change from natural conditions as a result of human activity. Some restriction on the beneficial uses of the waterbody. No impact on amenity. Some impact on wildlife and fisheries.

Poor Major change from natural conditions as a result of human activity. Some restrictions on the beneficial uses of the waterbody. Some impact on amenity. Moderate impact on wildlife and fisheries.

Bad Severe change from natural conditions as a result of human activity. Significant restriction on the beneficial uses of the waterbody. Major impact on amenity. Major impact on wildlife and fisheries with many species not present.

Figure 2.6 Definition of Status in the Water Framework Directive

Determination of the status of these classes is used to assess the overall status of a waterbody (Figure 2.7).

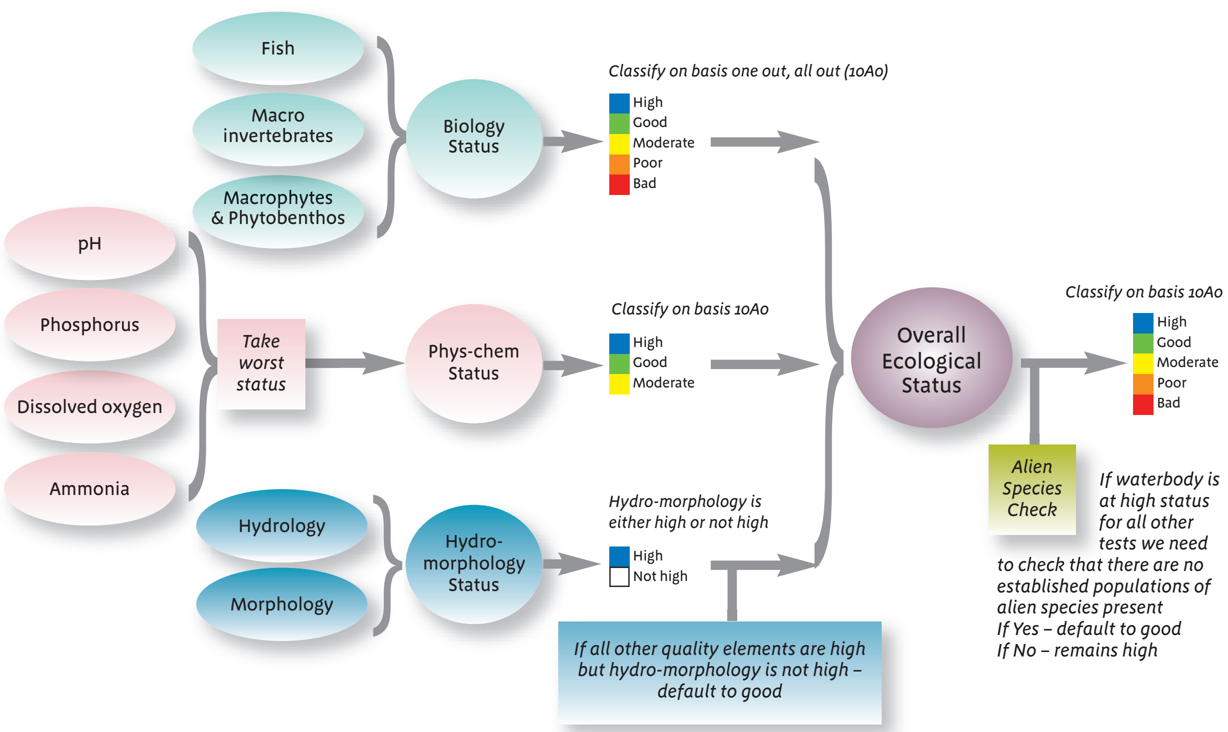


Figure 2.7 Flow diagram for determining overall Ecological Status in Waterbodies

Non-sensitive quality elements

Rivers	Transitional and Coastal	Lakes
Physico-chemical conditions	Physico-chemical conditions	Physico-chemical conditions
Specific pollutants	Specific pollutants	Specific pollutants
Diatoms	Phytoplankton	Phytoplankton
	Macro-algae	Diatoms
	Benthic invertebrates (quality)	Invertebrates

Sensitive quality elements

Rivers	Transitional and Coastal	Lakes
Macrophytes	Sea grass (extent)	Macrophytes
Invertebrates	Fish (Transitional waters only)	
Fish	Benthic invertebrates (extent)	

Figure 2.8 Quality Elements used to assess Ecological Potential

In a HMWB or AWB several different factors are considered when assessing the ecological potential. These factors are flow, Mitigation Measures, and biological and physico-chemical quality elements, which are all further defined below in the context of Fenland waterbodies.

First an assessment of flow is considered. This determines which quality elements (biological and physico-chemical) can be used to help classify the ecological potential of an HMWB or AWB. If flow conditions pass the required target then an assessment of HM and AWBs is based on a combination of Mitigation Measures and, if available, non-sensitive quality elements (Figure 2.8). Non-sensitive quality elements are those elements that are not affected by the modified or artificial nature of the waterbody e.g. the chemical quality of water in a waterbody is not sensitive to a sluice or weir structure. If flow conditions do not meet the required target then ecological potential is based on the worst result of either the Mitigation Measures assessment or any of the quality element assessments (Figure 2.9).

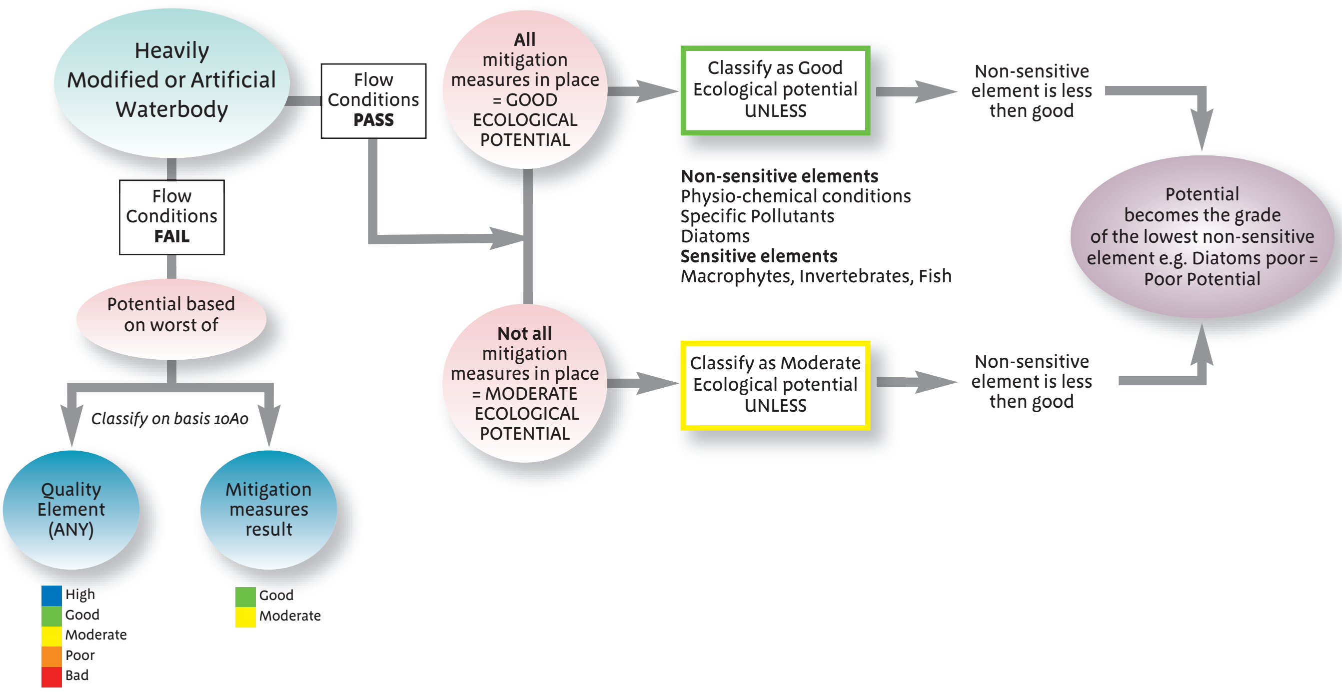


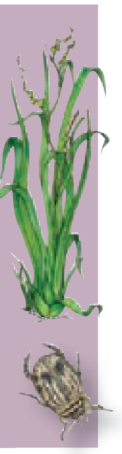
Figure 2.9 Flow diagram for determining overall Ecological Status in Heavily Modified and Artificial Waterbodies

Flow

Flow is assessed to establish whether the annual flows can support the ecology given potential pressures from abstraction.

The Environment Agency (EA) is responsible for assessing the available water resources on a catchment scale before considering abstraction licence applications. Since 2001 they have published the assessments in Catchment Abstraction Management Strategies (CAMS). This assessment has been refined to meet the requirements under the WFD and takes both surface and groundwater resources into account. Through modelling, a comparison is made between the actual flows in each waterbody with the flow estimated as the minimum required to protect the ecology. This 'ecological flow target' is called the Environment Flow Indicator (EFI). Where the actual flow is below the EFI target, the waterbody is considered to 'fail' for flow.

The Fenland watercourses differ from a normal lowland river system as the waters in these systems often contain slow-flowing water, retained behind sluices and pumped into main rivers or the sea, with no connection to groundwater. Therefore, the CAMS for the Fens evaluates of the supply of water into an area or individual catchment against the demand for abstraction and the levels required for navigation and/or biodiversity to assess whether further abstraction is possible.



The assessment derived from the EFI doesn't work where there is little or no flow. Hydrology investigations The Fens have screened out abstraction as an ecological pressure owing to the managed nature of the level based systems. Therefore, the flow conditions pass for most the waterbodies in the Fens.

Mitigation Measures

Physical alterations to waterbody hydromorphology can influence its ecological status and therefore reduce its ecological potential. To alleviate this effect, the WFD requires that the operating authority must look at what Mitigation Measures, or management interventions, can be taken to restore the hydromorphology. However, a Mitigation Measure must alleviate the effects of a human alteration without having a significant adverse effect on the use functions of that waterbody or on the wider environment. Only those Mitigation Measures that are genuinely relevant and likely to have a substantial effect on the hydromorphology, and hence on the ecology, should be taken into account. This will ensure that ecological objectives are both feasible and achievable.

Step 1 Define the characteristics of the drainage channel including the pressures and impacts on the waterbody
Step 2 Define a complete set of Mitigation Measures for the waterbody.
Step 3 Identify measures that do not have an adverse impact on use (MEP)
Step 4 Exclude measures that would only deliver a slight ecological benefit (GEP)
Step 5 Identify Mitigation Measures in place and what measures are still required to achieve GEP
Step 6 Review the effectiveness of Mitigation Measures
Step 7 Estimate financial and socio-economic costs
Step 8 Identify the most cost-effective combination of Mitigation Measures
Step 9 Identify actions to be taken, including monitoring the ecosystem response

Steps 1 – 4 define the MEP and GEP.

Steps 5 to 8 help to select cost-effective combinations of Mitigation Measures.

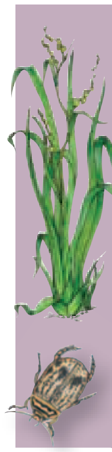
Figure 2.10 Key steps in selecting suitable Mitigation Measures (see Appendix 1 for further detail)

The UK's adopted 'alternative approach' to classifying HMWBs and AWBs is based on the Mitigation Measures that are in place and their assessment. Within the WFD there is a detailed, decision making process for such assessments (Figure 2.10 & Appendix 1). This was the process used to identify all the Mitigation Measures put forward for the River Basin Management Plan in 2015.

If Mitigation Measures are in place, then ecological potential is Good, but if Mitigation Measures are not in place, ecological potential is Moderate. These results can be further modified if an assessment of non-sensitive elements is less than Good, in which case ecological potential will depend on the grade of the lowest quality element.

Biological quality elements

Biological quality elements cannot be used to assess an HMWB or AWB in the same way as for an unmodified river, because some biological elements are sensitive to the waterbody modifications, such as altered hydromorpholgy. For example, fish may be at the best state they can be given a channel shape governed by flood protection and land drainage. But that standard may still be low given they are impacted by that channel shape. To assess that the waterbody is not at GEP because fish are 'not good' would be incorrect if they were the best they can be. Under normal circumstances 'non-sensitive quality elements' are used to assess GES for HM or AWBs. 'Sensitive quality elements' are used only if flow conditions fail the standard. This reflects the sensitive elements being impacted by the flow condition, not the channel modification. The table at Figure 2.8 shows which quality elements are used to assess ecological potential based on sensitivity to hydromorphological pressures.



In some cases, monitoring and assessment is still carried out for biological elements that are sensitive to the physical modifications. Although these element assessments are ignored for determining a waterbody status they are not ignored operationally. It should be determined whether the biology failures are due to physical modifications, rather than other pressures, acting on the waterbody such as chemical pollution or the impact of invasive species. If other pressures are affecting the biology, then these pressures need to be addressed.

The River Invertebrate Prediction and Classification System (RIVPACS) approach compares the 'observed' macroinvertebrate fauna and metric values with model derived, site-specific predictions of 'expected' values, based on environmentally similar high quality reference sites. This approach has been used to assess the ecological condition of UK waterbodies since the 1990s. RIVPACS pre-dates and helped inform the WFD.

With RIVPACS, sites are sampled to collect information on physical characteristics, chemistry and macroinvertebrates. This information is then used to predict what invertebrates are present from samples of physiochemistry from other similar sites. Thus there is confidence that the biological assessments in Fenland watercourses do take into account that there is little or no flow in these waterbodies.

Physico-chemical quality elements

Physico-chemical quality elements, such as pH, dissolved oxygen and nutrients, are those required to 'support' a functioning ecosystem. For example, fish cannot survive and reproduce unless there is sufficient dissolved oxygen. Class boundary values have been developed for these supporting elements corresponding to High, Good, Moderate, Poor and Bad ecological status. However, in overall classification, the supporting elements can only influence status down to Moderate. Only biological elements can determine Poor or Bad status, and in HMWBs only the non-sensitive biological elements. This reflects the fact that in some cases diverse biology may exist despite physico-chemical pressure; only when biology is significantly affected by that pressure is the waterbody 'good' or 'bad', and not if that pressure is a result of modifications.

Avoiding Hydromorphological Harm

As this document focuses on waterbodies where the hydromorphology has been changed to provide drainage and flood protection in the Fenland landscape, most have been designated as either AWB or HMWB (Figure 2.11).

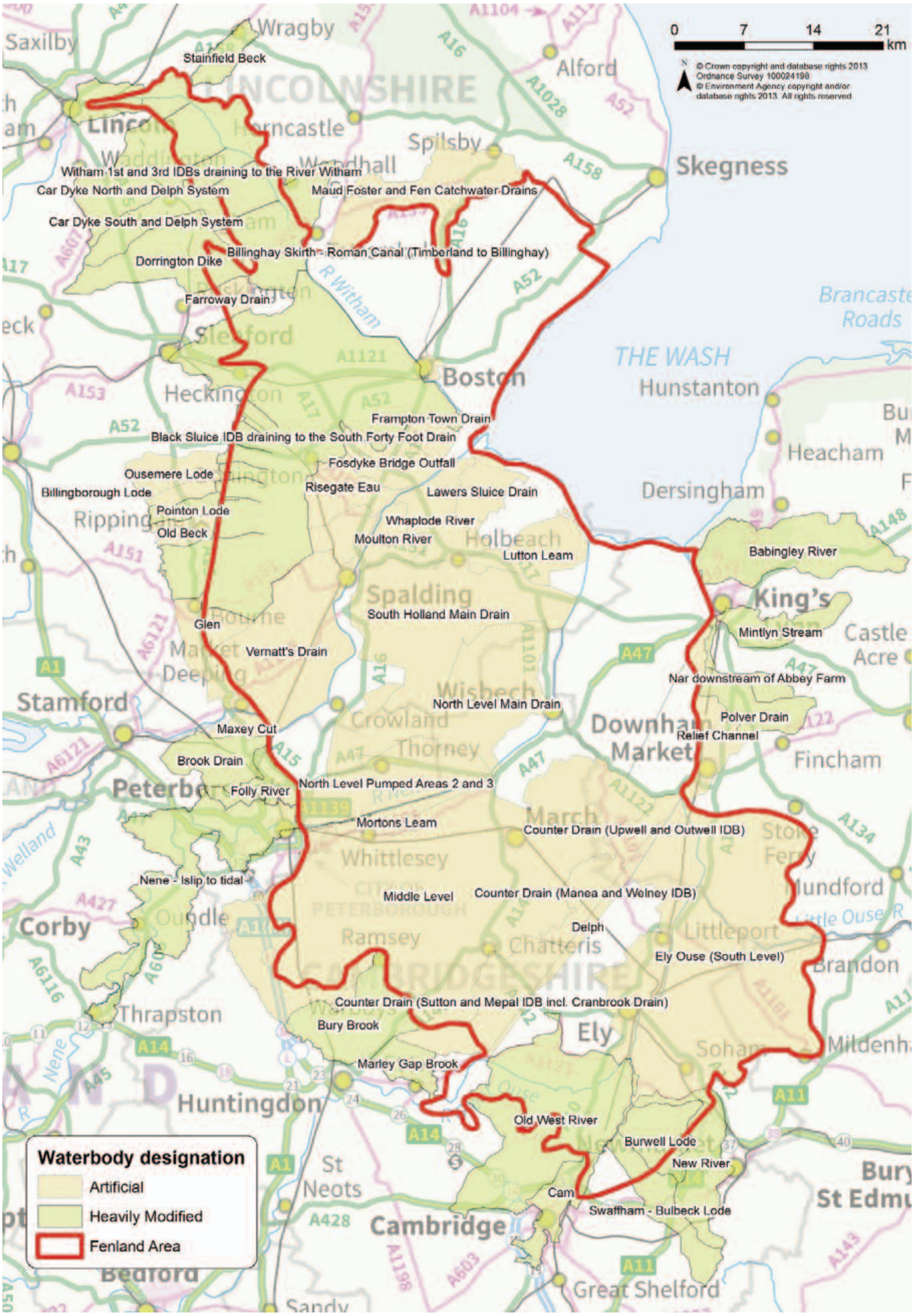


Figure 2.11 Map of Fenland showing designation (AWB and HMWB) of Fenland WFD waterbodies

The three exceptions to this are:

Smeeth Lode.
During the first cycle of the RBMP, monitoring showed this area to be heavily influenced by saline intrusion. This was not sufficient to class the waterbody as truly estuarine, but it was enough to prevent a freshwater classification. Therefore, it is classed as a waterbody that drains to a Transitional and Coastal waterbody. While no WFD monitoring takes place in the catchment, routine environmental monitoring does take place. Some of the Mitigation Measures described in this document would still help to improve the water environment in this catchment.

Land to the east of Welney Washes.
This is also classed as a waterbody that drains to a Transitional and Coastal waterbody as it drains into the Great Ouse where is still influenced by the tide. Routine environmental monitoring takes place within the catchment and the Mitigation Measures suggested in this guide will still help to improve the water environment in this catchment.

Welland – Confluence Greatford Cut to tidal.
This the upper part of the Welland within the Fens and has not been classified a HMWB or an AWB.

