Natural England Commissioned Report NECR240

Remedial Works for the Catch Dykes at Ebb and Flow Marshes

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Catch dykes (at the break of slope between floodplain and upland) have been given little attention in studies of wetland hydrology.

They can play an important role in the transmission of nutrients, interrupt the hydroseral succession on the valley side, and impact groundwater supply to the valley sides and/or floodplain fens. This work has confirmed that catch dykes may have significant implications for the management of wetland sites nationally and internationally.

The intention is to use this work to implement restoration of valley side hydrology on sites impacted by catch dykes.

This contract looked in more depth at Decoy Marshes, Acle/ Ebb & Flow Marshes within the Bure Broads & Marshes (delete as appropriate) to understand the site hydrology, the role of the catch dyke and to develop designs for the restoration of the catch dyke and valley side hydrology.

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Further information
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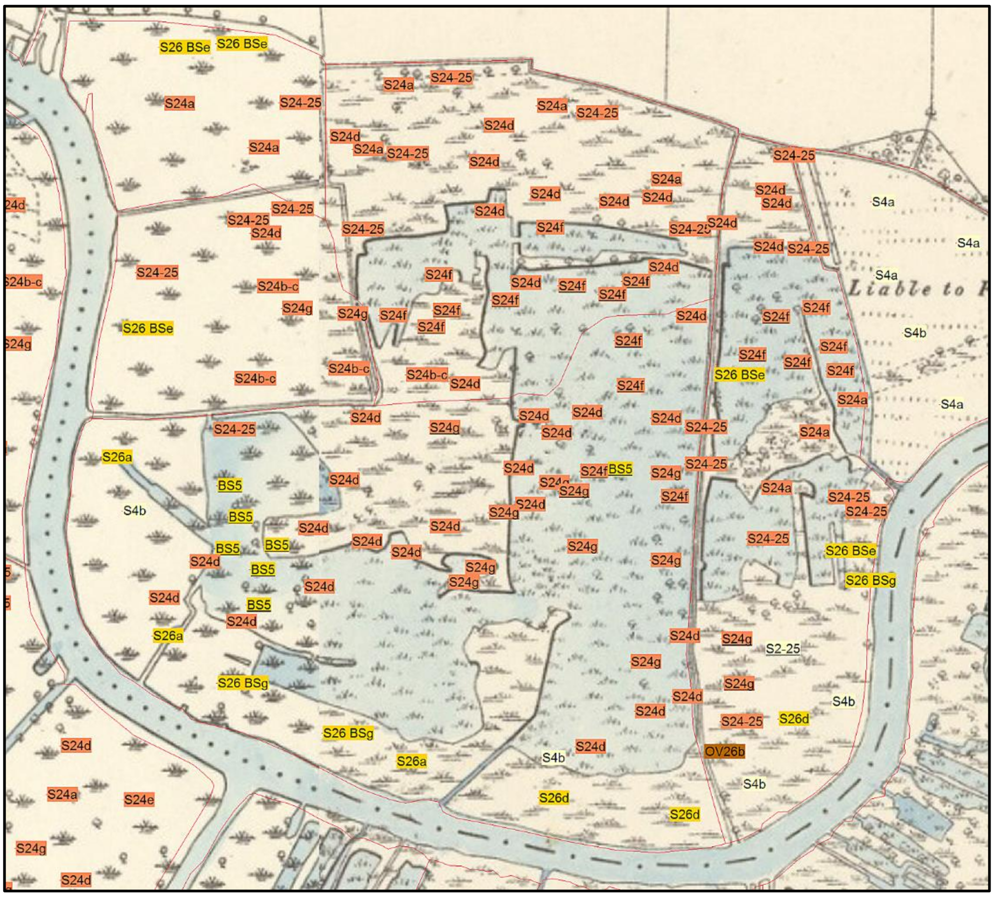
Remedial Works for the Catch Dykes at Ebb and Flow Marshes



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SUMMARY

In 2014, Natural England (NE) commissioned a review of the potential impacts of catch dykes on the hydrology and ecology of wetlands in the Broads. The report (OHES 2014) indicated such effects could be significant. NE then commissioned investigations into Ebb and Flow Marshes to identify the site-specific impacts of the catch dyke, and to suggest how natural functioning could be restored.

The protocols developed in OHES (2014) for investigating catch dykes was adopted, involving six stages: (1) Desk and Field Research (2) Defining the Problem (3) Develop Solutions (4) Proposals and Consents (5) Implementation and (6) Review: Proposed Monitoring.

Research included a summary of known information about the wetland, together with new fieldwork. The latter included topographical survey of the site, hydrological investigations, soil/stratigraphy survey along three transects and the analysis of existing hydrological and ecological data sets.

The research allowed the derivation of eco-hydrological models using the Wetland Mechanism approach developed by Wheeler et al (2004). The catch dyke appears to cause significant drawdown of the groundwater table in the toe slope area and in the fen. The shallow water table in the margin of the wetland flows toward the catch dyke, not down slope into the main peat body. The impacts of the catch dyke are limited by the presence of marine alluvium at shallow depth along the margin, and by the influence of river/marsh dykes.

The catch dyke is a *Type 1: Groundwater Dyke With Significant Direct Drainage*, and is rated as Severe Risk. The catch dyke is likely to cause the following:

- Change of ground water quality.
- Depletion of the water balance.
- Direct draw down of water table.
- Transfer of nutrients from arable land to the wetland.
- Truncation of the wetland to dryland transition at the valley margin.

Of particular surprise is the finding that the ground water table is being drained below the bed of the catch dyke. It is suggested that regional pumped drainage – the adjacent low-level IDB system – is responsible, drawing water through the course loams which form the valley margin.

The following package of measures has been proposed:

1. **Comprehensive infill of the catch dyke**. This is the core solution which addresses all of the five issues. Because groundwater is being depleted underneath the dykes, cross-barriers at depth will be required in addition to infill.

   Other ancillary measures include scrub removal, alterations to fence lines and new gates, a new access track, and post-project follow-up management to restore habitats.

   An initial estimate suggests catch dyke works would bring ground water tables within 1m of ground surface at approximately the 2.50m AOD contour. Arable farming between this contour and the catch dyke would be affected. This equates to 4.224ha.

2. **Change upland land use to restore the wetland to dryland transition at the valley margin.** This involves:
    - Reducing accumulated nutrients in topsoils through nutrient stripping cropping.
    - Improvements to farm practises on arable land that is being res9tored, adopting measures in Solution 3.
    - Stripping of the turf along the existing dyke-side access track.
    - Habitat establishment on land released from arable.