Hydromorphological Harm

'Hydromorphological Harm' is caused when recent management activities have an adverse impact that could affect a waterbody's WFD status. In a typical river, harm can be caused by any action that will change a river's morphological attributes, for example:

- River depth and width variation
- Structure and substrate of the river bed
- Structure of the riparian zone

Harm can be recognised by:

- Fresh bed or bank material, for example gravel, deposited on the river bank
- Dead fish or other aquatic organisms on the banks, for example freshwater mussels
- Loose vegetation deposited on the banks or a channel clearly stripped of in-stream vegetation
- Bare, steep earth banks containing digger bucket marks or signs of recent machine activity, for example machinery tracks

Maintenance works

- Time operations to avoid bird nesting season (March – July)
- Leave one bank and water margin of smaller channels uncut through to late summer
- Leave both bank and water margin of larger watercourse uncut through to late summer
- Leave one bank and water margin uncut all year and where possible alternate the side that is uncut the next year.
- Establish vegetated berms on all but the smallest channels

Capital works

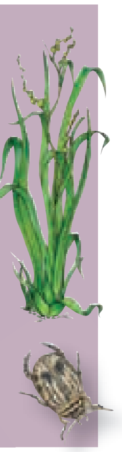
- Carry out pre-works screening, taking into account protected species and the WFD.
- Fully consider the options of delivering improvements by Mitigation Measures
- Plan to carry out the improvement works on one side only, leaving one bank and water margin undisturbed. Only carry out works on the second side once the vegetation has re-established on the first side.
- Time operations to avoid bird nesting season (March – July)

Figure 2.12 Best practice principles for maintenance and capital works

Fenland watercourses are different from typical river systems, as they were often constructed where there was no existing channel and engineered to facilitate drainage and flood protection. As a result, these watercourses are often quite intensively managed to maintain their functions by work such as bank reprofiling, which might be consider harm in a normal river system. However, in some cases, such maintenance practices may help maintain water vole habitat, and substratum disturbance may also benefit some plant communities. The Association of Drainage Authorities (ADA) Drainage Channel Biodiversity Manual gives a full guide to best practice for capital and maintenance works, and the principles are set out at Figure 2.12.

Importance of Mitigation Measures

From understanding hydromorphology and considering how the WFD classification system works it is evident that key to achieving GEP is implementing Mitigation Measures. These are not only important for the WFD waterbodies but they enhance the whole water environment. So, while the WFD focuses on a section of watercourse within a catchment, the GEP Working Group (the Group) believe that maximum gain can be achieved by implementing Mitigation Measures across the whole catchment to include all private drains and not just the WFD classified waterbodies.



The Group reviewed all Mitigation Measures and selected those that they considered could be implemented within Fenland waterbody catchments where land drainage and flood protection is the principle objective. Figure 2.13 (page 24-27) shows the list of Mitigation Measures relevant to Fenland watercourses and the related pressures and impacts, the case-studies and/or techniques and the hydromorphological and biological effectiveness of the Mitigation Measures. Indicators used to assess the potential effectiveness of the mitigating measures are shown below.

Hydromorphological and Biological Indicators for the potential effectiveness of Mitigation Measures

Hydromorphological indicators

- Hydrological regime – the flow and quantity of water and how it changes over time, including connection to ground-water bodies
- River continuity – the free movement of living organisms in a waterbody, such as fish migration and sediment not being inhibited by in-channel structures forming barriers to movement.
- Morphological conditions – physical characteristics of a channel, such as size, shape and structure

Biological indicators

- Phytoplankton – microscopic floating plants i.e. (those species difficult to see with naked eye)
- Macrophytes – large plants, many attached and some floating free i.e. (species that can be seen with naked eye
- Benthic invertebrates – aquatic animals and the aquatic larval stages of insects living on or in the bottom sediments of waterbodies, including dragonfly and stonefly larvae, snails, worms and beetles.
- Fish.

The eighteen Mitigation Measures are grouped into five generic types of techniques and management interventions:-

Working with form and function by improving the marginal habitat alongside Fenland watercourses and increasing their connectivity

A Remove obsolete structure

B Remove of hard bank reinforcement / revetment, or replace with soft engineering solution

C Preserve and, where possible, restore historic aquatic habitats

D Increase in-channel morphological diversity, e.g. install in stream features and two-stage channels

E Re-open existing culverts and alteration of channel bed within a culvert

F Flood bunds (earth banks) in place of floodwalls; set-back embankments; and improve floodplain connectivity

Structural modifications enabling fish passage around and through water management structures and utilising soft engineering solutions where appropriate

G Enable fish to access waters upstream and downstream of impoundment

H Manage fish entrainment in intakes

I Preserve and, where possible, enhance the ecological value of marginal aquatic habitat, banks and riparian zone

J Operational and structural changes to locks, sluices, weirs, beach control, etc.

Operations and maintenance management of marginal and channel vegetation and sediment as well as the control of invasive non-native species.

K Appropriate techniques to prevent transfer of invasive species

L Appropriate vegetation control regime

M Retain marginal aquatic and riparian habitats

N Develop or revise sediment management strategies

O Appropriate channel maintenance strategies and techniques

Management of water level and flow

P Appropriate water level management strategies, including timing and volume of water moved

Q Appropriate techniques to align and attenuate flow to limit detrimental effects of pipes, inlets, outlets and off-takes

Education

R Inform landowners on sensitive management practices

Figure 2.13 MITIGATION MEASURES TABLE – pressures, impacts, case-studies & information sources, and hydromorphological/biological effectiveness.

Group		Mitigation measure	Pressure	Impact
Working with form and function	A	Remove obsolete structure	Dams, sluices, weirs and gravel trap	Loss of sediment continuity (longitudinal) - build-up of sediment upstream, reduced bed load downstream
Working with form and function	B	Remove hard bank reinforcement / revetment or replace with soft engineering solution	Hard bank protection, such as steel piling, vertical walls. Includes hard bank protection in a state of disrepair	Loss of riparian zone / marginal habitat / loss of connectivity / loss of sediment input / loss of wave energy absorption; Loss of sediment continuity (lateral) - build-up of sediment in the channel (flood protection, land drainage, urbanisation only)
Working with form and function	C	Preserve and, where possible, restore historic aquatic habitats	Hard bank protection, such as steel piling, vertical walls. Includes hard bank protection in a state of disrepair	Loss of riparian zone / marginal habitat / loss of connectivity / loss of sediment input / loss of wave energy absorption; Loss of sediment continuity (lateral) - build-up of sediment in the channel (flood protection, land drainage, urbanisation only)
Working with form and function	D	Increase in-channel morphological diversity, e.g. install in-stream features; 2 stage channels	Realignment / Re-profiling / Re-grading	Loss of morphological diversity and habitat
Working with form and function	E	Re-open existing culverts; alteration of channel bed within culvert	Culverts	Loss of morphological diversity and habitat; continuity
Working with form and function	F	Flood bunds (earth banks) in place of floodwalls; set-back embankments; Improve floodplain connectivity	Flood banks and flood walls	Loss of riparian zone / marginal habitat / loss of lateral connectivity / loss of sediment input
Structural modification	G	Enable fish access to waters upstream and downstream of impoundment	Impoundments / Locks and weirs/ Dams, sluices and gravel traps/ tidal barrages	Loss of biological continuity; disruption of habitat connectivity/continuity - interference with fish population movements
Structural modification	H	Manage fish entrainment in intakes	Pumping station operations	Fish entrapment
Structural modification	I	Preserve, and where possible, enhance ecological value of marginal aquatic habitat, banks and riparian zone	Hard bank protection, such as steel piling, vertical walls. Includes hard bank protection in a state of disrepair; trampling and erosion of riparian zone	Loss of riparian zone / marginal habitat / loss of connectivity / loss of sediment input / loss of wave energy absorption; Loss of sediment continuity (lateral) - build-up of sediment in the channel (flood protection, land drainage, urbanisation only)
Structural modification	J	Operational and structural changes to locks, sluices, weirs, beach control, etc.	Impoundments / Locks and weirs/ Dams, sluices and gravel traps/ tidal barrages	Loss of sediment continuity - build-up of sediment upstream, reduced bed load downstream; loss of biological continuity - interference with fish population movements

Response		Hydromorphological effectiveness			Biological effectiveness			
Case study	ADA/NE Manual Technique Reference	Hydrological regime	River continuity	Morphological conditions	Phytoplankton	Macrophytes	Benthic invertebrates	Fish
Eldernell Sluice, Morton's Leam		✓	✓	✓	?	✓	✓	✓
Erosion control Also applies to **MM - F**	BC4	✗	✓	✓	?	✓	✓	✓
Creating reedbeds Great Fen – managing dykes, ditches and drains Also applies to **MM - D & I**	CA5 CC3&4 ML1-3 BA8 BC6&7 OC2	✓	✓	✓	?	✓	✓	✓
Ditch corner, junction and cul-de-sac freatures Also applies to **MM - C**	CL3&4 CC1-4 MC1&3	✗	✗	✓	?	✓	✓	✓
	CC6	✓	✓	✓	?	✓	✓	✓
Earth embankment compared with concrete wall Also applies to **MM – B** Long Eau Washlands	CC8	✗	✗	✓	?	✓	✓	✓
Fulney Lock fish pass	CC7	✓	✓	✗	?	✗	✗	✓
Donningtons pumping station refurbishment		✗	✗	✗	?	✗	✗	✓
Pre-planted, coir roll revetment Also applies to **MM - C**	CA5	✗	✗	✓	?	✓	✓	✓
See case studies at **G & H**	CC7	✗	✓	✗	?	✗	✗	✓

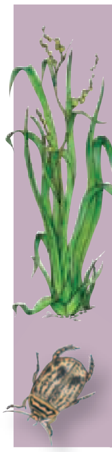
Figure 2.13 MITIGATION MEASURES TABLE – pressures, impacts, case-studies & information sources, and hydromorphological/biological effectiveness.

		Mitigation measure	Pressure	Impact
Operations and maintenance	K	Appropriate techniques to prevent transfer of invasive species	Vegetation control	Transfer and establishment of alien invasive species
Operations and maintenance	L	Appropriate vegetation control regime	Vegetation control	Physical disturbance of bed and or bank- increased sediment input; sediment mobilisation and loss of marginal / riparian vegetation
Operations and maintenance	M	Retain marginal aquatic and riparian habitats	Realignment / re-profiling / regrading	Loss of morphological diversity and habitat
Operations and maintenance	N	Sediment management strategies (develop and revise)	Sediment management (including dredging)	Direct loss of / impact to aquatic habitats / hydromorphology; transfer of fine sediment downstream; bankside erosion and impacts to riparian habitats;
Operations and maintenance	O	Appropriate channel maintenance strategies and techniques	Disturbance to channel bed and margins Removal/clearance of urban trash and woody debris	Loss of aquatic habitats; transfer of fine sediment downstream
Water Management	P	Appropriate water level management strategies, including timing and volume of water moved	Artificial water level management	Manipulation of water levels resulting in loss of habitats and access to habitats, increased erosion and impacts on riparian habitats and vegetation (at low water level), drowning of riparian habitats and vegetation (at high water level)
Water Management	Q	Appropriate techniques to align and attenuate flow to limit detrimental effects of pipes, inlets, outlets and off-takes	Pipes, inlets, outlets and off-takes	Hydromorphological alterations of water and sediment inputs through artificial means
Education	R	Inform landowners on sensitive management practices	Urbanisation; intensive agricultural practice	Changes to vegetation, hydrology and sediment supply

Notes to Table

- Mitigation Measure – see map (page 28) for measures in place in a schematic Fenland landscape referred to by the Mitigation Measures letter A - R
- See Section 3.1 for explanation of Mitigation Measure, pressure, impact and response
- See Figure 2.12 for further information on hydromorphplogical and biological indicators.
- Effectiveness: ✓ = Effective ✗ = Not effective ? = Effect unknown
- The column 'Case studies' list the case studies described in full in Section 3 of this guide. Where a case study may also apply to another Mitigation Measure (MM), this is indicated.
- The column 'ADA/NE' cites the reference numbers to appropriate management techniques described in ADA/NE 'The Drainage Channel Biodiversity Manual'

Response		Hydromorphological effectiveness			Biological effectiveness			
Case study	ADA/NE Manual Technique Reference	Hydrological regime	River continuity	Morphological conditions	Phytoplankton	Macrophytes	Benthic invertebrates	Fish
Controlling invasive non-native species		?	✗	✓	✓	✓	?	?
Leaving a protective vegetation fringe Ditch maintenamce regimes	CA1-4, 7&8 CL1&2 MA1-6 MC1-3 BA1-8, 17&18	?	✗	✓	?	✓	?	?
Creating a sunmerged berm Also applies to **MM – D & I**	CC1&2 MA1-6 MC1-3 BA1-8 BC1-3	✗	✓	✓	?	✓	✓	✓
Maintenance dredging	CL1-4 CC5	✓	✗	✓	?	✓	✓	✓
See case study at N	CL1-4	✓	✓	✓	?	✓	✓	✓
Water Transfer Ltd. Witham	CC7	✓	✗	✓	?	✓	?	?
Off-line storage facility	CC9	✓	✓	✓	?	✓	✓	✓
Moderating agricultural run-off		✓	✓	✓	?	✓	✓	✓



These Mitigation Measures are shown in place in a schematic catchment map in figure 2.14.

In Section three which follows, case studies illustrate the good practice implementation of Mitigation Measures.

Figure 2.14 Mitgation Measures in place in a schematic catchment.

Case Studies and Management Techniques for implementing Mitigation Measures

Introduction

The steps to identify the required Mitigation Measures and the actions to be taken to achieve Good Ecological Potential (GEP) are explained in Section 2 and Appendix 1. For each of the Mitigation Measures selected as relevant to drainage and flood protection in Fenland (Figures 2.13), this section presents some case studies of Mitigation Measures already implemented and/or refers to appropriate management techniques described in other manuals.

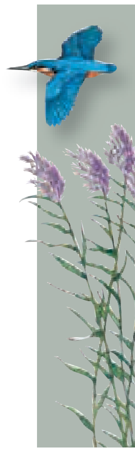
Where a case study is given for a Mitigation Measure, it is presented in a standard format -

Mitigation Measure This is the title of the measure that can be taken/implemented to reduce an adverse impact on the ecosystem. Each Mitigation Measure is identified by a letter (A to R) which refers to Figures 2.13 & 2.14 in the previous section.

Case Study The name of a case study which represents a good practice example of the Mitigation Measures(s) cited.

Summary which sets out:-

- **Pressure –** the hydromorphological pressure that requires management as it causes an adverse impact on the ecosystem (i.e. description of actual structure/management technique).
- **Impact –** the adverse impact(s) on the ecosystem which will be mitigated by the measure implemented.
- **Response –** the Mitigation Measures/operational action implemented to reduce/remove the impact of the ecosystem.
- **Location –** where relevant.
- **Cost –** in £k of operational response.
- **Completion date –** of implementing operational action.
- **Benefit –** beneficial impact on the ecosystem from Mitigation Measures.



Pressure and Impact details with supporting diagrams/photographs where appropriate

Response details of the action taken to implement Mitigation Measures with supporting diagrams/photographs where appropriate

Further information references to specific guidance on implementing mitigating measures in other manuals and publications.

A

Mitigation Measure A

Remove obsolete structure

Case study Eldernell Sluice, Morton's Leam

Summary

Pressure	Guillotine sluice gate
Impact	Limited water level control; no eel pass
Response	Replace with tilting sluice gate
Location	Morton's Leam, near Peterborough
Cost	n/a
Completion date	2016
Benefit	Improved water level control; eel passage

Pressure & Impact The Eldernell Sluice is located on the Morton's Leam Main River approximately 11km east of Peterborough. The Morton's Leam falls within the Nene Washlands Floodplain that was created in the 17th Century. The Nene Washlands has a number of designations, it is a Site of Special Scientific Interest, a Ramsar Site, a Special Protection Area, and a Special Area of Conservation. The management of water levels on the Washlands is key to sustaining both wildlife and livestock through the summer months. Freshwater is let into the Morton's Leam from the fluvial River Nene and flows through the network of ditches running through the Washlands. The Eldernell Sluice retains water in the Morton's Leam upstream of its location in the summer months; this fills the ditches with freshwater to create wet fences to keep cattle in their fields, provides a constant supply of fresh drinking water and supports the ecology of the Washlands. The old guillotine style sluice gate (Figure 1) offered limited control over water levels and no eel passage facility.

Response In 2016, the Eldernell Sluice was replaced with tilting weir gate (Figure 2) that offers more control over water levels and permits eel passage.

Figure 1 Eldernell Sluice with old style guillotine gate

Figure 2 Eldernell sluice with new tilting gate

Mitigation Measure B

Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution

Case study Erosion Control

Summary

Impact	Loss of riparian zone/marginal habitat; loss of connectivity
Response	Hard and/or soft bank protection as appropriate
Location	Watercourses in North Level IDB District and elsewhere
Cost	See below in individual case studies
Completion date	Not available
Benefit	Soft engineering less expensive; banks becomes vegetated contributing to ecology

Pressure & Impact The causes of watercourse bank or embankment failure vary - here are three examples:-

- Bank slip Land drains become blocked or damaged causing ground water to back-up in the pipe resulting in the ground around it becoming saturated. Eventually the saturated weight of the ground becomes too great and the bank gives way. The bank slips into the bottom of the watercourse blocking flows (Figure 1). This can also be caused by poor soil structure.
- Rotational slip or slump This commonly occurs in sections of the bank where there is a weakness in the soil structure. This combined with toe erosion, wave action and fluctuation in water levels causes the rotational slip; the bank gives way slumping down, forcing the bed of the drain up in a typical slip circle (Figure 2).
- Bank erosion It is not uncommon for soil types to change along a watercourse; some watercourses can have both heavy clays and marine silts. The bank erosion typically occurs on the marine silts, which have poorer structural qualities. The continued wave action simply washes the slit away into the drain leaving a vertical drop into the watercourse (Figure 3).

© Ed Johnson

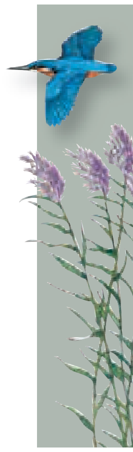
Figure 1 Bank slip caused by a land drain or poor soil structure

© Ed Johnson

Figure 2 Rotational slip or slump

© Ed Johnson

Figure 3 Erosion caused by wave action



Response When considering the choice of engineering solution for erosion control in Fenland watercourses there are two main factors to be considered: economic and environmental. The impact on these two factors will depend on the scale of the project to be undertaken. For example, a small slip repair 20m long will have a smaller impact than a 500m erosion repair project. The types of failure described here are common in Fenland arterial drainage systems. In consequence, most IDBs allow for some annual expenditure on bank protection within their annual estimates and works programmes to either repair or prevent future bank erosion or failure. There are several methods and materials available to engineers when designing the work which are classed as either 'Hard Engineering' or 'Soft Engineering'.

Hard engineering normally involves major construction work. This can prove expensive and have a significant impact on the ecology and hydrology of the watercourse. Soft engineering tries to work with the natural processes of the watercourse and uses more natural products such as timber, imported clays and vegetation. It does not involve the use of major construction work and structures. The challenges facing engineers is to design a solution that suits the natural environment while implementing a sustainable design to fix the problem. In some cases, this will be a combination of both hard and soft engineering methods. Here are three cases with examples of both:-

Case One **Timber versus Concrete**

© Ed Johnson

Figure 4 Stewards House Drain, North Level IDB

© Environment Agency

Figure 5 Stewards House Drain competed and in flow

Figures 4 and 5 shows a channel widening project on the North Level IDB's Stewards House Drain. This project used both timber and soil as a softer alternative to precast concrete sections. Figure 5 shows how a channel with restricted access and land can be widened using softer material sourced from sustainable suppliers. The channel was created with treated timber posts and boards and the banks with soil. The cost of this project was £250/m inclusive of materials, plant and labour.

Case Two **Thorn Faggots versus Gabion Stone**

© Ed Johnson

Figure 6 Thorn Faggots

© Ed Johnson

Figure 7 Gabion Stone

Figures 6 and 7 detail a similar problem repaired with different methods, both sites have erosion damage caused by wave action.

Figure 6 shows the soft engineering method of thorn faggoting: faggots are cut into bundles, carted to site, placed on a shelf excavated by a hydraulic excavator and covered with soil. The cost of making, carting, placing and covering the faggots is approximately £32.00/m, the materials were all sourced from local hedgerows within the Board's catchment making them a sustainable source of material.

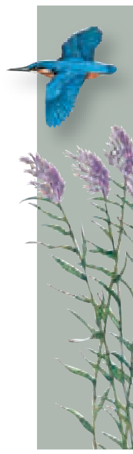
The alterative solution in Figure 7 shows the use of gabion stone; in this case faggots would not have worked. Because of the loss of silt material when the erosion occurred, there was no material left on site to cover the faggots. Therefore, soil would have had to have been carted to site to cover the faggots at extra cost making the project more expensive than using gabion stone. In this case one tonne of stone was placed per metre, at a cost of £31.00/m. This method allows for the stone to be placed in the void left by the erosion, the stone is placed no higher than the maximum summer retention level allowing it to be almost completely covered in the summer months.

Case Three **A Combination hard and soft engineering methods**

© Ed Johnson

Figure 8 Gabion stones being placed behind timber piles and boards

On some sites, where it is not always possible to implement one method to suit the site conditions, a combination of methods is used, Figure 8 shows how a combination of methods can be applied to a site. In this case, as the drain had eroded and slumped, faggots or gabion stone alone would not have provided enough structural strength to carry the weight of the bank, leaving it unstable. To provide stability, a toe line was installed using timber fir piles and treated timber boards. Then gabion stone was placed in the void behind the piles and boards up to the maximum summer retention level. The stone prevents further erosion of the bank by absorbing the wave action and the fluctuation in levels caused by pumping. The cost of this method is approximately £55.00/m inclusive of material, plant and labour.



The chosen method adopted to repair the damage would depend on the following factors:-

- the amount of weight to be supported behind the repair;
- the mode of failure, bank slip, erosion or slump;
- the local sustainable materials available e.g. thorn hedging, soil for backfilling;
- the wildlife present and affected on site;
- the environmental impacts of the favourable method i.e. carting quarried material to site;
- access to site and sufficient space to work and implement the design;
- impacts on local communities e.g. disturbance from noise;
- economic impacts i.e. cost comparison of the method and the benefits to the wider catchment; and
- the geology of the site i.e. different soil types allows for different methods to be implemented.

It is probably not possible to find one method of repair that would suit all sites; the influencing factors listed above would determine the method to be chosen. However, in most cases, a softer engineering method could be used as an alternative to hard engineering, or at the very least a combination of both.

Further information Technique BC4 in ADA/NE 'The Drainage Channel Biodiversity Manual'

C

Mitigation Measure C

Preserve and where possible restore historic aquatic environments

Also applies to

D

I

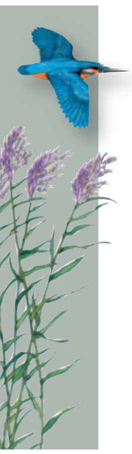
Case study Creating reedbeds

Also applies to Mitigation Measures D and I

Summary

Pressure	Vegetation removal
Impact	Loss of morphological diversity and habitat
Response	Widening watercourse to create reedbed and new shallow channels.
Location	Smeeth Lode Drain, near Tilney St Lawrence, Norfolk
Cost	Not available
Completion date	2012
Benefit	Creation of 1 acre of reedbed and shallow channels to improve in-channel
	biodiversity and meet BAP targets for reedbed restoration/creation.
	Also, increased storage capacity within the drain

Pressure & Impact Smeeth Lode Drain is the pump drain for King's Lynn IDB's largest pumping station. The Board's annual maintenance operations include the removal of all vegetation from that drain resulting in a loss of ecological diversity and habitat.



Response In 2011, King's Lynn IDB obtained funding from Defra's IDB grant scheme to improve their operational efficiencies, environmental performance and wider sustainable development. The Board proposed a reedbed creation scheme along Smeeth Lode Drain, near Tilney St Lawrence, Norfolk.

Figure 1 Excavation works in progress


© George Dann, King's Lynn IDB

Figure 2 Completed reedbed scheme

Reedbed is a UK Biodiversity Action Plan (BAP) priority habitat and a priority habitat in the IBD's BAP. This was achieved by widening one side of this watercourse, improving biodiversity and gave increased storage capacity within the drain, without adversely affecting flow conveyance to the pumping station.

The land where the drain widening was proposed was owned by the IDB but it had been let on a long-term basis. Therefore, the IDB had to agree terms with the tenant about handing the land back, advertise the proposals and carry out various other works in preparation for the drain widening. Excavation works began in March 2012 using IDB workforce, excavator, tractors and trailers (Figure 1). Although the IDB's original proposals had been to create two areas of reedbed, one much larger than the other, it was subsequently decided that the drain would be widened along one stretch only, while still creating around the same area of new reedbed. Excavated spoil was deposited and levelled across adjacent parts of the Board's land.

The finished scheme (Figure 2) has created an area of approximately 1 acre that will hopefully all become reedbed. The excavated area is at varying depths above and below typical water levels. It includes a shallow channel along one edge of the reedbed and two small channels linking this to the main drain, with the aim of maximising botanical diversity and interest to invertebrates and birds. Although it had originally been intended to leave the area to colonise with reed by natural expansion from the main drainage channel, the IDB transplanted a few small clumps of reed to encourage quicker growth.

Further information Technique CC4 in ADA/NE 'The Drainage Channel Biodiversity Manual'

C

Also applies to

D

I

Mitigation Measure C

Preserve and where possible restore historic aquatic environments

Case study Great Fen - Managing dykes, ditches and drains

Also applies to Mitigation Measures I and D

Summary

Pressure	Typical trapezoidal channel and pumped drainage
Impact	Loss of morphological diversity and historic habitats
Response	Engineer water retention to restore area of wetland
Location	Watercourses in the Great Fen restoration project area, between Peterborough and Huntingdon
Cost	Not available
Completion date	Ongoing
Benefit	Restoration and creation of wetland habitats; winter water storage

Pressure & Impact The wild Fens with their abundant wildlife once stretched for hundreds of miles across eastern England. Starting in the 17th century the land was drained for farming and more than 99% of this habitat with many rare species of plants and animals disappeared.

Response The Great Fen is a 50-year project to create a huge wetland; one of the largest restoration projects of its type in Europe. Two of the last fragments of wild fen, Woodwalton Fen and Holme Fen are National Nature Reserves (NNRs), but they are too small and isolated to effectively support the special wildlife of the original fens. The plan is to create an enveloping landscape of 3,700 hectares around the existing NNRs. By buying and transforming farmland, they will be joined together and greatly enlarged, recreating a range of wetland features with unprecedented conservation benefits for wildlife. As well as providing a haven for fen wildlife, the Great Fen will create a massive green space for people, opening new opportunities for recreation, education and business. It will incorporate areas where winter flood waters can be stored and will prevent the release of huge amounts of carbon dioxide each year.

Figure 1 Slacker, Old Decoy Farm

Figure 2 Re-profiled ditch

The Great Fen has inherited a complex and efficient network of drains, dykes and ditches whose primary purpose has been to get water away from the arable farmland as quickly as possible. Generations of farmers have deepened and straightened field ditches, and as a result, the peat fields rarely have any of the standing water that can be seen in other parts of the country after heavy rainfall. But now, a major aim of the project is to retain water, rather than to drain it away. Ideally, excess water will be taken from the main drains during the winter and retained on the Great Fen area throughout the summer months. These concerns are dealt with at a local level by IDBs, which have responsibility for pumping stations and major dykes, some of which cross the Great Fen area. Over a wider area in this part of the fens, the Middle Level Commissioners (one of the five Great Fen partner organisations) are responsible for flood defence and water-level management. There are 33 IDBs within the Middle Level and the Commissioners are responsible for the more major watercourses such as Great Ravely Drain, which borders Woodwalton Fen.

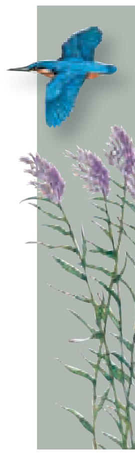
Moving from a regime of draining water to one of retaining it is a complex business, assisted by the following three interventions

- **Diverting a main drainage dyke - getting water through**

One of the main IDB dykes that crosses the Great Fen area has been responsible for taking water from the farms south of Holme Fen, north towards the Old River Nene. While this drainage is still most important, its original route would make wetland creation difficult so, after much discussion, a new route was agreed and an entirely new dyke is being constructed. Work began in early 2013; by September the sides of the deep dyke were already becoming vegetated. The next stage of this drainage diversion will be extending the dyke across the B660 road. However, it will be another year of fine-tuning and testing before the switch is made and drainage water flows freely along its new route.

- **Creating a 'slacker' - letting water in**

The major watercourses that border the Great Fen area on the north and east sides are generally at a higher level than the adjacent farmland - the water has been drained from arable fields into IDB dykes and then pumped up into these waterways to flow away eventually into The Wash. This difference in height means that it should be relatively easy to allow water from the main waterways to run down into the adjacent fields where it can be used to create wetland habitats. An example of this is at Old Decoy Farm which lies below the level of the River Nene (old course) as it flows north between high clay banks. Here, in the summer of 2013, the Middle Level Commissioners built a slacker so that, at certain times of the year water can be allowed to flow down from the river onto parts of Old Decoy farm. The slacker is essentially a large pipe through the river bank with the means to regulate the flow of the water (Figure 2); this simple construction will play a major part in creating future wetland habitats.



- **Re-profiling ditches - keeping water in**

For fields that are intended to be wet pasture, it is essential not to let water drain immediately away. For example, at Old Decoy farm there was a ditch that would take that water straight into the IDB dyke on the other side of the farm area. The solution to this problem was simply to fill in that ditch. Having removed this drainage route, the remaining network of ditches can be re-used to spread the water across the fields. However, as these ditches are often deeper than they need to be, if one side of the ditch is lowered along part, or all, of its length, then, when it fills with water, the overspill can saturate the adjacent field. So, the bank is made less steep and the ditch itself is made shallower.

Further information Techniques CC7, CL3&4,CC1-4, MC1&3 & OC2 in ADA/NE 'The Drainage Channel Biodiversity Manual'

D

Also applies to

C

Mitigation Measure D

Increase in-channel morphological diversity, install in-stream features

Case study Ditch Corner, Pool Creation and Cul-de-sac features

Also applies to Mitigation Measure C

Summary

Pressure	Typical trapezoidal channel
Impact	Loss of morphological diversity
Response	Creation of in-channel habitats
Location	Watercourses in the Middle Level Area
Cost	Not available
Completion date	Not available
Benefit	Improvements to in-channel habitats for aquatic plants, fish and invertebrates; improvements to the aesthetic value of the watercourse and to its recreational value

Pressure & Impact Typical trapezoidal channel which tends to be deeper than in which most emergent plants can grow.

Response

- Ditch Corner Shallow Water Habitat Creation

One of the scarcer but most valuable features in IDB drains are shallow water areas. However, there are some situations where a corner can be given for wildlife without compromising water movement, such as where a drain sweeps around a corner in a wide arc and the furthest corner can be a bit of a stretch for the excavators arm to reach. In such situations a deep main channel can be maintained while leaving the corner apex as a shallow area for emergent water plants to grow. The example

Figure 1 Ditch corner shallow water habitat

illustrated (Figure 1) shows where a Manea and Welney District Drainage Commissioners (MWDDC) drain turns a corner allowing plants to grow in the corner. The extra width of the channel at this point ensures the vegetation does not inhibit water movement. These shallow, undisturbed areas are particularly valuable as fish spawning sites, as are the following two methods.

- **Pool Creation at Ditch Junctions**

Like the example above, the extra width of channels at ditch junctions offer the opportunity to allow water plants to grow in an area they can occupy without inhibiting the passage of water which moves through via a deeper channel route (Figure 2) The position of areas identified as shallow pool areas should be indicated on the BAP Management map and shown to ditching contractors when they commence maintenance works.

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Figure 2 Ditch junction pool

- **Cul-de-sac Conservation Areas**

Leaving dead-end drains or head water ditches as conservation areas is a very positive biodiversity action. When an old diesel pump on the MWDDC drain was retired from service, the channel became a cul-de-sac on a spur off the main routes. By adopting a less frequent maintenance regime it became a very attractive conservation area where water violets and a good variety of other water plants thrived (Figure 3).

If drain priorities change in a district, opportunities may present themselves to designate sections for less frequent cleansing. They will still require occasional maintenance but costs will be reduced and valuable sites created for biodiversity. The position of channels identified as conservation areas should be indicated on the BAP Management map.

Further information Techniques CA5, CL3 & CC3 in ADA/NE 'The Drainage Channel Biodiversity Manual'. Sections 5.2.3.2 & 5.2.3.4 in 'The Middle Level IDN Biodiversity Manual

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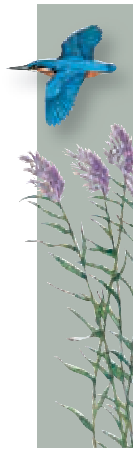
Figure 3 Cul-de-sac conservation area



F

Also applies to

B

Mitigation Measure F

Flood bunds (earth banks) in place of flood walls

Case study Earth embankment compared with concrete wall

Also applies to Mitigation Measure B

Summary

Pressure	Flood banks and flood walls
Impact	Loss of riparian zone/marginal habitat
Response	Soft engineering
Location	Whittlesey Washes
Cost	Not available
Completion date	Not available
Benefit	Direct benefits to biodiversity

© Tim Burgess RHDHV

Figure 1 Construction underway

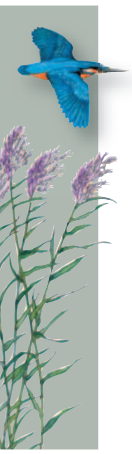
Figure 2 Embankment work completed

© Tim Burgess RHDHV

Figure 3 Wave wall construction underway

Figure 4 Wave Wall construction completed

Pressure & Impact The Whittlesey Washes flood storage reservoir lies to the south of the River Nene, east of Peterborough. It plays an important part in helping to reduce the risk of flooding during combined high tides and river flows. In construction and engineering it isn't always possible implement one design that will solve all the problems. In most cases there are several factors that will determine the design chosen. The design for this project was a combination of earth embankment and concrete wave wall.



Response The Whittlesey Washes South Barrier Bank Flood Defence Scheme is an example of a project where two different designs, one soft and one hard engineering, were used. Most of the 18km bank was strengthened with imported material that was placed on the south side of the bank, this material increased the strength of the bank reducing the likelihood of a bank failure. For the softer engineering option of an earth embankment to be implemented, sufficient space was needed to allow access for the construction equipment to carry out the work and for the new foot-print of the embankment (Figures 1 & 2).

For the sections of bank where it was not possible import material and make the embankment wider due to a lack of space, an alternative design had to be used that would offer the same strength and level of protection. In this case, the hard engineering option of a concrete wave wall was constructed which offered the same standard of protection but the design used less space to implement (Figures 3 & 4)

Further information Technique CC8 in 'The Drainage Channel Biodiversity Manual'.

Mitigation Measure F

F

Set back embankments and improve floodplain connectivity

Case study Long Eau Washlands

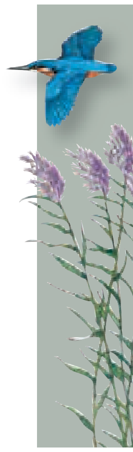
Summary

Pressure	Flood defence banks
Impact	Loss of lateral connectivity
Response	Set back embankments
Location	Long Eau near Manby, Lincolnshire
Cost	£60,000
Completion date	1995
Benefit	Pasture instead or arable; biodiversity in flood plain; flood water storage

Pressure & Impact The Long Eau is a high level carrier and drains areas of predominantly agricultural land. In order to increase the efficiency of land drainage for agriculture, both rivers were modified with raised embankments to increase capacity and protect adjacent land from flooding. The Eau was thus a typical example of an agricultural improvement scheme where heavily engineered flood defence banks constrained hydromorphological processes and cut off contact between river and floodplain, thereby reducing its flood storage potential.

Response Washlands were created in the floodplain of the Long Eau by setting back the old trapezoidal banks, opening up areas of the floodplain for seasonal flooding (Figure 1). Initially a farmer agreed to the washland creation scheme on his land after successful application for funding from the Countryside Stewardship Scheme (CSS). The works were carried out by the then responsible organisation, the National Rivers Authority, which funded the setback scheme only when the farmer agreed that setback would be permanent and the banks could not be moved back to their former position in the future. This was accomplished by lowering the left flood bank to just above field level creating a new bank set-back 300m from the river channel (Figures 2 & 3). On the successful completion of the first scheme, the land owner across the river also signed up to the CSS scheme to extend the washland to a total area of 22 ha. In both cases, land was in arable use before the scheme but was converted into pasture under the stewardship agreement. Although flood defence was a secondary element in the construction of the washland, the project created an area of floodplain with a storage capacity of 18,500m3 offering flood defence benefits to dwellings down-stream. It is estimated that the combined flood storage capacity of these two sites has increased flood protection against the 1 in 30 year return period event along a 3 km section of the River. The protection provided to these dwellings was used to justify the scheme in terms of flood defence.

Figure 1 The two washlands flanking the Long Eau (centre)



The site attracts wading birds on the shallow waters around the margins, and dabbling ducks and geese on deeper open waters; over 60 breeding pairs of redshank have been reported. The ideal condition for wildfowl is water retained on the site for 3-4 months over the winter months. The average duration of standing water is 3-4 days but can stand for months depending on frequency of flood events. The soil remains wet throughout the winter, especially in the low areas of the site, which is beneficial to birds such as snipe. The path of the River Eau was not altered during the set-back scheme, mainly because the river course maintains a meandering path. However enhancements were made to the channel to encourage increased biodiversity. Wet ledges (berms) were created to allow wetland marginal flora and fauna to establish and develop along the edge of the river. Riffles were constructed within the channel to alternate the depth of water between shallows and deep pools, which attract fish and aquatic invertebrates. The right bank of river which was not set back was re-profiled in places to produce cliffs to encourage kingfishers to return to the river. However the cliffs were prone to slips and have now been colonised by vegetation. Lowering the washland bank has had some negative effects upon the water vole (Arvicola terrestris) population in the area. The steep profiles of the previous engineered banks provided excellent habitat for water voles. The removal of these banks and creation of new banks with gentler profiles at a distance from the river has degraded their habitat. As water voles are abundant in this area of the UK, the loss of this particular habitat was not considered problematic; the project took place before water voles were placed under BAP listings. Setback projects today would need to take this into account.