    The extent of restoration of land upslope of the catch dyke depends on agreements reached with the current landowner.

3. **Improve Farm Practises.** On land not restored to semi-natural habitat, or if agreement cannot be secured for restoration of the valley margin, the following beneficial farm practises should be encouraged.
    - Contour ploughing.
    - Retaining winter stubbles.
    - Reduced application of fertilisers.
    - Extended uncropped headlands along the toe slope.

If implemented, eco-hydrological modelling suggests a groundwater seepage zone would develop, supporting uncommon fen plant communities. The seepage zone would be flanked by groundwater flushed zones and with groundwater enhancement of the peat mass on the floodplain. The ecological value of the site would be greatly enhanced.

The site is relatively unconstrained without infrastructure or built property that will be affected by remedial work. Arable land to the north will be affected and currently the landowner is not favourable although willing to discuss further.

Recommendations are made for implementation. A single works contract is suggested and an initial Bill of Quantities for works given. This is being used as a basis for securing funding.

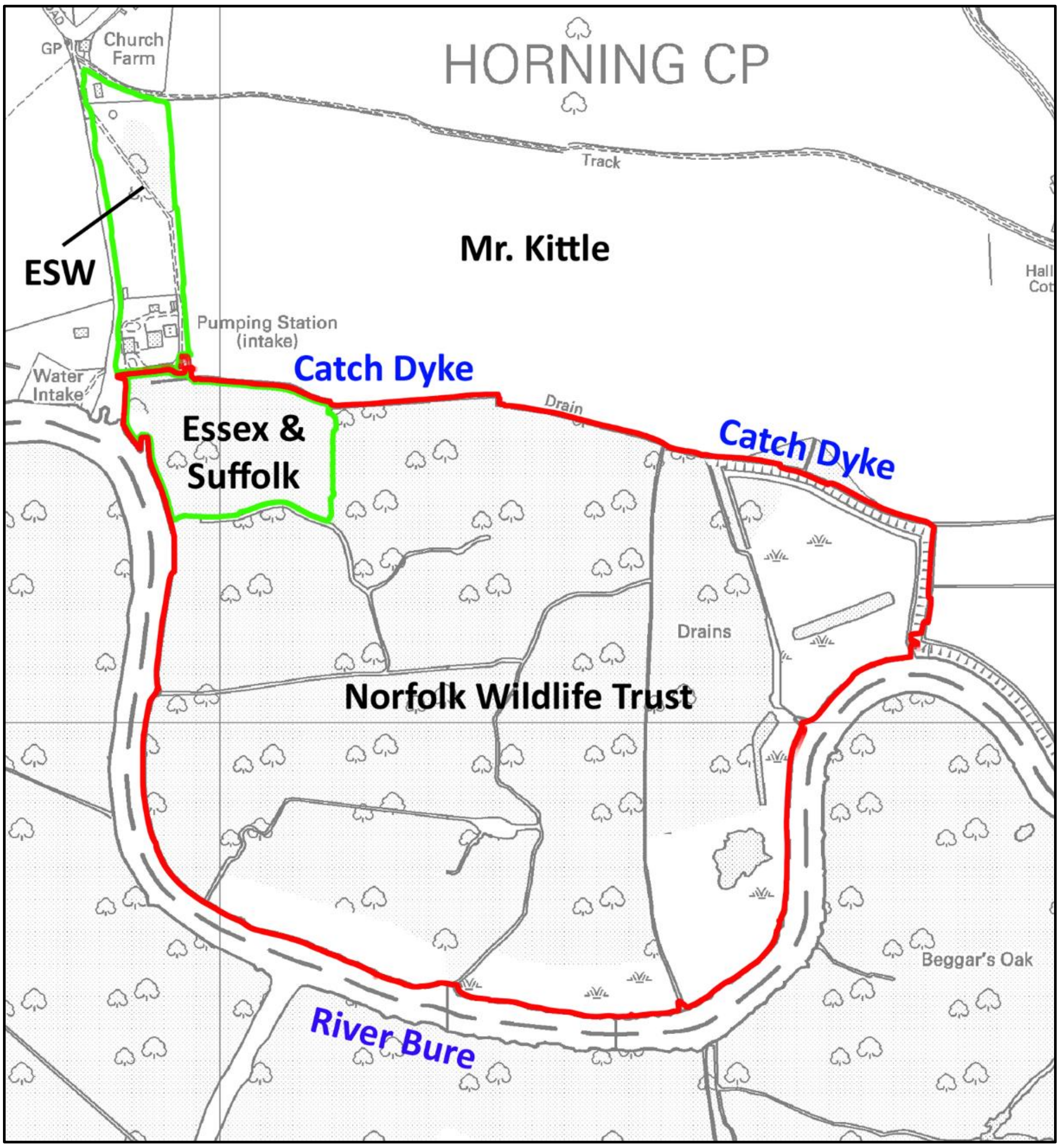
Hydrological and ecological monitoring is proposed. This consists of two belt transects perpendicular to the catch dyke corridor, stretching from up slope to down slope. Each transect includes up to 12 fixed vegetation monitoring plots paired with dipwells recording water table level. These have been installed and are being read fortnightly.

1. INTRODUCTION

1.1 Aims

The aim of this report is to develop practical proposals which remediate damaging impacts of catch dykes on the wetland interest of Ebb and Flow Marshes (part of the Bure Broads and Marshes SSSI). The site is shown on Figure 1.

Figure 1 : Ebb and Flow Marshes, Location and Landowners.



The project involves collation of desk information, collection of field data and development of remedial solutions to a sufficient level that a tender can be let for implementation.

The consents of regulators and main stakeholders are also scoped and the constraints placed upon remedial works taken account of.

1.2 Previous Work

The project arose initially from growing concerns that catch dykes were a significant hydrological issue for the toe slope zone of wetlands in the Broads. Evidence from programmes such as EA's Review of Consents was accruing which suggested many of the valley margin sites in Broadland were fed to some degree by shallow groundwater. Catch dykes may be intercepting and diverting such water and creating a range of issues that damage the nature conservation interest of the site.

Consequently, Natural England commissioned a scoping study (OHES 2014) reviewing the literature, identifying the range impacts of catch dykes in Broadland, laid out a methodology for investigating a site and outlining the kinds of management actions which could address such impacts. It also reviewed six sites with fieldwork as a test of the methods first developed.

The current report uses the framework contained in OHES (2014) as a basis for the investigation of the sites and assessment of the issues.

1.3 Selection of Sites

The six pilot case studies examined in OHES (2014) were reviewed along with other possible sites thought to have catch dyke issues. A short list of three was drawn up and initial discussions with landowners held. Sites where landowners did not wish to engage with the project were set aside, leaving Ebb and Flow Marshes and Decoy Carr, Acle. They became the study sites for this phase. Reports were split for practical reasons – see OHES (2016) for the report on Decoy Carr, Acle.

2. Methods

Desk Based Research

All available information for the site was gathered through desk research. The files at Natural England were searched and data from Environment Agency and other organisations and stakeholders gathered together. Site references in other technical reports such as Wheeler et al (2009) and publications of the Soil Survey were also sourced.

Topographical Survey

Gaps in understanding were then identified. Field survey work was undertaken. This included land and water topographical survey. A Hemisphere S320 GNSS Network Rover was used to set up Temporary Bench Marks (TBMs) around the site and to record topography in open areas. An optical (laser) level was used to level the core sample locations and dipwells.

The soil surface on the upland slope and toe were relatively consistent but the ground surface on the fen side of the catch dyke was very uneven. "Typical" levels were selected as much as possible, avoiding obvious hummocks and hollows, in order to provide the most representative surface levels. Note, however, individual levels on the peat are extremely variable over short distances.

Soils and Stratigraphy

Shallow stratigraphy was determined through soil coring. Depth was variable but was mostly around 2m below ground level on mineral soils and up to 3.25m on peat. Depth of coring was sometimes limited by contact with incoherent material (watery peat or running sand in particular). The ground level of each core was recorded to Ordnance Datum so that the level and relationships of the various strata observed could be related to each other (and to water levels) across the site.

Logs of soil cores were recorded (Appendix 1). Layers were described separately if there was a significant change in colour, texture or characteristics such as presence of mottling. The boundary of a soil layer was measured by extending steel tape below ground level. Boundaries are often diffuse and disrupted by coring, hence there will be some inaccuracy with such measurements. Texture was assessed in the field, the field description then being ascribed to the standard soil texture groups described in Hodgson (1997). Lab analysis was not undertaken. Soil colour was assessed visually. Soil series were ascribed to each profile, which allows reference to HOST classification and soil hydrological models.

Groundwater Determination

The water table was allowed to come to rest while other soil cores were undertaken. The rest water level, where the water table was contacted, was then measured below ground. Where groundwater was deep, it could be difficult to determine the precise water table position. In addition, it cannot be guaranteed that full equilibrium was achieved with the time available in the field. Hence water table determinations are approximate. All water levels quoted relate only to the day of survey. The coarse loams of the toe slope in particular responded rapidly to rainfall. Consequently, most of the coring within the SSSI was undertaken in as short a period as possible in autumn 2015.

The soil and water data in the transects allow toe slope to wetland profiles to be compiled to ordnance datum, providing comparability across the site.

Monitoring Equipment

Two monitoring transects were installed by Peter Frizzell Ltd. The piezometers were levelled into Ordnance Datum (rim of piezometer and ground level), although ground level on the fen itself is so variable this provides only an approximation.

Field Work For Design of Solutions

During design of remedial works, cross-sections of the catch dyke were recorded using the laser level although these were not to Ordnance Datum as they are intended only to illustrate the nature of the dyke and its immediate flanks, and to provide illustration of finished levels. A line survey of the long barrier were recorded to Ordnance Datum as specification of the barrier needs to be tied to a specific target depth below ground.

3. STAGE 1 : DESK AND FIELD RESEARCH

3.1 Ownership and Designations

Landowners (shown on Figure 1) are:

- Mr. Robert Kittle: Grove Farm, Upper Street Horning. All of the arable land north of the catch dyke
- Norfolk Wildlife Trust: All of the wetland south of the catch dyke, except the ESW land which they lease..
- Essex and Suffolk Water (ESW): the north-eastern compartment nearest their pumping station. Leased to NWT

All of the upland and floodplain is part of the Broads National Park

The wetland south of the catch dyke is within the following designations:

- Bure Broads and Marshes SSSI
- The Broads Ramsar Site
- The Broads Special Protection Area (SPA).
- The Broads Special Area of Conservation (SAC).

All of the wetland except the ESW parcel is part of the Bure Broads and Marshes National Nature Reserve (NNR).

3.2 Geology and Hydrogeology

The following is drawn mostly from Moorlock et al (2002).

3.2.1 Geology

The Drift deposits of the upland are sands, gravels and silts/clays of the Happisburgh Formation (formerly the Corton Formation). The Formation is stratified with glaciofluvial sand and gravel deposits (Corton Sands) over non-calcareous till (the Happisburgh Till, what is referred to in older accounts as the Norwich Brickearth). The nature of the Drift is very variable vertically and horizontally (Entec 2005). Happisburgh Formation deposits thin on the lower slopes.

A surface deposit of silty sandy Loess (the Cover Loam referred to in Tatler and Corbett 1977) of very variable thickness (never more than 1m) has been deposited on top of the Happisburgh Formation and forms the topsoil. Loess material covers most of the highland from the interfluve to the floodplain edge, but is variable in depth, being thickest in depressions and thinnest or even absent on exposed slopes. Its extent around Ebb and Flow has been mapped by Tatler and Corbett (1977).

Floodplain Drift deposits are the Breydon Formation. It is a complex inter-layering of peat and silty clays deposited during marine transgressions (referred to in the corings as the marine alluvium). The Upper Peat forms the ground at Ebb and Flow, a reed and sedge fen peat. It is underlain by Upper Clay, a silty clay of the Romano-British Marine Transgression of sometimes complex stratigraphy (Moorlock et al 2002). The Middle Peat is also complex stratigraphically with reed, sedge and brushwood type peats. All three of these layers are quite shallow on the landward edge of Ebb and Flow and were contacted during coring on the marsh. In the main valley away from the margin, the middle peat is underlay by Lower Clay, again a soft silty clay, and the Basal Peat, described by Moorlock et al (2002) as a thin and impersistent peat of brushwood passing to fen peat and then saltmarsh “peat” on the upper boundary with the Lower Clay. The lower layers of the Breydon Formation were not contacted in fieldwork for this project and their confirmation under the main fen is uncertain.