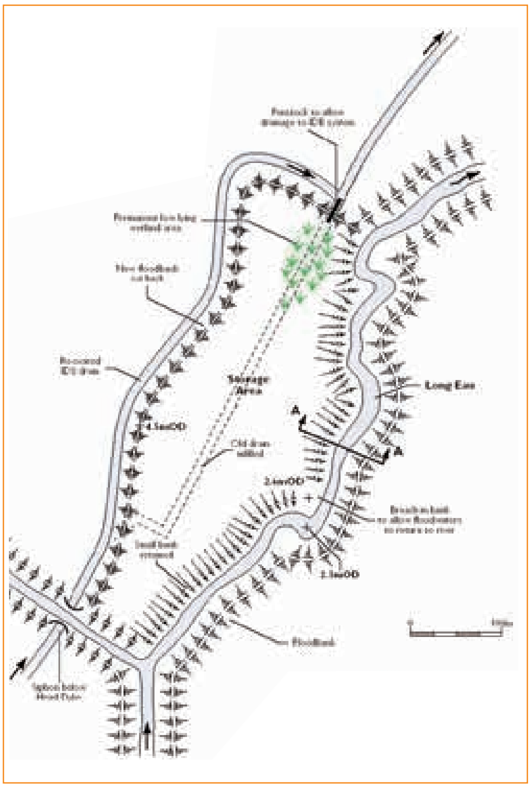


Figure 2 Plan of the first washland site on the Long Eau

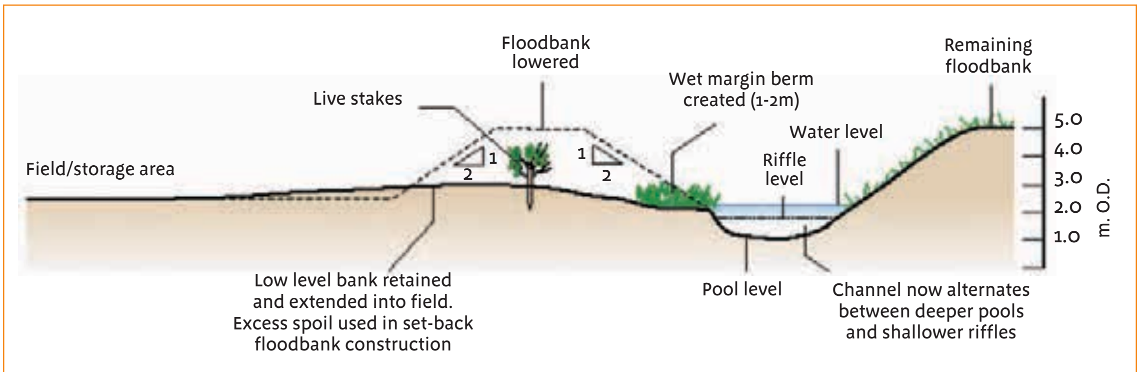


Figure 3 Cross section through flood banks at Manby

Generally, setting back embankments can deliver a wide range of direct and indirect benefits, including:

- Direct benefits to plants, invertebrates, birds and animals which live on the banks, riparian and floodplain zone
- Direct ecosystem benefits associated with the creation of new habitats (grassland instead of concrete), including maintenance of and improvements to biodiversity
- Climate change adaptation, allowing habitats and species to adapt to changing conditions
- Improvements to the aesthetic value of the watercourse and improvements to its recreational value
- Increases the potential for removal of fine silt from river systems – this will increase water clarity which in turn benefits ecology.

Mitigation Measure G

G

Enable fish to access waters upstream and downstream of impoundment

Also applies to

B

Case study Fulney Lock Fish and Eel Penstock Pass

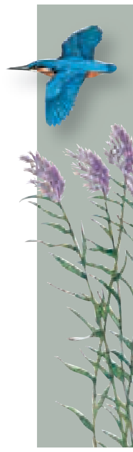
Also applies to Mitigation Measure B

Summary

Pressure	Lock with double set of pointing tidal doors
Impact	Obstruction to fish and eel movement
Response	Penstock fish pass installed
Location	Fulney Lock, Lincolnshire
Cost	£40k
Completion date	June 2015
Benefit	Increases opportunity for eel/fish migration; opens 23km of River Welland upstream of Fulney

Pressure & Impact Fulney Lock, in Spalding, marks the tidal extent of the River Welland, is owned by the Environment Agency and consists of a double set of pointing tidal doors (See Figure 1). This maintains a navigable depth of freshwater for upstream uses, and is also very occasionally used by boats to access the tidal Welland. This lock was an obstruction to the movement of fish, including eels, from the tidal to the non-tidal Welland.

Response The planned project outcome was to improve the passage for fish and eels past this obstruction, whilst maintaining the function of the existing lock and the security it provides to flood defence.



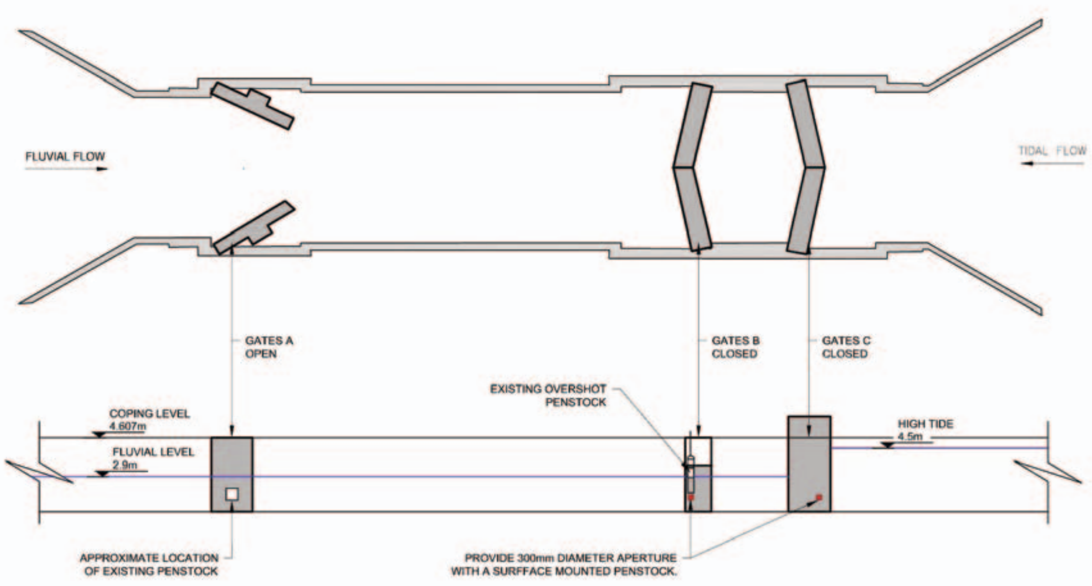


Figure 1 Fulney Lock in plan and elevation showing position of penstocks

Before being modified, eels had limited access through the lock at the very top of the tide through the downstream set of doors, which are open at low tide, and then over an overshoot penstock on the internal set of doors. However, this fish pass opportunity lasted only approximately 5 minutes in duration before the outer door automatically shut under pressure of the rising tide. Therefore, to increase the time window in which eels could negotiate the lock, and make it accessible for fish as well, a penstock fish and eel pass was installed in the outer doors (See Figure 2, left). The penstock has a 300mm aperture and is manually operated; its default position is open all year. Modelling showed that the aperture could be left open without affecting flood risk or upstream uses.

Figure 2 New penstock in outer tidal doors (left) and existing overshoot penstock on internal doors at top of tide (right)

The penstock requires minimal maintenance; being a rising stem type penstock rather than a non-rising stem with universal joint down close to the aperture. Much of the maintenance can be done on top of the gate, such as greasing the spindle and moving parts. An operation and maintenance note is currently being prepared by the designers. The one aspect which is of concern to flood risk management is what could be done if the penstock becomes blocked by large items and the penstock cannot be closed - small items such as free floating weeds simply wash off on each tide. This potential problem is to be checked with the designers and assessed by ongoing monitoring, but is presently seen as a small risk.

Monitoring of the functioning of the new penstock has shown eels and fish are using it to access the lock on the rising tide: when the water current was passing through the new penstock door, both eels and fish migrated through it with ease. Upstream of the doors, the flow from the fish pass door made the second set of pointing doors, that already contain penstock sluice doors (See Figure 2, right), very passable. These are initial findings from one tide's monitoring; a more comprehensive report will be produced when more monitoring has been completed.

Further information Technique CC7 in ADA/NE 'The Drainage Channel Biodiversity Manual'
Section 9.7 'Eel and fish support actions' in The Middle Level IDB Biodiversity Manual.
Environment Agency 'Fish Pass Manual'

Mitigation Measure H

Managing fish entrainment in intakes

Case study Donningtons Pumping Station refurbishment

Summary

Pressure	Pumping Station
Impact	Obstruction to movement of eels, potential of damage to fish and eels entrained
	in pumps
Response	Penstock fish pass installed
Location	Outfall of Donningtons Drain into South Holland Main Drain near Whaplode
	Drove, Lincolnshire
Cost	Fish friendly pumps - £30,000 more than more traditional types
	Eel pass and eel friendly discharge flap - £12,000
Completion date	February 2016
Benefit	Reduces likelihood of harm to fish and eels entrained by the pumps; opens 15km
	of IDB watercourse upstream to fish movement

Pressure & Impact Donningtons Pumping Station lies within the South Holland IDB district, and was built in 1973, replacing an earlier flapped gravity discharge. The station caters for the surface water drainage of a catchment area of some 700ha including the village of Whaplode Drove. There are 15km of IDB maintained watercourse within the catchment which discharge, via Donningtons Pumping Station, into the South Holland Main Drain. The station formed an obstruction to the movement of eels, and had the potential to harm fish entrained in to the pumps.

Response The pumping station needed refurbishment, including replacement of the pumps. As part of the works, eel Mitigation Measures were included under the Eel Regulations 2009:-

- The new pumps being 'fish friendly', to minimise damage to any fish, including eels, which pass through them (Figures 1 & 2), and
- The installation of an elver pass and eel friendly outfall flap, to allow passage of juvenile eels upstream during the migration period of their life cycle (Figure 3).

The new pumps and eel pass were installed in February 2016, and a few young eels were observed using the pass during the spring of that year (Figure 3)

Figure 1 The new fish friendly pumps and eel pass

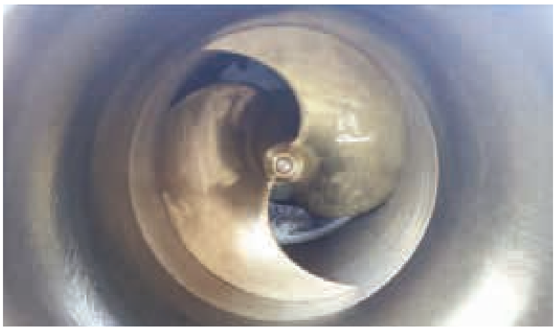


Figure 2 The impeller of one of the new fish friendly pumps installed at the station

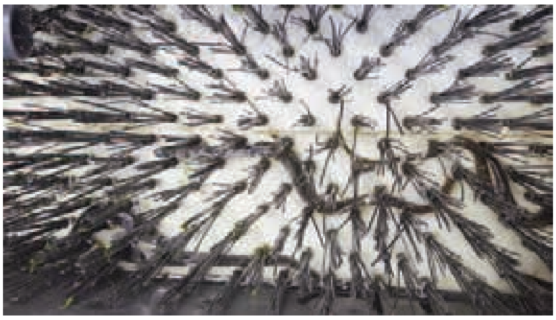


Figure 3 Eels going through the eel pass – June 2016

I

Mitigation Measure I

Preserve, and where possible enhance, ecological value of marginal aquatic habitat, banks and riparian zone

Also applies to

B

C

Case study Pre-planted coir roll revetment.

Also applies to Mitigation Measure B & C

Summary

Pressure	Hard bank protection
Impact	Loss of riparian habitat
Response	Install coir roll revetment
Location	Watercourses across Middle Level DB
Cost	Not available
Completion date	Not available
Benefit	A self-sustaining protection that provides a natural habitat for riparian species

Pressure & Impact The light or sandy soils that Fenland waterways pass through can make their margins vulnerable to erosion. When the channel is a navigation route the potential for erosion by wave action from boat wakes is increased on unprotected riparian edges. Hard revetment materials such as stone, timber or steel are used when bank slips are particularly bad but they are an increasingly expensive option and are not wildlife-friendly.

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Figure 1 - Coir rolls on the Sixteen Foot River near Bedlam Bridge four months after installation in January 2009. The coir roll is contained in a net of mesh that plant roots and water voles can penetrate. Yellow flag iris and lesser pond sedge are the plants showing good growth in the foreground.

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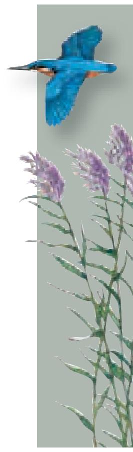
Figure 2 - The same site in September 2009.
Purple loosestrife have flowered and provided a bright source of nectar for many butterflies and other insects. In the background burr reed are starting to establish in front of the coir rolls on the river side.



Response As an alternative to hard revetment materials, 1,770 m of coir rolls have been installed on Middle Level main drains at 23 sites. Rolls 3m long and 30cm in diameter and are encased in a wide mesh net, and come pre-established with a mix of marginal native plants including sedges, grasses, rushes, and flowering plants. They are installed and retained at the water margin by five fence posts per 3m coir roll section, and positioned so that they are two-thirds in the water and one-third above it at typical summer water level. This may mean that the rolls are two thirds out of the water when they are installed during winter; local knowledge of the summer water level is important when installing in winter. The coir (coconut husk material) provides instant erosion protection to the bank toe and the plants roots grow through the coir into the bank and establish a self-perpetuating natural revetment.

Coir rolls can provide a cost-effect solution: on comparable lengths, coir rolls cost less and are quicker than hard revetment materials to install. They are proving to be a long-lasting technique; the oldest installations having been established for eight years and remain a strong and self-sustaining protection that offers the natural habitat for typical riparian species of fenland waterways (Figures 1 & 2). Although the coir rolls are probably too dense for water voles to burrow through them, the voles can make their above ground burrows among the good emergent plant cover created and make their underwater tunnels below the coir rolls.

There are situations where bank damage is so severe or extensive that only hard revetment materials are appropriate but coir rolls are very effective in providing 'a stitch in time' solution to prevent a small slip becoming a large one.

Further information Technique BC4 in ADA/NE 'The Drainage Channel Biodiversity Manual'
Section 5.2.3.1 'Coir roll revetment installation' in MLIDB Biodiversity Manual

K

Mitigation Measure K

Appropriate techniques to prevent transfer of invasive species

Case study Controlling invasive non-native species

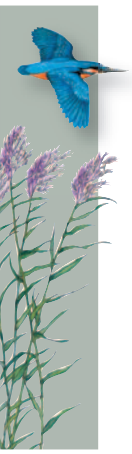
Summary

Pressure	Vegetation control
Impact	Establishment of invasive non-native species; out-compete/predate native species
Response	Avoid transfer and prevent/control establishment as appropriate
Location	Middle Level IDB Watercourses
Cost	Not available
Completion date	Not available
Benefit	Direct benefits to biodiversity by reducing impact on native species and habitats

Pressure & Impact Invasive species are non-native plants or animals that have been introduced either accidentally or deliberately. They often have no natural control mechanisms such as predators, and can cause environmental damage by out-competing or killing native species, degrading habitats and exacerbating flood risk.

Non-native invasive species already in the Middle Level IDB waterways, or nearby, are:

Aquatic Plants



- Floating pennywort *Hydrocotyle ranunculoides* – A floating plant which shades the surface of watercourses, damaging habitats for other plants and aquatic organisms. It can grow so thickly across watercourses that it may also clog intake pipes and prevent boating and angling. Not currently present in Middle Level, but in Cam, Great Ouse and South Level and the plant considered most likely to invade next.
- Water fern *Azolla filiculoides* – A floating plant which reproduces so profusely that it blankets channels (Figure 1), causing similar impacts to the floating pennywort. Widespread in Middle Level in bad years.

Bankside Plants

- Giant hogweed *Heracleum mantegazzianum* – A large invasive plant with poisonous sap, which grows in dense stands and outcompetes native plants. Occasional, but locally frequent.
- Japanese knotweed *Fallopia spp* – Can grow so vigorously that it can damage infrastructure. Locally frequent, especially near railways.
- Himalayan balsam *Impatiens glandulifera* – A plant which forms dense stands on river banks, outcompeting native plants and leaving banks exposed to erosion when it dies back in the winter. Occasionally found.
- Parrot's feather *Myriophyllum aquaticum* and New Zealand pigmyweed *Crassula helmsii* – are present at two urban sites in the District.

Animals

- American mink *Mustela vison* – Considered one of the major causes of the decline of the water-vole and may also predate on ground nesting birds. Widespread in Middle Level.
- Chinese mitten crab *Eriocheir sinensis* – Impacts include their habit of burrowing into banks increasing erosion, potential to block intake screens, and competing with and preying in native species including eating fish eggs. Spreading into all main channels in Middle level.
- American signal crayfish *Pacifastacus leniusculus* – A crustacean which is larger than the native white clawed crayfish, outcompeting them for habitat (though no native crayfish have been found in the Middle Level). The crayfish also prey on some fish eggs and de-stabilizes river banks by burrowing into them. Present in small numbers in Whittlesey Dyke.

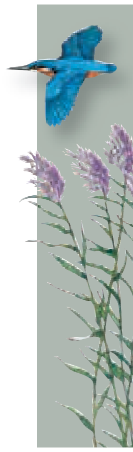
Response Measures aim to minimise the damage caused by non-native invasive species by ensuring they are controlled effectively so natural plant and animal communities are allowed to re-establish.

A range of techniques can be used to implement this activity including:

- Physical control measures – for example, cutting or trapping, complete removal and appropriate disposal
- Chemical control measures – through applying suitable herbicides
- Biological control measures – through releasing host-specific predator or parasite
- Prevent spread – through appropriate site management and cleaning maintenance equipment.

Biosecurity is important and, especially in the case of plants and some invertebrates, the 'check-clean-dry' campaign urges waterbody users to follow three simple steps when leaving the water:

- **Check** your equipment and clothing for live organisms – particular in areas that are damp or hard to inspect.
- **Clean** and wash all equipment, footwear and clothes thoroughly. Use hot water where possible. If you do come across any organisms, leave them at the waterbody where you found them.
- **Dry** all equipment and clothing – some species can live for many days in moist conditions. Make sure you don't transfer water elsewhere.



Measures that have, and are, being taken in the Middle Level and elsewhere in Fenland to control the non-native, invasive species are:

© Great Fen

Figure 1 Water fern cover a drain's surface

- Floating pennywort – Cut and collected by weed cutters. It is particularly important that parts of the cut plant are collected too and not allowed to drift downstream as it propagates vegetatively. A host specific weevil is currently being tested which shows promise for biological control.
- Water fern – Difficult to control by mechanical means or herbicides, but biological control with a host specific weevil has been successful.

- Giant hogweed and Japanese knotweed – Can be eventually controlled by mechanical and chemical means, or a combination of both. Non-native plants and contaminated soil must always be disposed of safely. In the case of Japanese knotweed, it is an offence to allow contaminated soil or plant material from any waste to spread into the wild.
- Himalayan balsam – Can be controlled chemically but is most often hand-pulled as very shallow rooting. To avoid additional spread do not disturb plants if seeds pods are visible; programmes should be undertaken in April or early May. If hand pulling after this time, bag plant tops to prevent seed spread.
- American mink – Are relatively easy to trap. Reducing their numbers in late winter and early spring (January to April) benefits not only water voles, but also nesting water and game birds, as well as fish stocks and poultry. There is some evidence that otters are hostile to mink, so encouraging their recovery may help mink control.
- Chinese mitten crab – Present control methods proving difficult; there is no national strategy.
- American signal crayfish – Presently controlled by trapping.

Controlling non-native invasive species can deliver a range of benefits, including:

- Direct benefits to biodiversity by allowing native species to recolonise an area
- Reduced erosion potential by reinstating natural vegetation cover and preventing excessive undermining by burrowing organisms
- Benefits for fish populations and commercial fisheries through removal of predators
- Improvements for navigation through removal of water-surface vegetation
- Public health improvements through removal of potentially toxic species
- Pest and disease regulation
- Reduction in flood risk

Further information Section 8 'Non-native and problem species management' in Middle Level IDB Biodiversity Manual. Appendix 7 in ADA/NE 'The Drainage Channel Biodiversity Manual'

Non-native plants and animals are such a serious threat that there are many sources easily found on the web to aid identification and to inform control and disposal – e.g. Environment Agency, CABI, Non-Native Species Secretariat – and many competent authorities also issue instruction leaflets and posters.