Below the Drift is Pleistocene Wroxham Crag Formation. It is an estuarine and near-shore Crag. It is also a variable deposit, being mostly iron-rich sands and gravels with thin and discontinuous clay and silt layers within. It differs from the older Norwich Crag in having more gravels with a higher proportion of siliceous pebbles, and by being coarser. Wroxham Crag is mapped by Moorcock et al (2002) as forming much of the highland slope to the north, with the Happisburgh Formation on the higher parts of the slope and interfluve. However, they note that the Crag is usually overlain by a sandy gravel “wash” which may be derived from both the upper surface of the Crag and overlying Happisburgh sediments. Distinguishing the boundary between the Crag and Happisburgh Formations can therefore be difficult on the slopes, a situation made more complex by the spread of silty Loess across the whole. The Wroxham Crag does not appear to be especially shelly, unlike the Red Crag which is relatively calcareous. Crag continues under the floodplain Breydon deposits (Entec 2005).

AW (2006) note a thin organic clay layer between the Crag and the Happisburgh Formation, also referred to by Wheeler et al (2009). This was not observed in the field but may have been below coring depth.

Below the Crag is the Upper Chalk Formation. The upper surface dips gently from west to east (Entec 2005). In the west of the region, the Wroxham Crag and Chalk overlie each other and are in direct hydraulic continuity. To the east, there is a layer of Eocene Clay of the Harwich Formation (commonly referred to as the London Clay), lying between the Chalk and Crag. The location of the edge of the clay is not clear. IGS (1981) place the boundary exactly between Horning and Ebb and Flow Marshes. Hence the Crag under Ebb and Flow may be divided from the Chalk by the clay, but at its eastern edge, the exact limit of the clay, its thickness and its possible discontinuity are all uncertain. Arthurton et al (1994) describe the clay boundary as “…a feather edge…”p17. Hence, the hydraulic continuity between Chalk and Crag under Ebb and Flow is uncertain and possibly variable.

3.2.2 Hydrogeology

The regional Chalk aquifer converges on the Bure valley from the north and the south (AW 2006). The Crag aquifer will mirror this. Although it is considered a minor aquifer in water resource terms by AW (2006) and ESW (2009), the Crag could still contribute significantly to the eco-hydrology of the wetland.

All reports agree that there is a general Chalk groundwater gradient from west to east. Chalk water levels 10km to the north-west were recorded by Entec (2005) as 2.5m higher than a chalk bore near to the site. During intense monitoring over three years, ESW (2009) recorded water levels in the chalk at Wroxham mostly varying between 0.7-0.9m AOD, while water levels in fen dipwells at Horning Marsh Farm varied between 0.4-0.5 mAOD. Chalk water levels at Wroxham were overall around 40cm higher than those in the fen. ESW (2009) conclude that there is potential for chalk water to rise into the Crag or Drift in unconfined conditions, and even to the surface where elevation is low. The degree of confinement caused by the Harwich Formation clay at Ebb and Flow is highly uncertain. Entec (2005) suggest the wedge of clay may in fact "split" the east-moving chalk water, causing some to glide over the clay surface and upwards.

Similarly, it is likely that water in the Wroxham Crag aquifer could pass to the drift deposits, especially along the valley margins where it outcrops. The conceptual hydrogeological models contained in AW (2006) and Entec (2005) both show potential groundwater inputs to the floodplain. Stratigraphical coring undertaken as part of the current study showed the fen margin along the catch dyke to be coarse permeable material unsealed by clay or alluvium until the Breydon Formation deposits feather-in along the floodplain margin.

In conclusion, although Crag or Chalk groundwater is unlikely to rise up and pass directly into the floodplain wetland from below due to aquacludes in the Harwich and Breydon Formation deposits, delivery of groundwater from Crag and Chalk along the permeable highland margin seems highly likely. The dykes may penetrate more deeply into shallow aquifers, although the degree of groundwater interaction will depend on the levels of silt in bed and banks.

None of the studies felt able to be certain or specific about groundwater flows to particular parts of the Bure Broads and Marshes SSSI, or even to provide a degree of quantification for the whole site. There are no studies specific to Ebb and Flow which indicate the degree of Crag or Chalk groundwater flow to the site.

While marginal groundwater may contribute to the wetland water balance and to hydrochemistry, the majority of the site away from the highland margin will be largely topogenous. Near-surface hydrology will be driven mostly by the level in the River Bure, by distribution of water by the internal dykes and by rainfall. Vegetation data support this proposition, with largely topogenous floodplain communities with indications of ombrotrophic conditions in the interior, at greatest distance from the marsh dykes. The dykes may be one mechanism whereby ground water could be distributed around the site. However, most dykes are silted and a circulating system is very restricted.

Entec (2005) modelled all abstractions in the area and concluded Ebb and Flow were not affected. No further action was recommended (EA 2009).

3.3 Soils

3.3.1 Previous Soil Surveys

Tatler and Corbett (1977) have mapped the district of Horning including Ebb and Flow. The upland is shown mainly as **Wick** and **Newport Series,** loamy or sandy brown earths respectively developed in terrace sands and gravels. In shallow depressions and hollows, along much of the toeslope and in places where stoneless loess has accumulated to significant depth, **Sheringham Series** have developed along with Wick. No gleyic soils are shown as transitional to the floodplain which is all described as peat of the **Adventurers** or **Raw** (now **Ousby**) **Series**. Coring for this project suggest this is an oversimplification, particularly around the toe slope/catch dyke area.

NSRI provides general soil hydrology and chemistry information. They are free draining, in unconsolidated sands or gravels with a variable silt and clay fraction. They have high permeability and high storage capacity. Water expressed from such soils would be non-calcareous, neutral to mildly acid. They have high leaching capacity with little to moderate ability to attenuate non-adsorbed pesticides and other diffuse pollutants. Underlying groundwater is vulnerable to contamination. Risk of run-off is low. Natural fertility is low. With modern methods, they provide very productive arable land. Under semi-natural conditions they would sustain acid to neutral grassland and woodland.

The underlying Crag provides more base-rich and calcareous groundwater which may influence shallow water tables around the toes slope and fen edge areas.

3.3.2 Stratigraphy and Soil Survey in 2015

In autumn 2015, an auger survey was conducted using three transects across the catch dyke from the toe slope to the peat fen. Locations of transects and cores is shown in Figure 2.

Figure 2: Location of Stratigraphy Transects at Ebb and Flow Marshes

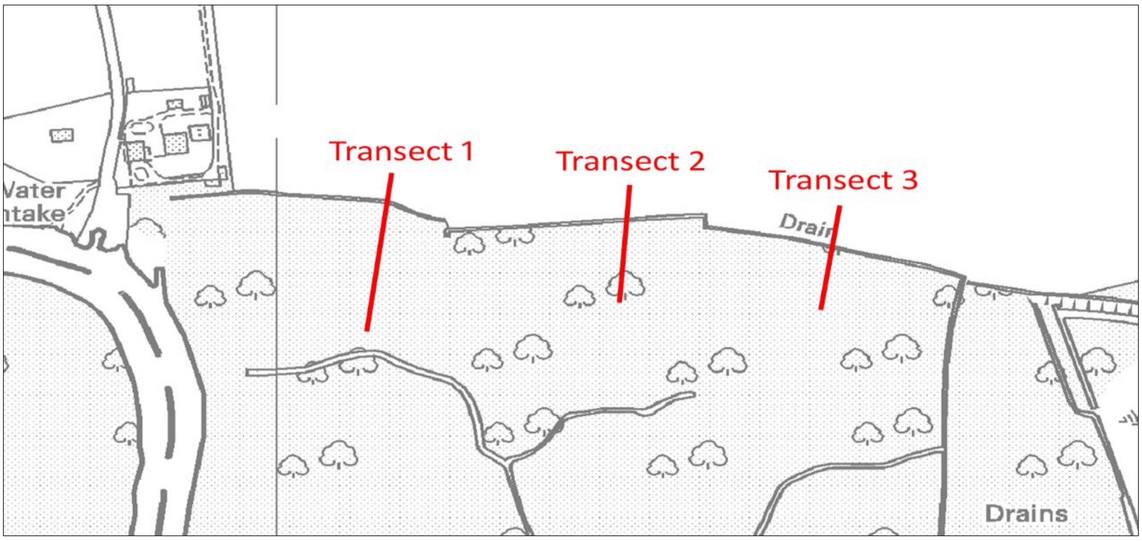


Figure 3a. Soil Type and Shallow Stratigraphy In Transect 1

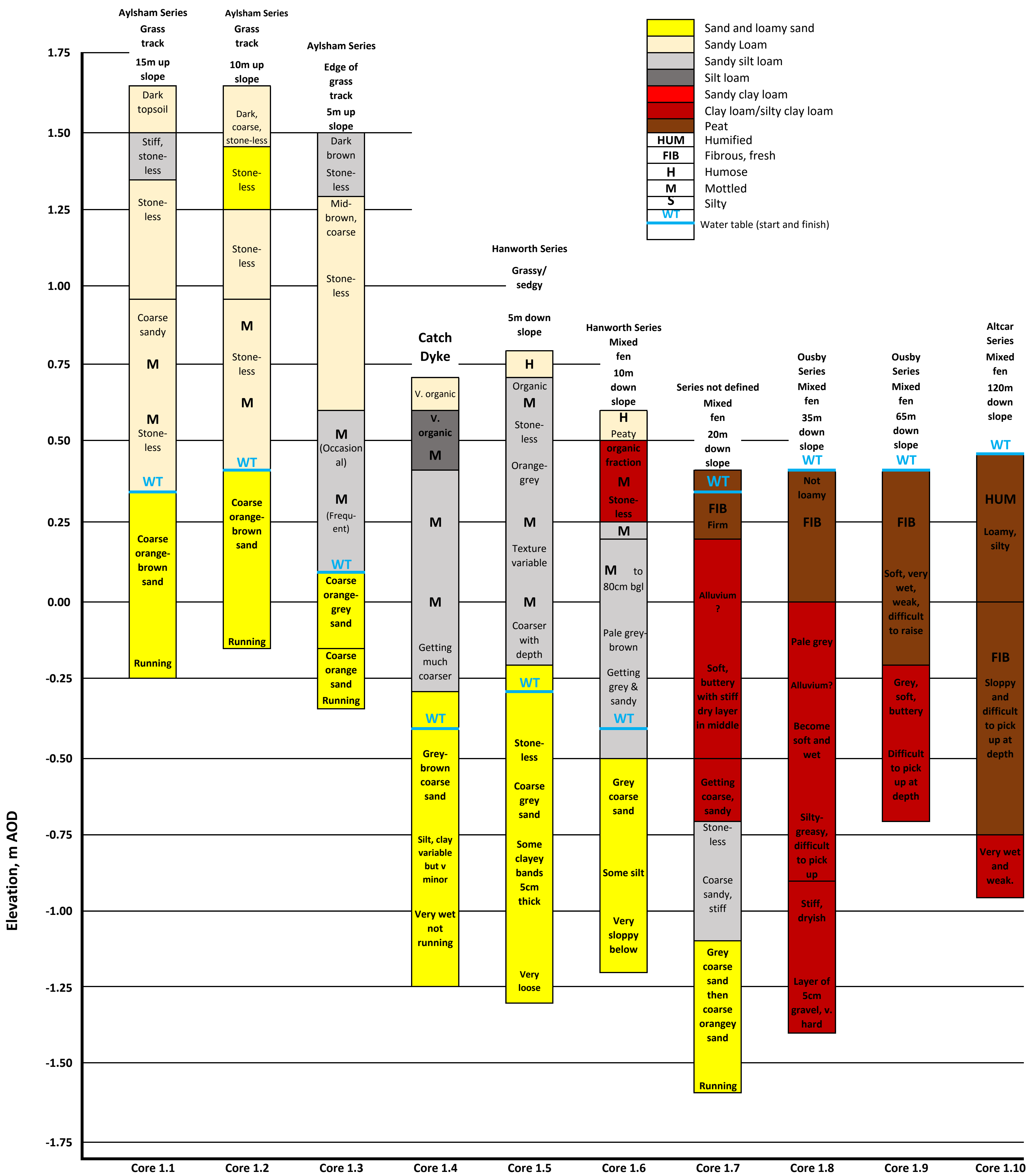


Figure 3b. Soil Type and Shallow Stratigraphy In Transect 2

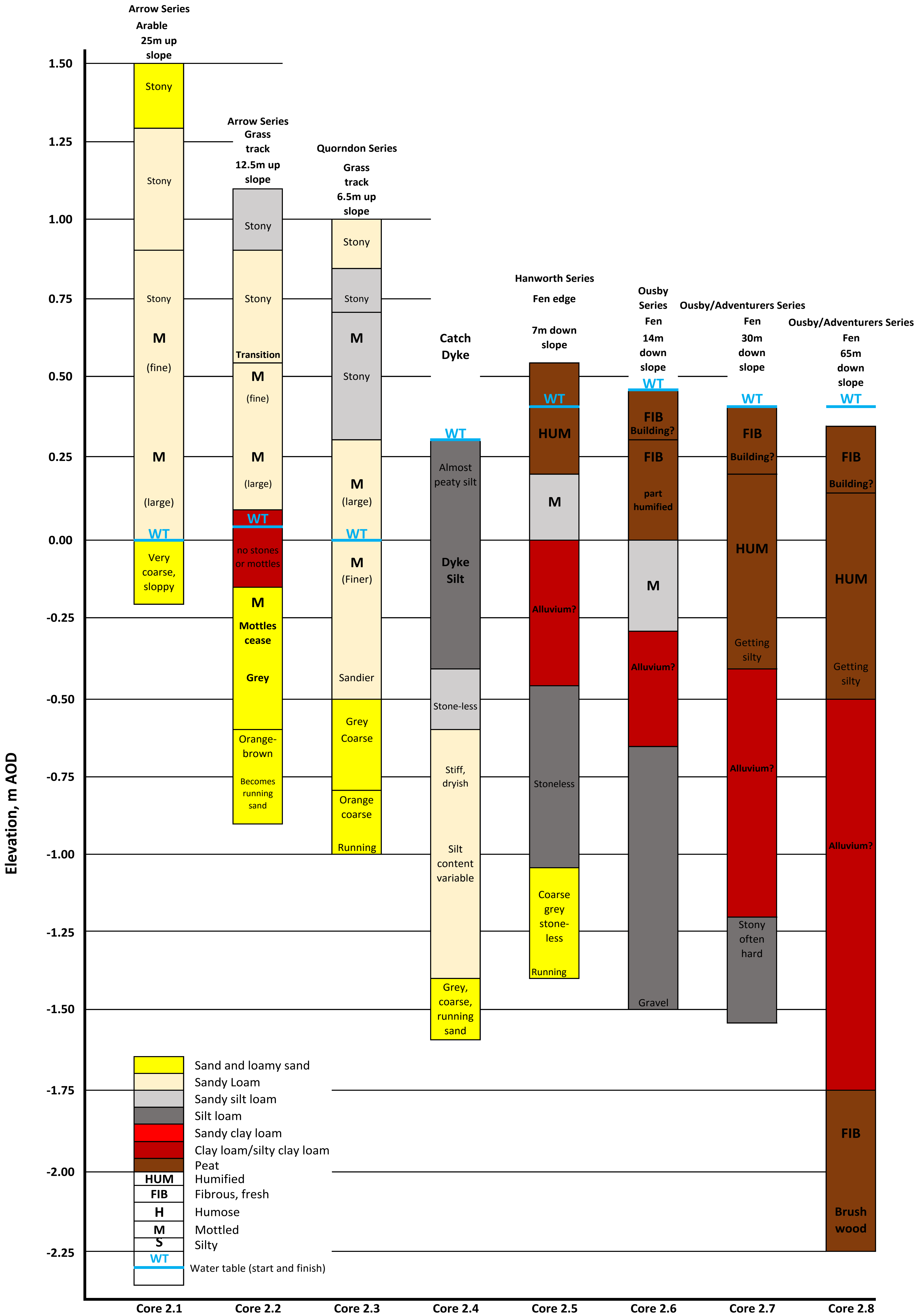
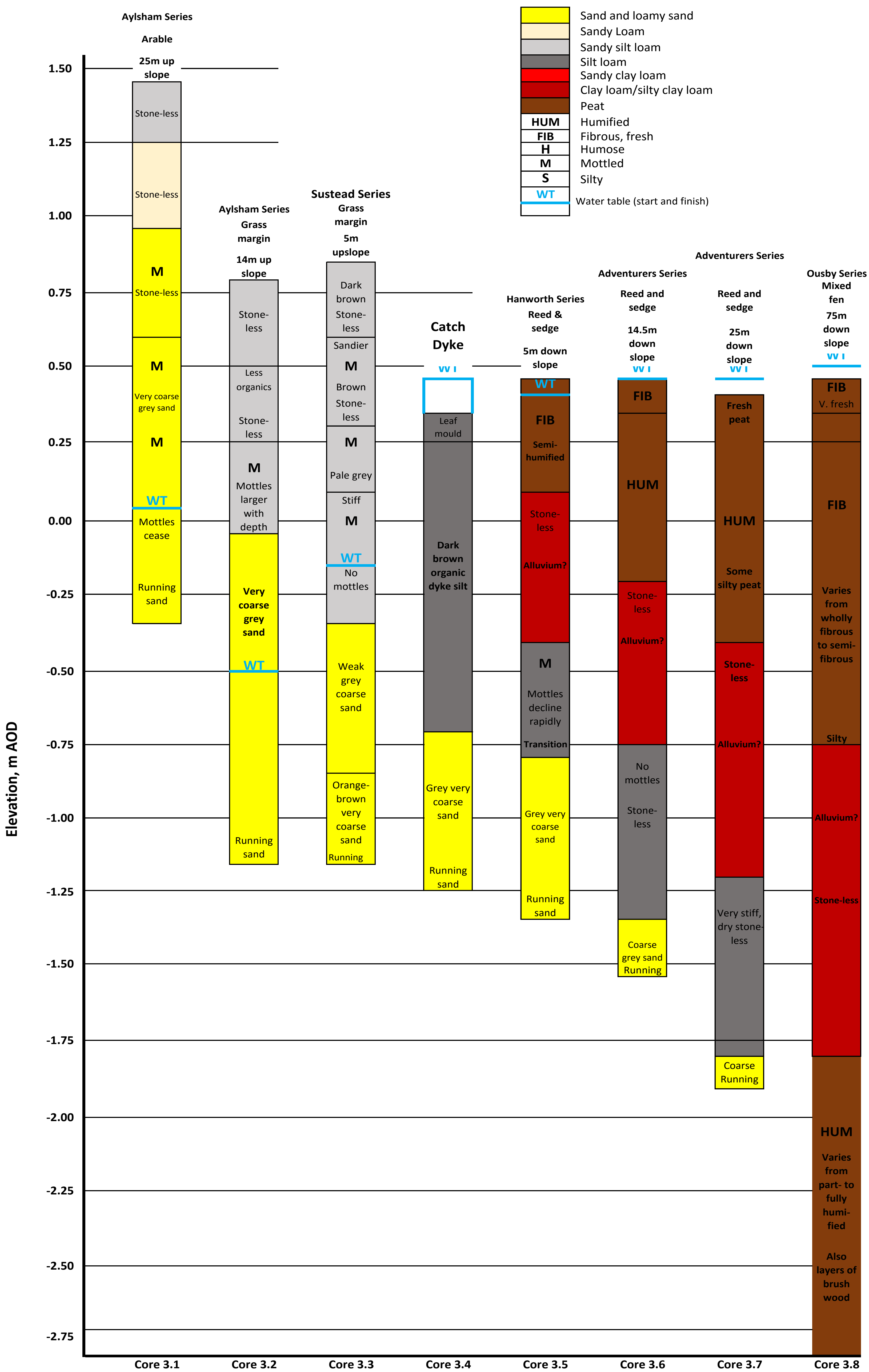


Figure 3c. Soil Type and Shallow Stratigraphy In Transect 3



Results are shown on Figures 3a-3c. Coring of the more elevated upland during the Pilot project (OHES 2014) showed Wick and Newport Series, confirming mapping by Tatler and Corbett (1977). Consequently, coring for the current phase concentrated on the lower slopes and wetland.