Mitigation Measure L

Appropriate vegetation control regime

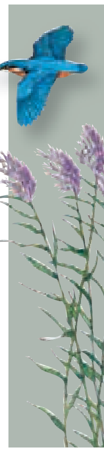
Case study Leaving a protective vegetation fringe

Summary

Pressure	Typical trapezoidal channel
Impact	Loss of riparian zone/marginal habitat
Response	Leave a small fringe of vegetation at water's edge
Location	Middle Level IDB water courses
Cost	Not available
Completion date	Ongoing
Benefit	Prevents erosion and benefits biodiversity

Pressure & Impact It has been traditional to control vegetation in drainage watercourses by mowing down to the water's edge. While this does leave a neat looking edge, it often is at the price of removing or suppressing vegetation that has a positive role in protecting and stabilising the bank toe.

Response Leaving a small fringe of vegetation 300 to 500mm wide at the water's edge forms a natural protection for the vulnerable soil/water margin which helps prevent erosion and undercutting of banks that eventually requires re-profiling (Figure 1). It is also one of the most valuable contributions to ditch biodiversity as a site for invertebrates to overwinter and a habitat for birds and other wildlife.



This feature isn't appropriate for narrow ditches, those with a width of less than about 3m, where the whole of its bottom may need to be clear to provide an unobstructed channel for the water movement. However, it is appropriate for drains that are more than 3m wide which will still have a clear centre channel of 2.5m when fringes of up to 500mm are left. In many cases drains will have been widened by re-profiling to reduce bank steepness through toe erosion, and may therefore be wider than their original maximum designed capacity. In such cases, leaving a vegetation fringe does not affect water management but does contribute to preventing further erosion.

© Cliff Carson

Figure 1 A fringe left on a drain

This vegetation fringe also has a valuable role in preventing cut material sliding into the ditch where it could create blockages at culverts or de-oxygenation problems. In a flood event when water rises out of the normal channel, the fringe, especially the wider versions, will act as a comb, retaining the cut vegetation which would otherwise be swept into the channel. That ability to hold material that would otherwise add to the burden of material to be dealt with at culverts and pumping station grids is an under-rated benefit compared to over-rated benefit of keeping the channel sides completely clear of vegetation.

Grass doesn't provide a good stabilising root structure right at the water edge because it doesn't cope with the changing water levels; emergent, aquatic plants are best suited in this position, especially sedge. This marginal fringe can be cut when the drain requires maintenance to give the machine operator a view of the channel. Eventually a more stable plant community including sedges will succeed from the pioneering reed and this can be encouraged by not mowing it excessively short. If sedge tussocks are regularly cut very short, they may eventually be suppressed and replaced by less useful vegetation.

To provide increased vegetation age diversity, some bank sides should be cut on alternate years, leaving the other side un-mown. On many Middle Level IDB drains this is now established practice and is carried out where late lifted crops such as sugar beet and potatoes prevent access when the contractor's machine is available to carry out the maintenance programme. Where two root crops are grown consecutively, the aim would be to ensure the bank is mown as normal during the second late summer/autumn. Reed that remains standing into a second spring and summer are significantly more valuable as a food source for species such as reed warblers that eat invertebrate larvae that over-winter in the stems (Figure 2). It is beneficial to manage the drain to allow reed to grow on a shelf created halfway between the summer and winter levels. Reed is one of the few plants that can cope with a wide seasonal range of water levels and a stand can provide significant protection to soft fen soils both by its barrier of stems and in binding the soil with its rhizomes.

© Cliff Carson

Figure 2 A moth larva over-wintering inside a reed stem

Bank mowing maintains a dense, strongly rooted sward for bank protection. In some conditions a cutting height can be set so low that the sward and roots are damaged by scuffing to the soil which, at the toe and on light soils, can lead to erosion. In hot summers, very short swards that expose bank soil to sunlight can contribute to soil cracking and slips. A slightly longer grass sward helps protect soil from direct sunlight and helps retain dew and existing moisture. In dry conditions consideration should be given to setting minimum cutting heights at 75mm to 100mm, the higher being preferred in drier conditions.

Further information Section 7 'Bank management' in 'The Middle Level IDB Biodiversity Manual' Technique BA2 in ADA/NE 'The Drainage Channel Biodiversity Manual'

Mitigation Measure L

Appropriate vegetation control regime

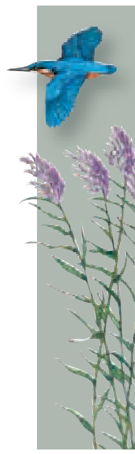
Case study Ditch maintenance regimes

Summary

Pressure	Vegetation control
Impact	Physical disturbance/loss of vegetation
Response	Sensitive, appropriately timed management
Location	Middle Level IDB
Cost	Not available
Completion date	Not available
Benefit	Maintains ecological diversity

Pressure & Impact Formerly, keeping IDB drains tidy was an important objective, but less vegetation means less biodiversity. Most IDBs have only one bank cut per year, usually in late summer after harvest. Increasingly, Boards are looking for opportunities to reduce costs and benefit biodiversity by cutting the sides of drains in alternate years.

Response Diversity of management will produce biological diversity in the banks and drains being managed. As there are over thirty different IDBs and District Drainage Commissioners within the Middle Level, each with a different Board and differing management programme, this means that diversity already exists throughout the catchment. Within the Middle Level Biodiversity Partnership there are many different methods and rotations already used for ditch maintenance, that include:-



Majority of the whole district cleansed lightly every year. Some IDBs cleanse up to 80% of their district every year. This is potentially the most rigorous of the rotations in terms of its effects on wildlife. Moderating the impact on biodiversity is very much in the hands of the operator and the type of dredger bucket used. With a light approach and an open or basket-type bucket, an operator can carry out this maintenance and minimise damage to the ecology. The second and third year after cleansing are often the best years for in-channel water plant diversity, therefore with annual cleansing some plants may not get the opportunity to recover and flower so well as in a longer rotational cycle.

The annually repeated rotation is at its best when it is carried out by the same operator each year. A new operator may be tempted to remove more material than is strictly necessary to 'show they are doing a good job', but a regular operator will be more familiar with the district and aware of how to minimise material removal to keep the ditches in good order. The 'little and often' approach works for several IDBs, using their own machine and operator. In that situation, the operator can use a lot of skill in judging how much material to remove and from where. In leaving small but important areas unmanaged for longer they retain essential plants and structure that support the ecology.

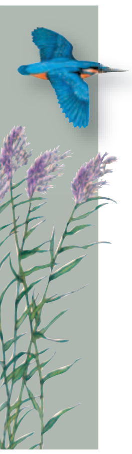
Regular Light Touch, as required. Boards which have their own machines are able to use this method to good effect. The ditches to be cleansed are identified on an annual basis. It is the most flexible approach and can be quite a wildlife-friendly method, especially if used with a fairly open bucket. Only the sections in need of immediate attention are tackled and then usually lightly that allows species to recover quickly. It offers opportunities for the operator to leave valuable habitat in place for a year or two because it is easy to return and manage it as required.

Two Year Rotation. Not widely carried out as a rotation. Many plants and invertebrates reach their optimum condition in their second or third year after management has been carried out. This rotation would inhibit that happening, unless cleansing is carried out lightly.

Three Year Rotation. This regime can benefit wildlife as it gives two years that are undisturbed for the plants, insects and related wildlife. It is best when the bank mowing regime follows the same rotation. If rigidly followed, a three-year rotation can result in some sections being dredged unnecessarily frequently. This rotation is best when some sections are skipped if the annual review indicates they will 'last another year'. Modern machines have much faster tracking speeds than previously, so tracking to a location out of sequence is not the problem it once was.

Four-year rotation. A good rotation period that produces a useful balance between recently cleared ditches and more mature ones without allowing many ditches become over mature and resulting in monocultures of single dominant species. Usually bank mowing follows the same rotation in this regime, being carried out on both sides of the ditches to be cleansed in the fourth year. This gives three years of undisturbed growth for vegetation to the benefit of the insects, breeding birds, bats and fish. If there is a large growth of vegetation in a channel before the fourth year, usually resulting from an inflow of nutrient runoff following a heavy rainfall period, clearance may be required in a localised area out of sequence. This would add to the diversity of management in the system and variety in age structure of the vegetation community.

Only when required. This approach can produce some mature ditch and bank vegetation that is attractive to wildlife. However, as the channel vegetation grows older the ditch becomes less attractive to wildlife, or at least to the greater variety of wildlife than a more regularly maintained ditch. One disadvantage of leaving ditches as long as possible between maintenance action is that when cleansing is eventually carried out the major disruption involved in removal of a lot of material can set back some species that would survive less rigorous but more frequent treatment. On the positive side, there are some plant species that respond to this type of management and only germinate when a major cleansing is carried out.



Other variations on the above rotations are carried out. No ditching regime is completely right or wrong. However, a system that is designed to be flexible and accommodate diversity reflects the thought that has been given to the process by the IDB concerned. Broadly speaking, the greater variety of dredging frequencies within a District, the greater the diversity of species and age diversity that will be supported. If a section of a ditch planned for cleansing does not require dredging, consider not cleaning it just for the sake of completeness. If it is left untouched it will be a valuable source for invertebrates and other species for re-colonising the newly cleansed sections of ditch. To avoid unnecessary ecological damage, maintenance should be avoided during certain times of the year, depending upon the species concerned:-

- Birds - Vegetation clearance should be avoided during the bird nesting season (March – July)
- Water voles - Works should be avoided during the winter hibernation period (October – March) and summer breeding season (May – July)
- Fish - Avoid undertaking work which reduces shelter for migrating fish and juvenile fish. This timing varies depending upon the species

Ensuring that vegetation management is undertaken at the appropriate time can deliver a range of benefits, including:-

- Direct ecosystem services benefits associated with maintaining and improving biodiversity;
- Aesthetic improvements to the watercourse, by providing a more natural look; and
- Reduced costs of appropriate vegetation management regime

Mitigation Measure M

Retain marginal aquatic and riparian habitats

M

Also applies to

B

C

Case study Creating a submerged berm

Also applies to Mitigation Measure D & I

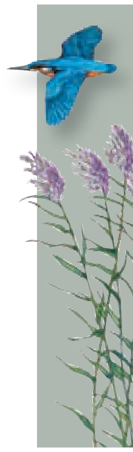
Summary

Pressure	Typical trapezoidal channel
Impact	Loss of morphological diversity
Response	Two stage channel installed
Location	Watercourses across Lindsey Marsh Drainage District, Lincolnshire
Cost	Not available
Completion date	Ongoing
Benefit	Creation of marginal habitat favouring emergent plants, insects and breeding water birds; increased channel capacity during times of high flow

Pressure & Impact One of the scarcer but ecologically valuable features in Fenland watercourses are shallow water areas. Drains tend to be deeper than most emergent plants can thrive in with little marginal habitat as they were constructed to perform their primary function of enabling the efficient conveyance of water.

Response A submerged berm was formed. This is a narrow ledge at the base of the bank just below the normal summer water level which creates greater marginal habitat where emergent aquatic plants can establish. This two stage channel also increases the capacity to store additional volumes of water during flood conditions (see Figure 1).

Each berm is formed 10-20cm below the normal retained summer water level. It is desirable to avoid creating a berm that is absolutely level, and the machine operator is briefed to create some



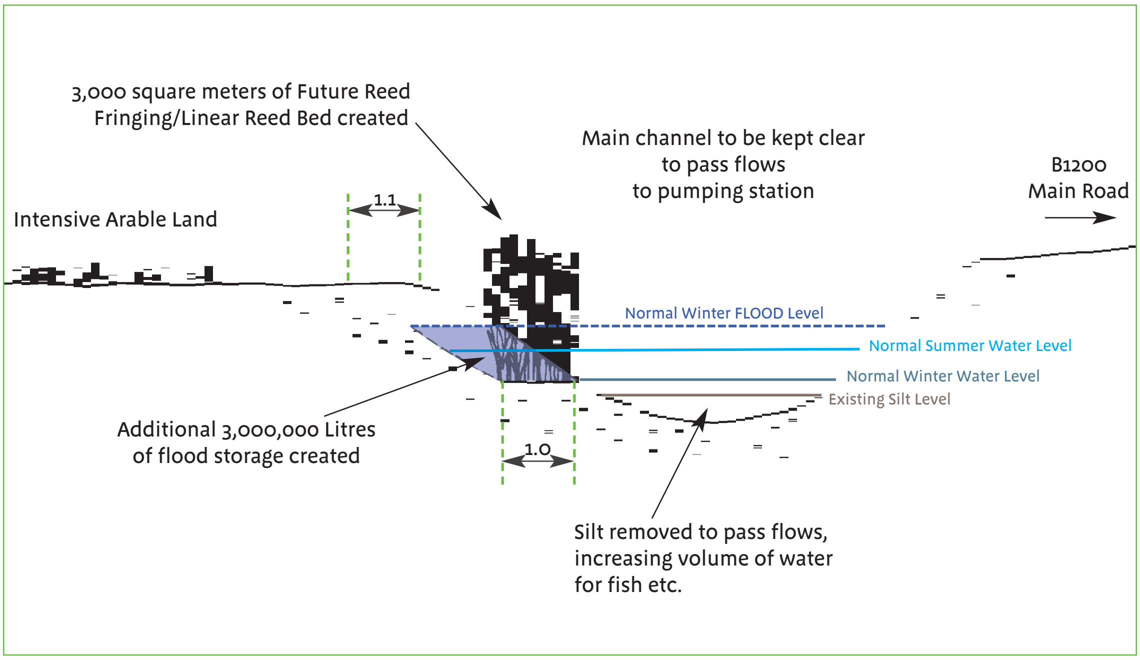


Figure 1 Cross section of a typical two stage channel

unevenness, 10-20 cm over 3-5m lengths (see Figures 2 and 3). The different water depths will also favour different plants, creating a more diverse habitat structure. Hydro-seeding and use of plug plants should be considered to enable vegetation to develop more quickly and help stabilise the bank. Works do require a narrow strip of land-take and cooperation with the land owner is negotiated by the IDB through a management payment.

Further information Section 5.2.2 'Creating and maintaining ditch margins' in MLIDB Biodiversity Manual. Technique MC2 in ADA/NE 'The Drainage Channel Biodiversity Manual'

Figure 2 Newly formed berm

Figure 3 A berm becoming vegetated

Mitigation Measure N

N

Sediment management strategies

Case study Maintenance Dredging

Summary

Pressure	Sediment management, including dredging
Impact	Removal of habitat and associated species; disturbance
Response	Sectional dredging to allow species recolonization and recovery
Location	Middle Level IDB
Cost	Not available
Completion date	Not available
Benefit	Optimising protection and recovery of biodiversity

Pressure & Impact Dredging large sections of a watercourse at one time removes animals such as molluscs, plant rhizomes and seeds which are required for regeneration and may destroy fish spawning areas. Many species only recover slowly after dredging. Nesting birds may also be disturbed. Other resources sensitive to change or loss through excavations for watercourse management include archaeological remains.

Response Where possible, material should only be removed from the middle of the ditch to encourage the establishment of marginal ledges on either side and to prevent bank damage and erosion (see Figure 1). Ensure the machine operator is aware of any ditches for which specific management practices are required, such as leaving existing marginal ledges to preserve features of particular interest or rarity. The district management plan map which indicates where those features are located is an important resource.

Maintenance dredging should normally take place between September and March. This avoids the fish spawning season and the period when low dissolved oxygen levels present a potential problem

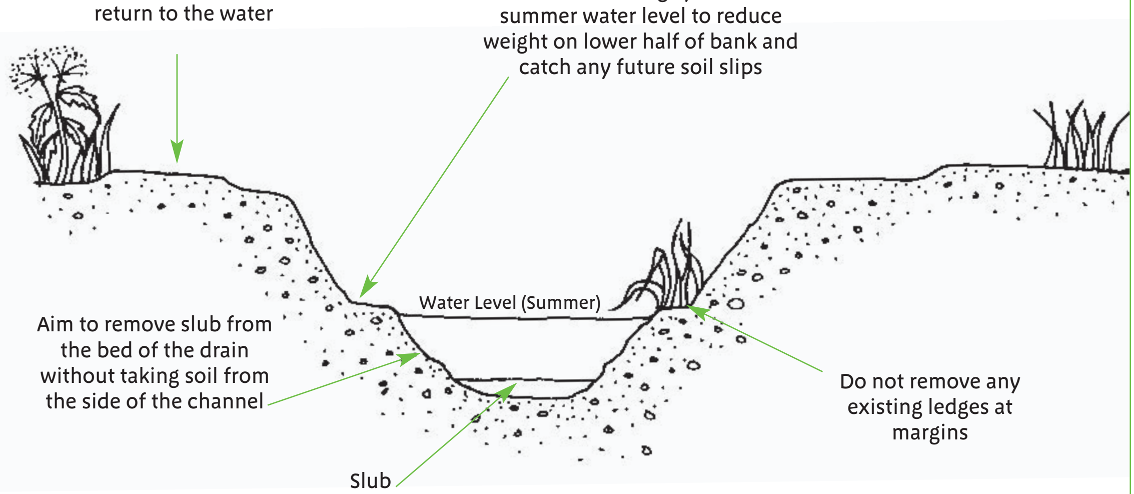
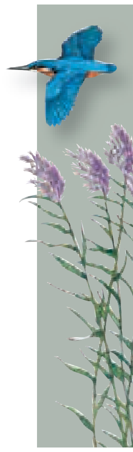


Figure 1 Drain cleaning diagram



of fish kills. It also avoids the main bird breeding season from April to August. Outside these dates, early nesting species like mallard and kingfisher and some late nesting species may be present.

If, in very exceptional circumstances, dredging (or weed cutting/removal) is necessary for flood defence purposes during the nesting season (7th April to 15th July) a survey to check for the presence of nesting birds must be undertaken by an experienced breeding bird surveyor. This is time-consuming, so management during the breeding season should only be implemented in an emergency. The survey should identify and mark areas where nesting birds are present so these are left temporarily undisturbed. The machine operators should still be watchful for any flushed birds and thus avoid disturbing nests in the reed margins or where spoil is placed at the back (non-river side) of the banks. Species which are particularly vulnerable include little grebes, coots and moorhens nesting on vegetation at the water's edge, and reed warblers with nests in the bank-side reeds. Also, mallard, pheasant and other birds may nest on bank sides where spoil water may spill or areas on bank tops where spoil may be spread. If a bird is flushed from a likely nest site, avoid the area by leaving the spoil as far away from the probable nest location as possible.

If widening works are to be undertaken, the Historic Environment Teams of the relevant local authorities should be contacted to give advance notice where the works are to be located. A check can then be made on the Historic Environment Record to see if any statutorily protected sites or significant non-designated are likely to be affected. Avoiding these sensitive areas should be the priority.

Further information Section 5.2 'Maintenance dredging' in MLIDB Biodiversity Manual
Techniques CC1-4 & CC5 in ADA/NE 'The Drainage Channel Biodiversity Manual'

Mitigation Measure P

Appropriate water level management strategies including timing and volume of water moved

Case study Water Transfer Limited, Witham

Summary

Pressure	Pumped drainage
Impact	Loss of water supply for irrigation during dry years
Response	Water transfer scheme
Location	Witham Fourth District IDB
Cost	£60,000
Completion date	Not available
Benefit	Growers have access to water; environmental connectivity and water quality; navigation and recreational advantages

Pressure & Impact In the 1980's growers in the Witham Fourth District IDB had become increasingly concerned about water supply during dry years with threats from the then National Rivers Authority (NRA) not to renew irrigation licences due to a lack of resource in the system.