All three transects show a classic hill slope soil sequence, from deep permeable brown earths (Wick/Newport) through to brown earths showing some gleyic features in the lower profile (Arrow/Aylsham), then to true groundwater gleys on the toe slope flanking the catch dyke (Sustead/Quorndon) and finally on the transition to true floodplain soils, there are gleyic brown earths with humic or peaty topsoils (Hanworth Series). The floodplain is characterised by peat over alluvium. There are significant differences in the detail between transects.

The line of the catch dyke very neatly divides the upland and fen side soil types. The dyke is asymmetrical throughout, being much higher on the upland side.

Transect 1

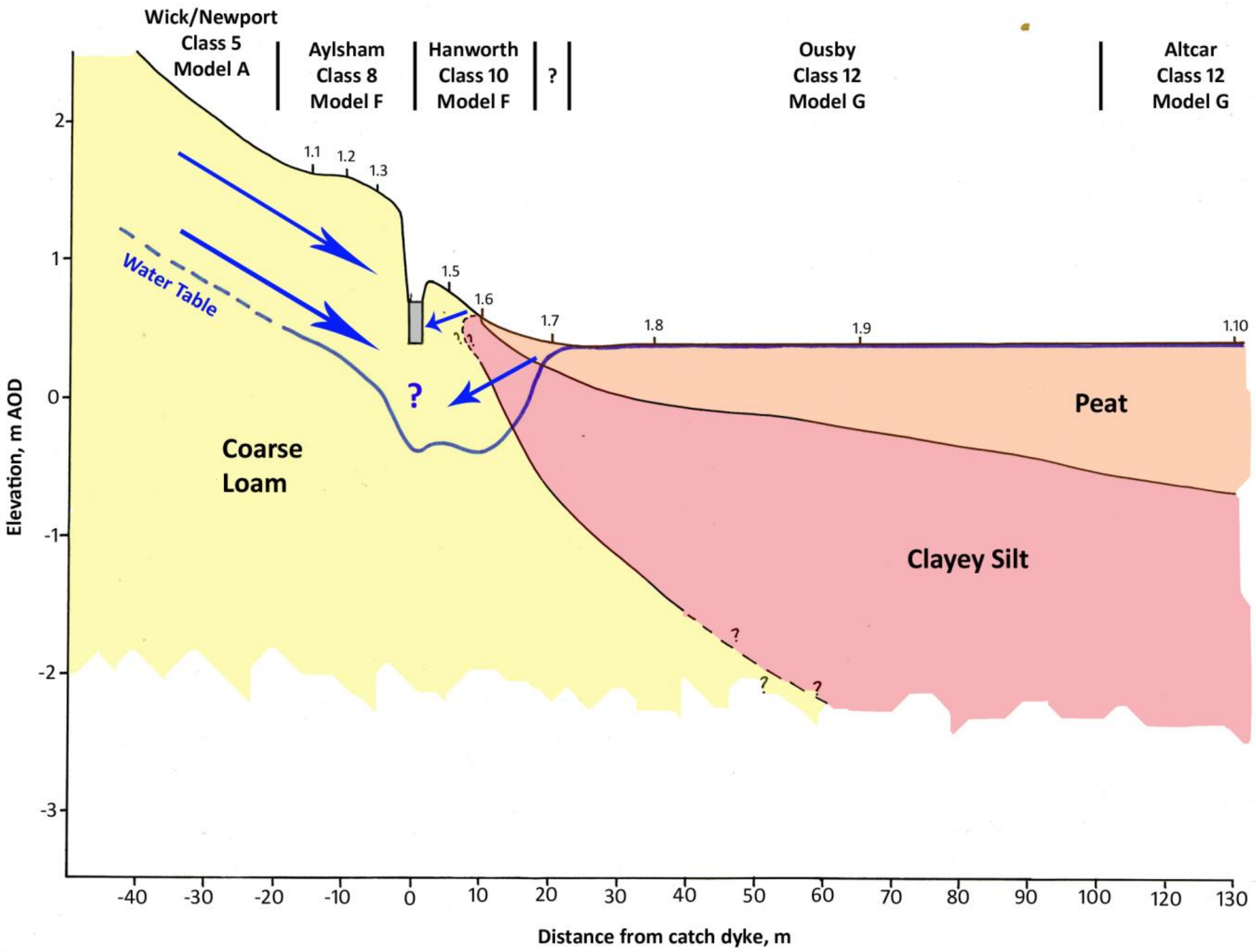
Transect 1 is located at the west end of the catch dyke. A generalised cross-section is shown in Figure 4. Up-slope of the catch dyke, all three profiles were gleyic brown earths in coarse loamy and stoneless drift, the Aylsham Series. Surface deposits of loess were shallow, with only thin deposits of sandy silt loam in the upper horizons. All profiles are very permeable. A fluctuating water table is shown by 0.5-0.75m of mottling in the profile. Towards the base of the soils, a very coarse, brown or orange brown sand is contacted.

The catch dyke is dug into very similar material. The upper 0.3m of the bed is highly organic dyke silt, with an additional 0.7m of silty loam below. All of this silty material could be dyke infill since it was first excavated. Thereafter, the dyke bed is on coarse sand.

On the fen side, the first 10-15m has a very similar stratigraphy although the sandy silt loam near the surface is much thicker. Mottling is at about the same elevation AOD as was observed in the upland cores, but because of the drop in ground surface, mottling is very close to the surface downslope of the dyke. Soils are therefore true groundwater gleys with the humose or peaty topsoil placing them in the Hanworth Series. Both profiles are bedded into coarse grey sand. Core 1.6, 10m downslope of the dyke, shows 25cm of slightly fine sandy, clayey silt which is rather stiff and may be the upland edge of marine alluvium.

True floodplain fen soils begin at around 15m downslope of the centre of the dyke. They are characterised by peat over marine alluvium, both thickening with distance into the fen. The peat often has a surface layer of soft, loose fibrous peat suggesting recent formation. Only deeper into the fen (Core 1.10) is there humified surface peat. Also notable is the soft, weak and sloppy peat below the surface in Cores 1.9 and 1.10, suggestive of the infill of a former peat digging. The peat was rather shallow, only 1.2m at 120m from the dyke. The marine alluvium is rather variable from stiff and dry, through to soft, buttery material, to very weak and loose silty material. Under the alluvium there was coarse grey sand, which may extend under the whole site but was not contacted after Core 1.7.