Response Agreement was reached between NRA and Witham Fourth that a scheme to transfer water was possible but at a cost to the growers; approximately 50 growers joined forces and formed Water Transfer Ltd. In consequence, a structure was built to transfer water from the River Witham into the

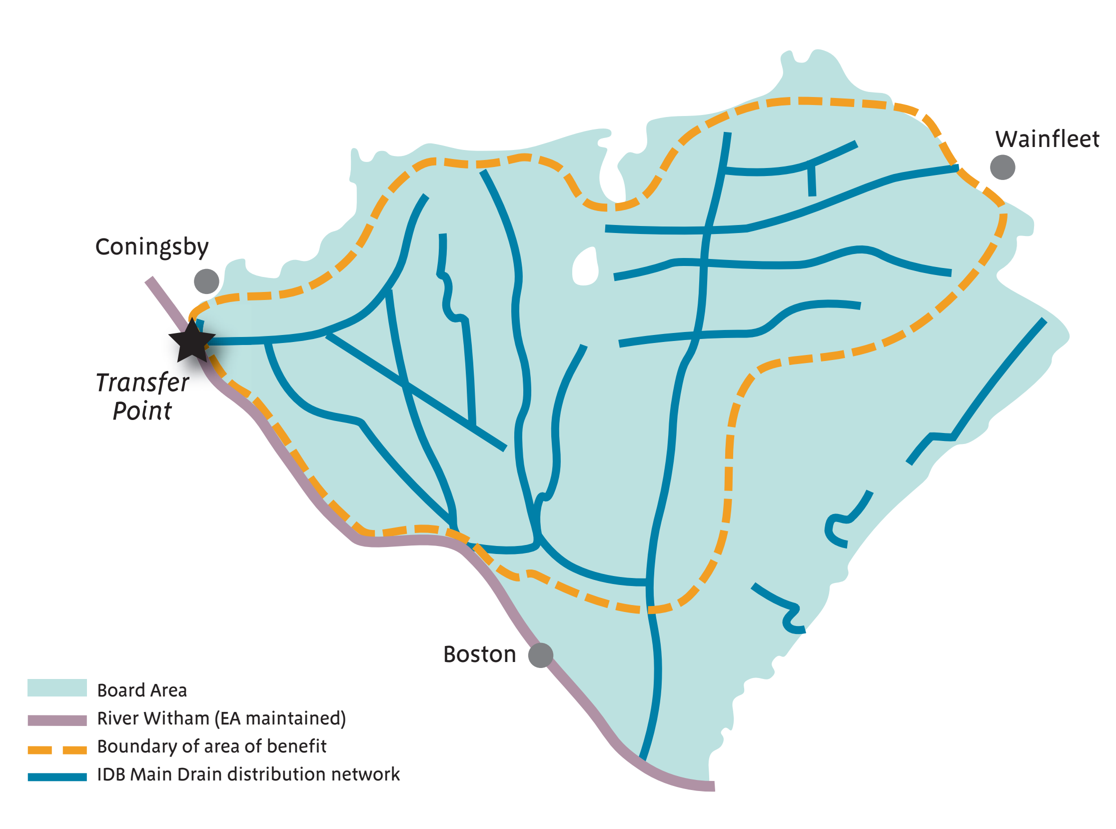
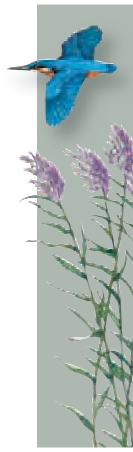


Figure 1 Witham Fourth Ltd area, and the area benefited by Water Transfer Ltd



upper reaches of the catchment (see Figure 1). Water Transfer Ltd now have an Environment Agency (EA) licence to transfer up to 850,000m3 of water from the River Witham; members' contributions are based on the size of their abstraction licence. The transfer point consists of a simple penstock arrangement with weed screen. Water is distributed around the area via gravity, impacting levels in watercourses over 30km away from the intake.

The Witham Fourth IDB manage the transfer point liaising with Water Transfer Ltd and the EA to maintain adequate levels across the catchment. The abstraction is metered, with weekly returns being sent to the EA including a forecast of the coming week's demand and salinity levels. The cost of general supervision of water levels is met by the Board as part of its routine operations but Water Transfer Ltd pay for the weekly salinity testing and reporting, administrative costs and all costs relating to the upkeep of the transfer point and meter, plus cleaning of the inlet weed screen.
This arrangement means that the IDB retains control of water level management in its catchment, the EA can balance its own network (at critical times water is pumped by the EA from the River Trent into the Witham via the Fossdyke Canal), and abstractors have access to water.

In addition to providing the additional quantity of water for abstraction, the transfer also provides improvements to water quality to the advantage of both agriculture and the environment (including reduced likelihood of algal blooms), There is also a more consistent depth of water for navigation, recreation and angling. The transfer structure has also been used purely for the benefit of the environment allowing transfer of water to freshen up the usually static network of watercourses downstream. It has also provided connectivity within the catchment where once there was none.
One disadvantage to the IDB is that the transferred water can have higher nutrient content which can result in higher levels of weed growth than would normally be expected. In recent years, the transfer of invasive species has also become a concern, so improved catchment connectivity may also be a potential disbenefit.

Mitigation Measure Q

Appropriate techniques to align and attenuate flow to limit detrimental effects of pipes, inlets, outlets and off-takes.

Case study Off-line storage facility

Summary

Pressure	Rapid run-off
Impact	Flooding and pollution from industrial catchment
Response	Off-line reservoir constructed
Location	Padholme catchment, Peterborough
Cost	Not available
Completion date	Not available
Benefit	Slows down and limits the flows downstream to the pumping station,
	preventing inundation and potential flooding of the lowest land.
	Also provides an additional wildlife habitat

Pressure & Impact Padholme catchment serves the industrial site of Fengate in Peterborough, Cambridgeshire (Figure 1). This is classed as Main River and is maintained by the Environment Agency with the Padholme Pumping Station at its outfall pumping into the River Nene. The urban nature of the catchment with its heavy industry and large, impervious areas results in rapid surface water run-off during heavy rainfall events.

Response An off-line storage facility was provided to store water during heavy rainfall/rapid run-off events (Figures 2 & 3). In addition to providing additional storage capacity, this reservoir serves to

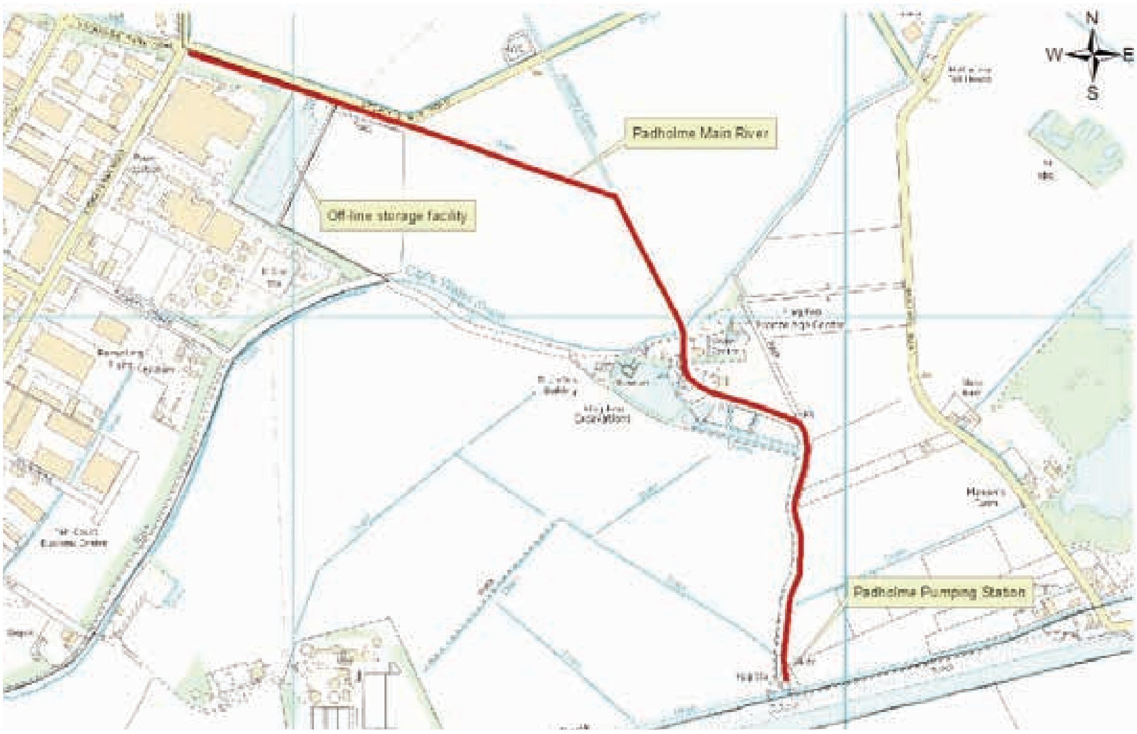
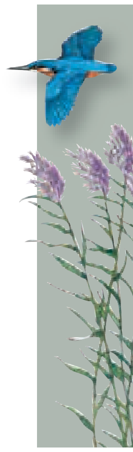


Figure 1 The Padholme catchment showing the reservoir, main river and pumping station



slow down and limit the flows downstream to the pumping station, preventing inundation and potential flooding of the lowest land. It also provides a good habitat for birds and mammals with its extensive, well established reed bed.

Further information Technique CC9 in ADA/NE 'The Drainage Channel Biodiversity Manual'

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Figure 2 The Padholme catchment reservoir

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Figure 3 The entrance to the reservoir showing the concrete structure over which water flows in times of high rainfall

Mitigation Measure R

Inform landowners on sensitive management practices

Case study Moderating agricultural run-off

Summary

Pressure	Agricultural run-off; diffuse pollution
Impact	Ecosystem damage from pollutants and sediment
Response	Soil management, grass buffers, interception ponds and off-line storage
Location	Loddington, Welland Catchment
Cost	Not available
Completion date	Not available
Benefit	Ecology

Pressure & Impact Most Fenland waterbodies fail to reach GEP due, in part, to levels of phosphate in the water. Sources of phosphate are primarily treated sewage effluent and agricultural run-off (Figure 1). Phosphate and other chemicals are often bound up with sediment. Excess phosphate and sediment can encourage profuse weed growth and algal blooms (Figure 2). The weed growth can impact water in a fen drain, and algal blooms can strip the water of oxygen in certain conditions. Sediment itself can impact the ecology of a fenland watercourse.

Response Landowners have a role to play in reducing agricultural run-off entering Fenland water bodies. There are a range of interventions a landowner may consider to reduce diffuse pollution entering a fenland watercourse. Examples are shown at Figure 3.

Not all interventions may be suitable for a particular location; a combination of interventions working together may be best, for example 'no-till' drilling and buffer strips. The effectiveness of these measures in any particular location is being assessed in the Welland catchment at Loddington at the Allerton Trust Water Friendly Farming project. Stewardship grants and options may be available for these interventions depending on the location. As well as preventing diffuse pollution from entering watercourses these interventions can also provide considerable wildlife benefit especially when they are 'mature'. Maintenance frequency of these interventions, particularly those that are designed to trap silt, depend on their individual locations, and is one of the areas of research at Loddington.

Figure 1 Agricultural run-off

Further information The Allerton Trust, managed by the Game and Wildlife Conservation Trust are pleased to advise landowners.

© Rodney Burton

Figure 2 Excess weed growth

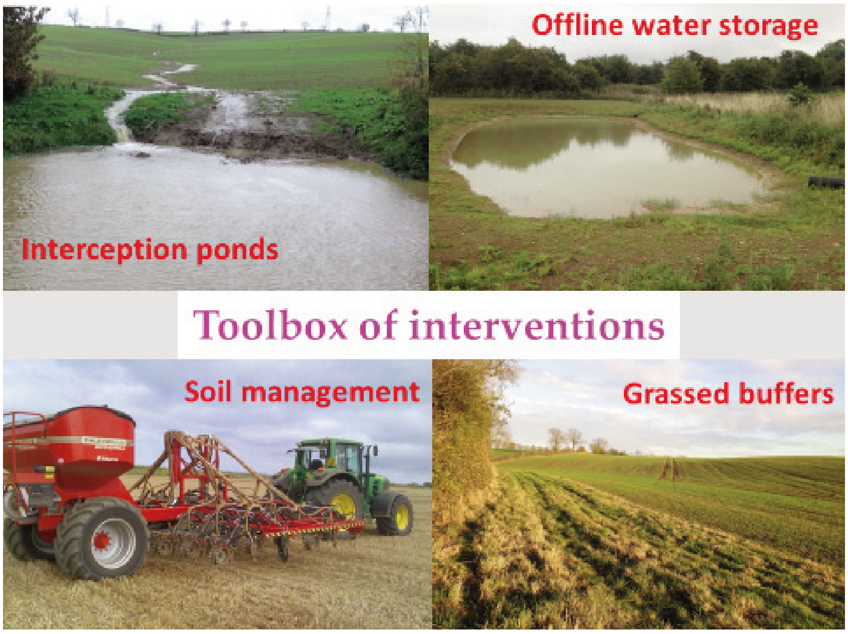

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Figure 3 Toolbox of interventions to reduce agricultural run-off

Appendix One

Process to identify Mitigation Measures to achieve GEP

Introduction

In determining the GEP that a watercourse could achieve, assessors are faced with the challenge of deciding which characteristics of the waterbody are alterable, whilst still retaining the functions provided by it, such as flood defence or land drainage. This is an application of expert judgement. So, to translate the theory of defining MEP and GEP into an operational management strategy to implement the WFD, this section outlines an approach which assessors could follow. This decision-making process selects the measures that will be taken and in planning the objectives to achieve GEP for the HMWBs and AWBs.

The Environment Agency 'Digital Good Practice Manual: Identifying Mitigation Measures for Good and Maximum Ecological Potential' and the Association of Inland Navigation Authorities (AINA) Report on 'Measures for the Inland Navigation Sector' set out more useful details on each of these steps. They include several useful guidelines and tools which are also generally applicable or easily transposed to the Land Drainage and Flood Protection Sectors.

The steps summarised in Figure A1.1 below are offered as a guide for expert assessors to identify Mitigation Measures to define MEP and GEP.

Step 1	Define the characteristics of the drainage channel including the pressures and impacts on the waterbody
Step 2	Define a complete set of Mitigation Measures for the waterbody.
Step 3	Identify measures that do not have an 'adverse impact on use' (MEP)
Step 4	Exclude measures which would only deliver a slight ecological benefit (GEP)
Step 5	Identify Mitigation Measures in place and what measures still required to be implemented to achieve GEP
Step 6	Consider the effectiveness of Mitigation Measures
Step 7	Estimate the financial and socio-economic costs
Step 8	Identify the most cost-effective combination of measures
Step 9	Identify actions to be taken including monitoring ecosystem response.

NB Steps 1 – 4 define MEP and GEP, and Steps 5 to 9 help to select cost-effective combinations of Mitigation Measures.

Figure A1.1 Step by step process for defining MEP and GEP

Process to identifying a complete set of Mitigation Measures

Steps 1- 4 define MEP and GEP.

Step 1 is used to gather information required to define Mitigation Measures in Step 2. In step 3 measures are eliminated based on whether or not they affect use. This leaves a sub-set of measures that define MEP. In step 4 all those measures which are predicted to have only slight ecological benefit are eliminated leaving a list of measures that define GEP.

Step 1 Define the characteristics of the drainage channel including the pressures and impacts on the waterbody.

The waterbody is surveyed and described by the hydromorphological pressures and impacts present.

Key Points in Step 1

- Determine the type of waterbody - AWB or HMWB?
- Determine the pressures on the waterbody, for example the presence of structures such as hard bank protection and locks, or management actions such as dredging or weed cutting. (See Figure 2.13 which sets out the Mitigation Measures, the pressures and impacts grouped as Working with Form and Function, Structural Modification etc.)
- If the associated impacts can be clearly shown to be absent or not applicable to that waterbody those measures need not be taken forward.
- Record the presence of pressures and associated impacts with comments and notes.

Step 2 Define a complete set of Mitigation Measures for the waterbody.

All the possible Mitigation Measures that may be applied to the waterbody are identified.

Key Points Step 2

- Only consider the applicability of the measure with regard to waterbody type, i.e. AWB or HMWB. However, most can be applied to both.
- Do not consider the effectiveness of the measures, costs of the measures, socio-economic aspects or other uses at this step. These aspects are addressed in later steps. This is important to ensure the list of Mitigation Measures that define MEP and GEP are consistent with their definition under the WFD.

Step 3 Identify measures that do not have an 'adverse impact on use' (MEP)

All the measures that are considered to have an adverse impact on the waterbody for the purposes of land drainage and flood protection (and navigation) are removed. If all the remaining measures are implemented, then MEP will be achieved.

Key Points Step 3

- This step must involve discussions with IDB staff and/or the relevant Competent Authority.
- Of the Mitigation Measures identified at Step 2 only those that affect use and or the wider environment are removed at Step 3. (Do not consider costs / socio- economic costs / effectiveness at this stage. This is to ensure that MEP is in keeping with the definition outlined in the 'Alternative Approach' and the WFD.
- All decisions, and reasons given, for removing Mitigation Measures at this stage should be clearly recorded.

Step 4 Exclude measures which would only deliver a slight ecological benefit (GEP)

Of the measures that remain after Step 3, remove those that, if implemented, would only deliver a slight ecological benefit.

Key Points Step 4

- All Mitigation Measures must be moved forward except those that are considered to only deliver slight ecological benefit (do not consider costs / socio-economic costs at this stage). This is to ensure that GEP is in keeping with the definition of the 'Alternative Approach' and the WFD. So, GEP is defined as the ecological conditions expected when all these Mitigation Measures are employed.
- Consider the benefit to the whole waterbody, not just local benefit.
- Effectiveness of measures will depend on the specifics of the site. Determining effectiveness must involve discussion between people with knowledge of the drainage system and ecology of the waterbody, and Competent Authority staff.
- Table at Figure 2.13 provides a summary qualitative score for the effectiveness of each measure on hydromorphology and biology. These scores should be used as a guide and point of initial discussion.
- All decisions made at this step should be clearly recorded.

Steps 5- 9

Steps 5 to 9 are designed to identify whether GEP has been already met, and if not to identify cost-effective combinations of measures to achieve GEP.

Step 5 Identify Mitigation Measures in place and what measures still required to be implemented to achieve GEP

Those measures that are already being fully implemented are identified.

Key Points Step 5

- Identify Mitigation Measures already in place and those required to achieve GEP.
- If all Mitigation Measures remaining after Step 4 are currently in place, then GEP is being achieved and there is no need to progress further.
- The desired result of this stage is a clear understanding of the remaining impacts on the water system. Understand the extent to which any Mitigation Measures have been implemented and identify those measures that are still required to be implemented to achieve GEP.

Step 6 Review the effectiveness of Mitigation Measures

The measures' effectiveness is assessed considering hydromorphology, ecology and timescale over which effectiveness will be observed and duration of effectiveness.

Key Points Step 6

- Information from Table at Figure 2.13 showing effectiveness of measures will be used in Step 8 to help rank combinations of measures.
- Determination of effectiveness should involve discussion between people with knowledge of the drainage and flood defence system, implementation of Mitigation Measures and ecology of the waterway.

Step 7 Estimate financial and socio-economic costs

Unit financial costs of the measures at Step 6 are estimated, including capital and operational costs. Socio-economic costs are calculated and included too at this stage.

Key Points Step 7

- Where possible, financial costs include capital and operational should be standardised and tabulated as a tool to allow comparisons.
- Socio-economic costs can be positive as well as negative and should be considered at this stage.

Step 8 Identify the most cost-effective combination of measures

From the information collated in Steps 5-7, the most suitable combination of measures is selected in relation to effectiveness, costs and socio-economic costs; taking account of synergistic effects is important.

Key Points Step 8

- Consideration of various combinations of Mitigation Measures should be guided by impacts, such as priority impacts and the need to address multiple impacts.
- Interactions between measures, for example synergistic effects, can be complex, and can affect overall effectiveness and financial costs. Consideration of interactions must involve discussion between people familiar with the drainage system and Mitigation Measures, including ecologists.
- The financial costs and negative social/economic effects should be as low as possible; whilst the environmental benefits (effectiveness) as high as possible.

Step 9 Identify actions to be taken

Actions identified at this stage besides implementation, might also include monitoring the situation or discussions with regulators or other authorities. Those actions then identified to be taken to comply with the WFD should be compatible with the relevant River Basin Management Plan.

Key Points Step 9

- Initiating implementation of a mitigation (or set of mitigation) measures.
- Further monitoring or survey work (as identified from step 5) to determine the extent and nature of impacts i.e. the response of the ecosystem to the Mitigation Measures put in place.
- Further discussion with regulatory authority, or other staff may be required. NB This guidance does not apply to waterbodies designated as Natura 2000 sites i.e. Special Areas of Conservation of Special Protection Areas) under the EC Habitats Directive (92/43/EEC) or Birds Directive (79/409/EEC) respectively. This is because they will have special WFD objectives reflecting the reasons for their protection under those Directives. GEP will therefore not apply to them.
- An agreed timescale for implementation should be established to ensure that the most cost-effective measures are implemented first. However, measures implementation may need to be phased over two or more cycles of the River Basin Management Planning process.

Appendix Two

Glossary

The definitions given below are in the context and usage of the subject of the Guide.

Adventurers Persons who invested money through contracts with King Charles 1 to drain the fens in the 17th Century.

Anthropogenic Influence of human beings on nature, usually referring to damaging activities such as physical impacts and pollution.

Aquatic plants Plants that have adapted to living in a freshwater environment.

Aquifer Subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability that allow either a significant flow of groundwater, or the abstraction of significant quantities of groundwater.

Artificial water body (AWB) Man-made water body, often constructed where none existed before. Many of the watercourses in Fenland are AWBs.

Batter Sloping side of a man-made drain or watercourse.

Berm Low level, narrow ledge, occasionally constructed in smaller watercourses to benefit biodiversity and increase flow capacity. Berms tend to be colonised by wetland plants and form important habitat corridors.

Biodiversity Variety of different types and numbers of plant and animal species in a particular habitat or area.

Biodiversity action plans (BAPs) National, local and sector-specific plans established under the United Kingdom Biodiversity Action Plan, with the objective of securing the conservation and sustainable use of biodiversity.

Biological element Collective term for a characteristic group of animals or plants present in an aquatic ecosystem (for example phytoplankton; benthic invertebrates; phytobenthos; macrophytes; macroalgae; phytobenthos; angiosperms; fish).

Biological indicators Parameter that can be monitored to estimate the value of a biological quality element. Indicators may include the presence or absence of a particularly sensitive species.

Biological quality element Characteristic or property of a biological element that is specifically listed in Annex V of the Water Framework Directive for the definition of the ecological status of a water body (for example composition of invertebrates; abundance of angiosperms; age structure of fish).

Calcareous Where the predominant geology underlying a river or lake water body is calcareous (e.g. limestone or chalk)

Carr Wet or fen woodland and scrub.

Catchment Area drained by a river and its tributaries. In river basin management, this can refer to larger management catchments and smaller operational catchments.

Catchment abstraction management strategies (CAMS) Developed for the management of water resources at a local level. They provide information on water resources and licensing practice to allow the needs of abstractors, other water users and the aquatic environment to be considered in consultation with the local community and interested parties.

Catchment flood management plans Strategic planning tools through which the Environment Agency works with other important decision-makers within a river catchment to identify and agree policies for sustainable flood risk management.

Chemical status Classification status for the surface water body against the environmental standards for chemicals that are priority substances and priority hazardous substances. Chemical status is recorded as good or fail. Chemical status and ecological status together define the overall surface water status of a water body.

Classification Method for distinguishing the environmental condition or status of waterbodies and placing them into categories.

Climate change Change in the state of the climate that can be identified by changes in average climatic characteristics, and that persist for an extended period, typically decades or longer.

Coastal flood defences Outer, main tidal flood defence wall for which the EA is responsible, while riparian owners are responsible for the secondary and tertiary defences. Many of the latter are rich grass sward covered banks that act as linear corridors for wildlife that break up the intensively farmed landscape.

Competent authority Authority or authorities identified under Article 3(2) or 3(3) of the Water Framework Directive. The competent authority will be responsible for the application of the rules of the Directive within each river basin district lying within its territory. The Environment Agency is the competent authority in England.

Confined (aquifer) Aquifers that are overlain or covered by a confining layer, often made up of clay.

Connectivity Degree to which the landscape enables the movement of plants and animals between patches of habitats or sites. The extent to which a landscape is connected influences the potential for organisms to move in response to climate change.

Cost effective Describes the least cost option for meeting an objective in the context of river basin management planning. For example, where there are several potential actions that could be implemented to achieve good status for a water body, the option that delivers the objective for the least overall cost is the most cost effective option.

Cradge Temporary trench to contain dredged wet material to allow it to dry before being landscaped back into a flood defence bank.

Cradge bank Permanent bank that is constructed at a lower level to the main flood banks and that would be overtopped before the main defence banks.

Culvert Watercourse channelled through a length of pipe.

Dam Barrier constructed to hold back water and raise its level.

Diffuse pollution Pollution that comes from many sources that may be small individually but damaging collectively.

Disbenefits Any negative consequence (negative impact, cost, trade-off) that society and/or the environment will bear from implementing measures to improve the water environment.

Disproportionate cost Decision-making procedure that assesses whether the benefits of meeting good status in a water body are outweighed by the costs.

Ditch Narrow channel dug at the side of a road or field, to hold or carry away water.

Drain Artificial watercourse larger than a typical agricultural field ditch designed for land drainage and flood defence purposes.

Drainage channel Collective name for several different types and sizes of, usually, man-made watercourses used for drainage purposes.

Dredging Removal of sediment/mud from a channel. Also, referred to as 'mudding' or 'slubbing'.

Dyke Artificial watercourse usually associated with land drainage.

Ecological potential Status of a heavily modified or artificial water body measured against the maximum ecological quality it could achieve given the constraints imposed upon it by those heavily modified or artificial characteristics necessary for its use.

Ecological status Applies to surface water bodies and is based on the following quality elements: biological quality, general chemical and physico-chemical quality, water quality with respect to specific pollutants (synthetic and non-synthetic), and hydromorphological quality. Ecological status and chemical status together define the overall surface water status of a water body.

Ecosystem Community of plants, animals and micro-organisms together with their non-living environment, interacting as a functional unit.

Ecosystem services Services that people receive from the natural environment that improve people's quality of life, such as improved water availability during drought, pollinating insects for pollination of crops, natural flood regulation and recreational opportunities.

Elver Young eel, especially one that is migrating up a stream from the ocean; also, called a 'glass eel'.

Emergent vegetation Aquatic plants that are rooted in shallow water with their vegetative parts (e.g. stems, leaves and flowers) emerging above the water surface.

Environment Flow Indicator (EFI) Through modelling, a comparison is made between the actual flows in each waterbody with the flow estimated as the minimum required to protect the ecology. This 'ecological flow target' is the EFI.

Estuary Lower course of a river where it flows into the sea, and where the water is a changing mixture of fresh and salt. (see also 'Transitional water').

Eutrophication Enrichment of waters by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life. Often produces an undesirable disturbance to the balance of organisms present in the water and the quality of the water concerned.

Faggotting Hawthorn bundles placed in layers to stabilise soils along waterway banks. A 'faggott' is a bundle of hawthorns that are often sourced from local landowner hedges on rotation, or from hedges on drain and river banks.

Fens/Fenland Flat low-lying areas peat or silt soils mainly in Lincolnshire, Cambridgeshire, and Norfolk. Formerly marshland but largely drained for agriculture since the 17th century.

Fen lighter Traditional wooden barge between 30-40ft long, 10ft wide with a draft of 2ft when empty, that could carry a load of between 20-25 tons. Mostly propelled by humans or horse power, although sails were also used.

Freeboard Safety factor used in the design of river and drainage management and directly associated with Water Level Management Plans. It defines the water depth between the water level design for a catchment and any associated infrastructure relating to it and provides a margin of operation whether in drought or in flood

Fretting Erosion and undercutting of banks due to wave action; also by the wash from boats.

Good ecological potential Surface waters that are identified as Heavily Modified Water Bodies and Artificial Water Bodies must aim to achieve 'good ecological potential'; recognising that changes to morphology may make good ecological status very difficult to meet.

Good ecological status See 'Ecological status'

Good status Good status is a term meaning the status achieved by a surface water body when both the ecological status and its chemical status are at 'least good'.

Groundwater Water that is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

Groundwater body Distinct volume of groundwater within an aquifer or aquifers. An aquifer may have one or more groundwater bodies.

Gravity drainage Water flowing under its own weight without the need for pumping.

Headwater Upper reaches of a watercourse furthest away from an outfall and often left minimally managed to benefit of wildlife.

Heavily modified water body Surface water body that does not achieve good ecological status because of substantial changes to its physical character resulting from alterations by human use. Designated in accordance with criteria specified in the Water Framework Directive, as 'heavily modified'.

High ecological status Surface water body where the values of the hydromorphological, physico-chemical, and biological quality elements correspond to conditions undisturbed by anthropogenic activities.

Highland carrier Watercourse taking runoff from the surrounding uplands that is elevated and embanked above ground level, often having little or no connection with the drainage network of the lower land area; usually managed by the Environment Agency.

Hydromorphology Hydrological and geomorphological processes and attributes of surface water bodies. For example, for watercourses, hydromorphology describes the form and function of the channel as well as its connectivity (up and downstream and with groundwater) and flow regime, that defines its ability to allow migration of aquatic organisms and maintain natural continuity of sediment transport through the fluvial system. The Water Framework Directive requires surface waters to be managed in such a way as to safeguard their hydrology and geomorphology so that ecology is protected.

Impoundment Permanent or temporary structure used to hold up water, often for irrigation purposes or for differential water level management within a catchment or sub catchment.

Improvement Design modification of an existing watercourse or the creation of a new one.

Internal drainage boards Public bodies that undertake works to reduce flood risk to people and property, and manage water levels for agricultural and environmental needs across internal drainage districts.

Invasive non-native species Accidentally or deliberately introduced species of non-native plants and animals that cause serious problems to the aquatic and riverine ecology and environment. They often rapidly proliferate as they have no native predators or competitors. Problems include detrimental effects on native species, deoxygenation of water causing fish mortalities, blocking of rivers and drainage channels, predation and competition with native species, and in some cases, may pose health risks to the public or livestock.

Landscape scale conservation Conservation action that covers a large spatial scale, usually addressing a range of ecosystem processes, conservation objectives and land uses, and often to ensure connectivity.

Lawton principles Professor Sir John Lawton's report 'Making Space for Nature' in 2010, described the state of England's wildlife sites and the connections between them. This report emphasised the need to buffer core wildlife-rich areas such as nature reserves, and to provide wildlife corridors and stepping stones for species to move in response to threats, or simply to spread out and increase in number. The report's principles are summarized as: More, Bigger, Better and Joined

Leam Large, artificial drainage channel, such as Morton's Leam.

Lighter See 'Fen Lighter'

Lode Artificial water body that is usually embanked and elevated, frequently encountered in the southern Fenland. Many are connected with main rivers and were often constructed in association with monasteries and priories, and probably used for the transportation of goods across the wider Fenland.

Main River Environment Agency managed rivers such as the Nene, Welland, Witham and Great Ouse and several other large water bodies. They are classed as highland carriers before reaching their tidal outfalls.

Manning formula Empirical formula estimating the average velocity of a liquid flowing in a conduit that does not completely enclose the liquid, such as water in a drainage channel.

Mannings N Roughness coefficient Used in the Manning's formula to calculate water flow in open channels.

Marine transgression Successive marine transgressions (sea incursions) and regressions (sea recessions) occurred across The Fenland basin following the last glaciation as sea levels rose and fell. This resulted in the habitat zones moving landward and seaward with this exchange between marine and freshwater conditions.

Maximum Ecological Potential (MEP) Best condition that a waterbody is expected to achieve if all possible Mitigation Measures were implemented to offset the physical alterations.

Mitigation Measure Practicable steps that can be taken to mitigate adverse impact from human activities under the European Water Framework Directive. In the case of flood risk management and land drainage, these are impacts from physical modifications to watercourses (as well as coasts and estuaries).

Morphology Describes the physical form and condition of a water body, for example the width, depth and perimeter of a river channel, and the structure and condition of the riverbed and bank.

Natura 2000 sites Protected Areas established for the protection of habitats or species under the Birds Directive (79/409/EEC) Special Protection Areas and the Habitats Directive (92/43/EEC) Special Areas of Conservation.

Natural England Government-funded body whose purpose is to promote the conservation of England's wildlife and natural features. The previously existing organisations English Nature, the Countryside Agency and Rural Development Service were merged to form Natural England.

Ordinary watercourse Watercourse that does not form part of a main river.

Outfall Any point where water finally discharges into another water body e.g. a dyke into a drain or a river into an estuary etc.

Palaeoecology Branch of ecology that uses information from fossils and subfossils to describe and reconstruct the ecosystems of the past.

Penstock Manual or automatically operated valve, flap or gate for releasing or holding water.

Phytoplankton Unicellular algae and cyanobacteria, both solitary and colonial that live, at least for part of their lifecycle, in the water column.

Pointing doors Pair of doors hinged on their outer vertical edges that open and close with water pressure. Normally fitted to navigation locks or gravity outfalls, they open when the tide goes out and close on the incoming tide.

Pollution Direct or indirect introduction of substances into aquatic ecosystems from human activity which is harmful to human health and/or the environment.

Pressures Human activities such as abstractions, effluent discharges or engineering works that have the potential to have adverse effects on the water environment.

Pumping station Building or infrastructure containing electric and/or diesel powered pumps and equipment for pumping water for land drainage purposes.

Quality element Feature of an aquatic ecosystem that can be described as a number for the purposes of calculating an ecological quality ratio, such as the concentration of a pollutant; the number of species of a type of plant.

Ramsar Wetland area designated for its conservation value under 'The 1971 Convention on Wetlands of International Importance, especially as Waterfowl Habitat'. The Ramsar Convention promotes the conservation of listed wetlands and their wise use.

Reach Section or length of a watercourse.

Red-listed species Species of plant or animal on the IUCN Red List of Threatened Species, that is widely recognized as the most comprehensive, objective global approach for evaluating the conservation status of plant and animal species. The IUCN (International Union for Conservation of Nature) is the global authority on the status of the natural world and the measures needed to safeguard it.

Reprofiling Taking a watercourse back to its original dimensions following encroachment over several years.

Revetment Sloping structures placed on drainage channel banks to absorb the energy of the water.

Riparian Interface between land and water along a watercourse. Plants growing along the margins or bank of a watercourse are known as riparian vegetation.

River Description of a type of water body

River basin Area of land from which all surface run-off and spring water flows through a sequence of streams, lakes and rivers into the sea at a single river mouth or estuary. It comprises one or more individual catchments.

River basin district River basin or several river basins, together with associated coastal waters. A river basin district is the main unit for management of river basins under the WFD.

River basin management plan For each river basin district, the Water Framework Directive requires a river basin management plan to be published that sets out the environmental objectives for all the water bodies within the river basin district. The plans are based on a detailed analysis of the pressures on the water bodies and an assessment of their impacts, and summarise the programme of measures that will be taken to achieve the environmental objectives.

RIVPACS (River Invertebrate Prediction and Classification System) Statistical model that enables the user to estimate the ecological health of running water sites. Drawing on datasets of macroinvertebrate communities in 'pristine' conditions, it can predict what macroinvertebrates should be present at the new site with its particular habitat type. The difference between the expected macroinvertebrate fauna and that observed then indicates the ecological status of the water. This provides river managers with supporting data for preventing or reversing the loss of habitat quality and biodiversity.

Roddon Ancient fenland rivers and their tributaries that have emerged as low sinuous mounds of silt in Fenland as the surrounding peat has shrunk.

Runoff Water flowing into a catchment area following rainfall either overland or through urban piped systems.

Site of special scientific interest (SSSI) Area of land notified under the Wildlife and Countryside Act 198 by the appropriate nature conservation body as being of special interest by its flora and fauna, geological or physiogeographical features.

Slacker Gravity, manual or mechanically operated flap to control the flow of water one way.

Slip Collapse of a watercourse bank.

Slub Accumulated silt and other debris at the bottom of a drainage channel.

Sluice Gravity, manual or mechanically operated water level control structure that allows water movement between catchments and at tidal outfalls. An archaic fenland term for a sluice is a gote or gowt, hence Anton's Gowt near Boston and Tydd Gote and Four Gotes near Wisbech.

Special area of conservation (SAC) Category of Natura 2000 site that is designated under the EU Habitats Directive. All SACs are also notified as SSSIs. See also 'Natura 2000 sites'

Special protection area (SPA) Category of Natura 2000 site that is designated under the EU Birds Directive. All SPAs are also notified as SSSIs. See also 'Natura 2000 sites'

Stoning Placement of frost proof stone above and below the waterline to protect the edge of a watercourse from fretting or water erosion. The planting of sedge or reed plugs and/or coir rolls is considered as a more ecologically beneficial alternative.

Succession Natural, ecological process of change in the species structure of an ecological community over time, usually applied to plant communities. In a drainage channel, it is usually the change from a very open channel with little vegetation after vegetation or silt clearance, to progressively a more vegetated channel.

Tilting door Adjustable door that can be finely adjusted to allow water to pass over when lowered, or hold water back when raised.

Transitional water Water Framework Directive term for 'bodies of surface water near river mouths that are partly saline in character because of their proximity to coastal waters but are substantially influenced by freshwater flows'. Transitional waters include estuaries and saline lagoons.

Vertical or guillotine door Adjustable water retaining structure on a gravity outfall to control the water level on the upstream side of the structure.

Wash/Washland Floodplain area usually surrounded by artificial banks that, in a flood event, fills with water and provides temporary storage of flood water and flows.

Waterbody Unit of surface water, being the whole or part of a river or watercourse. A Water Framework Directive term for a discrete and significant element of surface water.

Watercourse Collective term for all natural, modified or artificial channels through which water flows or is pumped for drainage.

Water Framework Directive (WFD) European Union legislation, Water Framework Directive (2000/60/EC) establishes a framework for the protection of inland surface waters (rivers and lakes), transitional waters (estuaries), coastal waters and groundwater to ensure that they meet 'good status'.

Water level management plans Plans that provide a means by which water level requirements for a range of activities including agriculture, flood defence and conservation can be balanced and integrated.

Water table Upper limit of the saturation zone for groundwater

Weed screen Steel grid placed in front of a pumping station or other water level control structure to prevent floating plants and other debris damaging pump impellers and obstructing flow. The screen can be cleared of debris mechanically, automatically or manually.

Weir Structure to hold back water at a certain level within a watercourse and/or for environmental or irrigation purposes.

Wetland Area of land where the water table is seasonally or permanently high, often in river valleys and/or where the drainage is impeded.

Appendix Three

Further reading and information

Action: Manage ditches to benefit wildlife. Coservation Evidence
http://www.conservationevidence.com/actions/135

Addy S, Susan Cooksley, Nikki Dodd, Kerry Waylen, Jenni Stockan, Anja Byg and Kirsty Holstead (2016) *River Restoration and Biodiversity: Nature-based solutions for restoring rivers in the UK and Republic of Ireland*. IUCN NCUK and CREW

Archaeology, Arable Landscapes and Drainage in the Fenland of Eastern England. Archaeological Project Services Report No. 27/02.

Association of Inland Navigation Authorities, 2008. *Management strategies and Mitigation Measures for the inland navigation sector in relation to ecological potential for inland waterways*. Royal Haskoning, Peterborough

Astbury, A.K. 1958. *The Black Fens*. Cambridge: The Golden Head Press Ltd.

Baker J, Beebee T, Gent T & Orchard D. 2011. *Amphibian Habitat Management Handbook*. Amphibian and Reptile Conservation, Bournemouth

Brew D S, Horton B P, Evans G, Innes J B, & Shennan I 2014 *Holocene sea-level history and coastal evolution of the north-western Fenland, eastern England*. Proceedings of the Geologists' Association 126 72-85

Buisson, R.S.K., Wade, P.M., Cathcart, R.L., Hemmings, S.M., Manning, C.J. & Mayer, L. 2008. *The Drainage Channel Biodiversity Manual: Integrating Wildlife and Flood Risk Management*. Association of Drainage Authorities and Natural England, Peterborough.

Cadbury C.J., Prosser M. & Wallace H. 2001. *The ditch flora of the Ouse Washes (Cambridgeshire/Norfolk)* A report for the English Nature, Royal Society for the Protection of Birds and Wildfowl and Wetlands Trust.

Carson, C. 2012. *The Middle Level Internal Drainage Board Biodiversity Manual - Giving Wildlife an Edge – A guide to the management of drainage channels for biodiversity for the drainage boards of the Middle Level Biodiversity Action Plan Partnership*. Middle Level Commissioners.

Chisholm M 2007 *Re-assessing the navigation of draining the Fens in the seventeenth century*. Proceedings of the Cambridge Antiquarian Society XCVI pp175-192

Coles J & Hall D 1998 *Changing landscapes: the Ancient Fenland*. Cambridgeshire County Council

Colston, A., Carter, B. and Broadbent Yale, P. 2001. *The Wicken Fen Vision – a large new wetland reserve for people and wildlife in Cambridgeshire*. The National Trust.

Darby, H.C. 1940. *The Medieval Fenland*. David & Charles, Newton Abbot.

Darby, H.C. 1956. *The Draining of the Fens*. Cambridge University Press

Darby, H.C., (ed.), 1938. *The Cambridge Region*. Cambridge University Press

Davis R & Cunningham R 2004 *The Water Framework and flooding. Implications for flood defence and coastal management in England & Wales*. RSPB, Sandy

Drake, C.M. 2004. *Grazing marsh assemblages and site classification using invertebrates*. English Nature Research Report No. 579. English Nature: Peterborough.

Driscoll R J 2007 *A Bibliography of Ditch Surveys in England and Wales Part 1: Surveys 1878 to 1999* Buglife, Peterborough

Edgar P, Foster J, & Baker J 2010. *Reptile habitat management handbook*. Amphibian and Reptile Conservation, Bournemouth.

Environment Agency 2010 *About the Water Framework Directive*
http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/About.aspx

Environment Agency 2010 *Guidance on selecting Mitigation Measures*
http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/Decisiontree.aspx

Environment Agency 2015 *Hydromorphological Harm* http://www.greensuffolk.org/assets/Greenest-County/Water--Coast/Suffolk-Flood-Partnership/General-Information/Hydromorphological-Harm-External-Professional-Partners-Note-ar.pdf

Environment Agency 2010 *Fish Pass Manual: Guidance Notes on the Legislation, Selection and Approval Of Fish Passes In England And Wales*. Environment Agency

European Commission 2012 *Implementation of the WFD. Good practices as identified by the Member States*

European Communities 2005 *Common Implementation Strategy for The Water Framework Directive* (2000/60/EC) Guidance Document No 13 Overall Approach to the Classification of Ecological Status and Ecological Potential

Evans, C. and I. Hodder. 2006. 2 Vols *The Haddenham Project: Woodland Archaeology:: Neolithic sites at Haddenham and The Haddenham Project: Marshland Communities and Cultural Landscape – From the Bronze Age to the Present Day*. McDonald Institute, Cambridge.

Fenland Drainage Ditches. Local Habitat Action Plan for Cambridgeshire and Peterborough. 2009 Cambridgeshire and Peterborough Biodiversity Action Plan

Fens for the Future 2012. *A Strategic Plan for Fenland: A Proposal for an Enhanced Ecological Network*. Mere Oak Ecology

French, C. & Pryor, F. 1993. *The South-West Fen Dyke Survey Project 1982–86*. East Anglian Archaeology 59.

French, C. 2003. *'The development of the Cambridgeshire fenlands of eastern England'*, in Geoarchaeology in Action, Studies in soil micromorphology and landscape evolution, 133 142. Routledge. London.

French, C.A.I. and F.M.M.Pryor. 1993. *The South-West Fen Dyke Survey Project 1982 1986*. East Anglian Archaeology 59. Fenland Archaeological Trust.

Friend, P. 2008 *Southern England*. Looking at natural landscapes. Harper Collins

Gaffney V., Fitch S. and Smith D. 2009. *Europe's Lost World: the rediscovery of Doggerland*. CBA Research Report. No. 160.

Gent, T & Gibson S 1998. *Herpetofauna Workers' Manual.* JNCC, Peterborough

Godwin, H. & Vishnu-Mittre 1975. *Studies of the Post Glacial History of British Vegetation. XVI. Flandrian Deposits of the Fenland Margin at Holme Fen and Whittlesey Mere, Hunts*. Phil Trans Roy. Soc. London, B270, 561-604.

Godwin, H. 1978. *Fenland: its Ancient Past and Uncertain Future*. Cambridge University Press.

Godwin, H.1940. *Pollen analysis and forest history of England and Wales*. New Phytol. 39, 370-400

Godwin, H.1940. *Studies of the post-glacial history of British vegetation. III. Fenland pollen diagrams. IV. Post-glacial changes of relative land and sea-level in the English Fenland.* Phil. Trans. Roy. Soc. London B230, 239-303

Graham J & Hammond M 2015 *Investigating ditch biodiversity and management practises in the arable landscape of the Ouse Washes Landscape Partnership Area : a survey of vegetation and aquatic Coleoptera.* http://www.fensforthefuture.org.uk/admin/resources/downloads/ouse-washes-lp-ditch-surveysgraham-hammondfinal-report2015.pdf

Graham, J. 2011. *A survey of the aquatic macrophytes associated with the drainage ditches of the Ouse Washes Site of Special Scientific Interest (SSSI)*. Unpublished report for Natural England.

Hall, D. 1987. *The Fenland Project No.2: Fenland Landscapes and Settlement between Peterborough and March*. East Anglian Archaeology 35.

Hall, D. 1992. *The Fenland Project No.6: The South-Western Cambridgeshire Fens.* East Anglian Archaeology 56.

Hall, D. 1996. *The Fenland Project No.10: Cambridgeshire Survey: The Isle of Ely and Wisbech.* East Anglian Archaeology 79.

Hall, D. & Coles, J. 1994. *Fenland Survey: An essay in landscape and persistence.* English Heritage. http://archaeologydataservice.ac.uk/archives/view/eh_monographs_2014/contents.cfm?mono=1089028

Harris, L. E. 1953. *Vermuyden & the Fens: A study of Sir Cornelius Vermuyden & the Great Level.* Cleaver-Hume Press Ltd., London.

Haslam, S.M. Sinker, C. & Wolseley, P. 1975. *British Water Plants.* Field Studies Council.

Haslam, S.M. & Wolseley, P.A. 1981 *River vegetation: its identification, assessment and management.* Cambridge University Press

Hayes, P. & Lane, T. 1992. *The Fenland Project No.5: Lincolnshire Survey, The South-West Fens.* East Anglian Archaeology 55.

Healy, F. 1996. *The Fenland Project No.11: The Wissey Embayment: Evidence for pre-Iron Age Occupation.* East Anglian Archaeology 78.

Herzon, I. & Helenius, J. 2008. *Agricultural drainage ditches, their biological importance and functioning.* Biological Conservation, No. 141, 1171-1183.

Hill, M.J., Chadd, R.P., Morris, N. et al. *Aquatic macroinvertebrate biodiversity associated with artificial agricultural drainage ditches.* Hydrobiologia (2016) 776: 249.

Hodge, C.A.H. Burton, R.G.O., Corbett, W.M., Evans, R., and Seale, R.S. 1984. *Soils and their use in Eastern England.* Soil Survey of England and Wales. Bulletin No. 13.

Holman, IP and Kechavarzi, C. 2011. *A revised estimate of peat reserves and loss in the East Anglian Fens.* Cranfield University.

Holmes N & Raven P 2014 *Rivers* British Wildlife Publishing

J.N.C.C. 2005. *Common Standards Monitoring guidance for ditches.* Joint Nature Conservation Committee: Peterborough.

Kirby, P. and Lambert, S. 2003. *Fenland farm ditch surveys (Farcet Fen, Kingsland and Tick Fen).* Unpublished report to Cambridgeshire Biodiversity Partnership.

Knight, M. 2009. *Excavating a Bronze Age timber platform at Must Farm, Whittlesey, Peterborough*, in PAST no 63. Prehistoric Society, London.

Knight, M., M. Brudenell and D. Gibson. *Pattern and Process: Landscape Prehistories from Whittlesey Brick Pits. The Bradley Fen and King's Dyke Excavations.* CAU Flag Fen Basin Depth & Time Series Volume 1.

Knittl, M. A. 2007. *The design for the initial drainage of the Great Level of the Fens: an historical whodunit in three parts.* Agricultural History Review 55 (1): 23–50

Lane, T. 1993. *The Fenland Project No 8: Lincolnshire Survey, the Northern Fen-Edge.* East Anglian Archaeology Report No. 66, Heritage Trust of Lincolnshire.

Lane, T. & Morris, E. L. (Eds) 2001. *A Millennium of Saltmaking: Prehistoric and Romano-British Salt Production in the Fenland.* Lincolnshire Archaeology and Heritage Report Series No. 4.

Lane, T. 1993. *The Fenland Project No.8: Lincolnshire Survey, the Northern Fen-edge.* East Anglian Archaeology 66.

Lott, D A D A Procter & A.P. Foster 2002 *East Anglian Fen Invertebrate Survey* English Nature Research Reports Number 477

MEP/GEP Guidelines in a nutshell. Scope for local interpretation on ecological objectives for the Water Framework Directive. 2005 Ministry of Transport, Public Works and Water Management, The Netherlands

Miller, S.H. & Skertchly, S.B.J. 1878. *The Fenland Past & Present.* Leach & Son, Wisbech.

Milsom, T.P, Sherwood, A.J, Rose, S.C. Townd, S.J. & Runham, S.R. 2004. *Dynamics and management of plant communities in ditches bordering arable fenland in eastern England.* Agriculture, Ecosystems and Environment No. 103, 85–99.

Mossman H. L., Panter C.J., Dolman P.M. 2012. *Fens Biodiversity Audit.* School of Environmental Sciences, University of East Anglia.

Mountford, O. & Arnold, H. 2006. *Aquatic Plant Diversity in Arable Ditches: Scoping Study.* Centre for Ecology & Hydrology, Abbots Ripton.

Natural England, 2010. *England's peatlands: carbon storage and greenhouse gases* (NE257).

Natural England 2013 *National Character Area Profile 46 The Fens.* Natural England

Newbold, C., Honnor, J. & Buckley, K. (1989). *Nature Conservation and the Management of Drainage Channels.* Nature Conservancy Council & Association of Drainage Authorities.

Oates, R 2002. *Restoring the Fens – The report of The Fens Floodplain Project.* RSPB.

Palmer, M. 1975 "*Study of the flora and fauna of dykes at Woodwalton Fen NNR*". (Unpublished 100pp).

Palmer. M, Drake. M and Stewart, N. 2013. *A manual for the survey and evaluation of the aquatic plant and invertebrate assemblages of grazing marsh ditch systems – Version 6*. Buglife: Peterborough.

Pankhurst T. 2002 "*The Ditches of Woodwalton Fen NNR – Botanical Survey and Analysis*". English Nature.

Parker A K & Pye D 1976 *The Fenland* David & Charles, Newton Abbot

Phillips, C.W. (Ed). 1970. *The Fenland in Roman Times*. Royal Geographical Society Research Series: No.5.

Ponds Conservation Trust. 2003. *Aquatic ecosystems in the UK agricultural landscape*. DEFRA Project PN0931.

Pritchard, O, Farewell, T & Hallet S 2015 *Enhanced visualization of the flat landscape of the Cambridgeshire Fenlands*. Geology Today, Volume 31, Issue 5 Pages 187–192 DOI: 10.1111/gto.12105

Protecting and improving the water environment. Water Framework Directive compliance of physical works in rivers, available on request from the Environment Agency

Pryor, F. & French, C. 1985. *The Fenland Project No.1: Archaeology and Environment in the Lower Welland Valley*. East Anglian Archaeology 27.

Pryor, F.M.M., 2001, *The Flag Fen Basin: Archaeology and Environment of a Fenland Landscape*. English Heritage Archaeological Reports. London.

Pursglove, J. 2015. *Taming the flood. Rivers, wetlands and the centuries-old battle against flooding*. Harper Collins

R.F. and Redhead, J.W. (2012). *Monitoring of Higher Level Stewardship: Interim Report on 2011/12 Programme*. CEH Project NEC03703.

Redding M 2013 *Glossary of useful Fenland IDB Land Drainage Terms*. Association of Drainage Authorites

Rotherham, I.D. 2013. *The lost Fens. England's greatest ecological disaster*. The History Press

RSPB, 1998. '*Wet Fens For The Future*, Final Report.

RSPB, NRA & RSNC 1994 *The new rivers and wildlife handbook*. RSPB

RSPB. *Advice for farmers: drainage channels* https://www.rspb.org.uk/our-work/conservation/conservation-and-sustainability/farming/advice/details.aspx?id=204265

Shaw RF, Johnson PJ, Macdonald DW and Feber R E. 2015. *Enhancing the Biodiversity of Ditches in Intensively Managed UK Farmland*. https://doi.org/10.1371/journal.pone.0138306

Shennan, I. 1986. *Flandrian Sea Level Changes in the Fenland I: The Geographical Setting and Evidence of Sea Level Changes*. Journal of Quaternary Science, 1, 119-154.

Shennan, I. 1986. *Flandrian Sea Level Changes in the Fenland II: Tendencies of Sea Level Movement, Altitudinal Changes, Local and Regional Factors*. Journal of Quaternary Science, 1, 155-179.

Silvester, R. 1988. *The Fenland Project No.3: Norfolk Survey, Marshland and the Nar Valley*. East Anglian Archaeology 45.

Silvester, R. 1991. *The Fenland Project No.4: Norfolk Survey, Wissey Embayment and Fen Causeway*. East Anglian Archaeology 52.

Skertchly, S.B.J. 1877. *The Geology of the Fenland*. Geological Survey of Great Britain.

Sly R 2003 *From punt to plough. A history of The Fens*. The History Press

Sly R 2010 *Soil in their souls. A history of Fenland farming*. The History Press

Smith, D., Zalasiewicz, J., Williams, M., Wilkinson, I. P., Redding, M., & Begg, C. I. 2010. *Holocene Drainage Systems of the English Fenland: Roddons & their Environmental Significance*. Proceedings of the Geologists' Association 121, 256–269.

Smith, D., Zalasiewicz, J., Williams, M., Wilkinson, I. P., Scarborough, J., Knight, M., Sayer, C., Redding, M., & Moreton, S. 2012. *The anatomy of a Fenland roddon: Sedimentation and environmental change in a lowland Holocene tidal creek environment*. Proceedings of the Yorkshire Geological Society, 59, 145–159.

Storey E.1978 *Summer journey through The Fens*. Robert Hale

Storey E 1995 *The winter Fens*. Robert Hale

Summers, D. 1976. *The Great Level: A History of Drainage & Land Reclamation in the Fens*. David & Charles, London.

Sutherland W J & Hill D A 1995 *Managing habitats for conservation*. Cambridge University Press

Thomas, G.J., Allen, D.A. & Grose, M.P.B. 1981 *The demography and flora of the Ouse Washes, England.* Biol. Consv. 21:197 – 229.

UKTAG 2008 *Guidance on the Classification of Ecological Potential for Heavily Modified Water Bodies and Artificial Water Bodies*
http://www.wfduk.org/resources%20/guidance-defining-good-ecological-potential

UKTAG 2008 *Criteria and Guidance Principles for the designation of heavily modified water bodies*
http://www.wfduk.org/sites/default/files/Media/Setting%20objectives%20in%20the%20water%20environment/HMWB%20rapid-case%20designation%20tool_Final_010308.pdf

UKTAG December 2013 *River flow for good ecological potential Final recommendations*
https://www.wfduk.org/sites/default/files/Media/Assessing%20the%20status%20of%20the%20water%20environment/UKTAG%20River%20Flow%20for%20GEP%20Final%2004122013.pdf

UKTAG 2015 *ALIEN SPECIES ALARM* LIST
http://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/UKTAG%20INNS%20Alarm%20List%20v1.2.pdf

UKTAG 2015 *Revised classification of aquatic alien species according to their level of impact*
http://www.wfduk.org/sites/default/files/Media/Assessing%20the%20status%20of%20the%20water%20environment/UKTAG%20classification%20of%20alien%20species%20working%20paper%20v7.6.pdf

Waller, M. 1994. *The Fenland Project, Number 9: Flandrian Environmental Change in Fenland.* East Anglian Archaeology Report, 70. Cambridge.

Waller, M. 1994. *The Fenland Project No.9: Flandrian Environmental Change in Fenland*. East Anglian Archaeology 70.

Wells, S. 1830. *The Great Level of the Fens Called Bedford Level – Vols I & II.* R. Pheney, London.

West, R. G. (1993), *On the history of the Late Devensian Lake Sparks in southern Fenland, Cambridgeshire, England.* J. Quaternary Sci., 8: 217–234.

West, R.G., Andrew, R., Catt, J.A., Hart, C.P., Hollin, J.T., Knudsen, K.-L., Miller, G.F., Penney, D.N., Pettit, M.E., Preece, R.C., Switsur, V.R., Whiteman, C.A., Zhou, L.P. (1999). *Late and Middle Pleistocene deposits at Somersham, Cambridgeshire, U.K.: A model for reconstructing fluvial/estuarine depositional environments.* Quaternary Science Reviews, 18 (10-11), pp. 1247-1314.

Wheeler, A.J. (1992). *Vegetational succession, acidification and allogenic events as recorded in Flandrian peat deposits from an isolated Fenland embayment*. New Phytologist, 122 (4), pp. 745-756.

Wheeler, A.J. (1995). *Saltmarsh development from fen: Analysis of late Holocene deposits from north-central Fenland, U.K.* Quaternary International, 26 (C), pp. 139-145.

Wheeler, R. C. (Ed) 2008. *Maps of the Witham Fens from the Thirteenth to the Nineteenth Century*. Lincoln Record Society.

Wheeler, W.H. 1990 (Ed). *A History of the Fens of South Lincolnshire.* 2nd Edition. Paul Watkins, Stamford.

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