Figure 4: Cross Section at Transect 1 showing Water Table and Shallow Stratigraphy

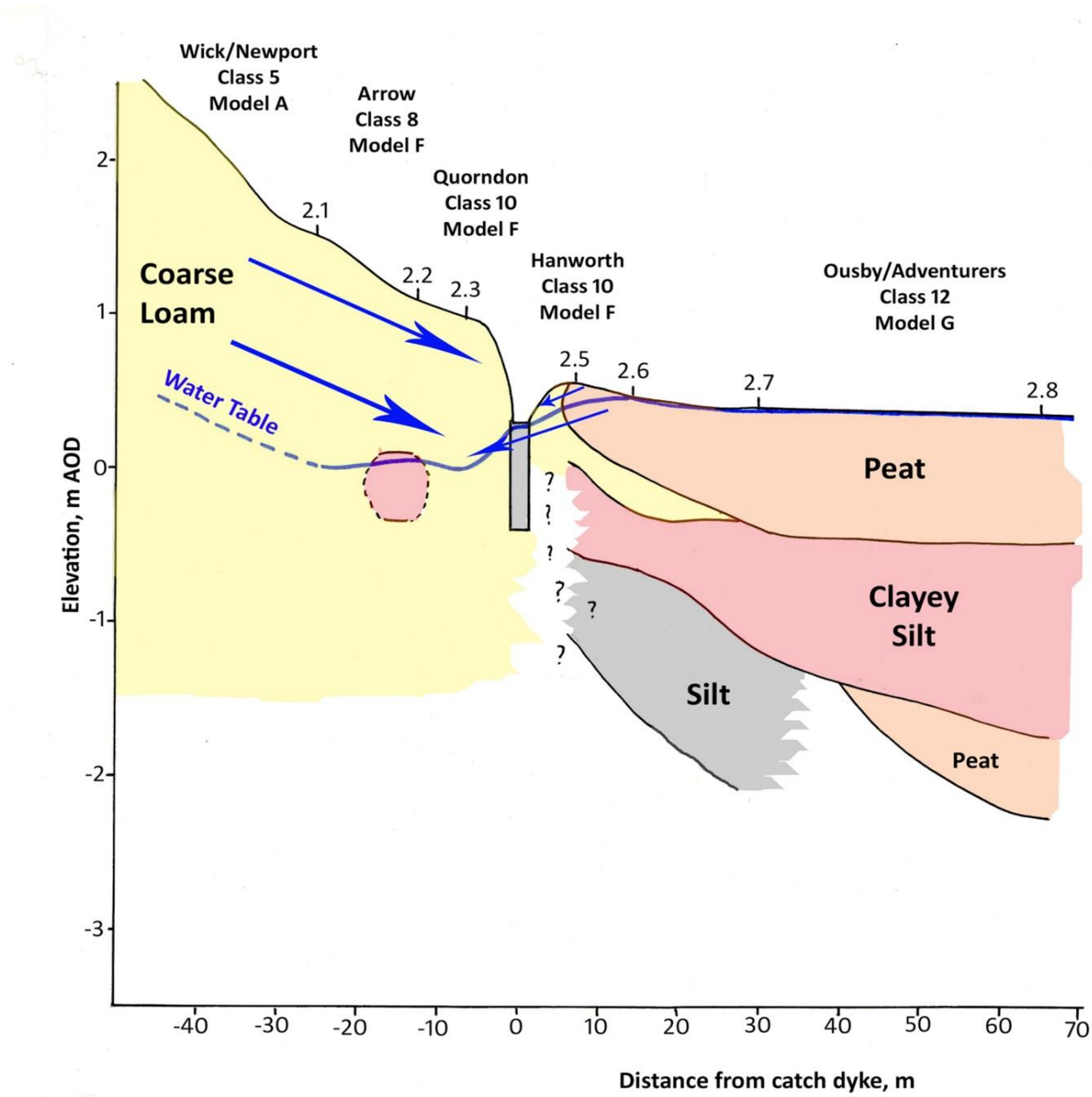


The water table on 15/10/15 shows a deep trough below the catch dyke, with no perched water in the dyke itself. The expected water table shape – highest on the slope, declining toward and then across the floodplain until the river level and groundwater equilibriate – has clearly been disrupted by the catch dyke. Reversed groundwater flow from the fen to the catch dyke occurs, against the topographic gradient. The water table only meets the fen surface when the thick clayey and silty alluvium is reached, 20m downslope of the catch dyke (Core 1.7). River levels, distributed by the meagre dyke system, maintains the fen water table from this point, with no groundwater support. The water table gradient back towards the catch dyke is very steep, reflecting the steepness of the aquaclude margin.

Transect 2

Figure 5 provides a cross-section of Transect 2, in the mid-section of the site. The three up-slope soil profiles have a very similar stratigraphy to Transect 1, with deep sand or sandy loam through to depth with only a little sandy silt loam. Around 1m of mottling occupies much of the mid-profile, suggesting a greater water table range than in Transect 1.The first two profiles are gleyic brown earths but where mottling reaches close to the surface in Core 2.3 nearest to the catch dyke, there is a true ground water gley. The profiles are in stony drift along this transect hence they are **Arrow** and then **Quorndon Series**. In Core 2.2, there is a thin lens of silty clay loam in the deep subsoil which seems to lift the water table a little.

Figure 5: Cross Section at Transect 2 showing Water Table and Shallow Stratigraphy



The catch dyke lies in similar coarse loamy drift. There is around 0.75m of organic dyke silt, the upper parts almost peaty, supporting shallow water.

Downslope of the catch dyke, Core 2.5 shows a transition to true fen soils. Surface peat is first recorded, although here at the fen edge it is very shallow and well humified. There is a thin band of sandy silt loam between the peat and alluvium which is strongly mottled indicating a fluctuating water table. Marine alluvium is also contacted for the first time, underlain by a layer of stiff fine sandy silt which *may* also be marine alluvium but of a different texture to the clayey silt above. At the base of the core is coarse sand continuing from the upland margin.

Further into the fen, the shallow sandy silt loam soon disappears and both peat and alluvium thicken so that the base sand was not contacted. As with the first Transect, the surface peat is soft and fibrous, suggesting the surface is building. However in Transect 2, under this surface layer the peat is humified, suggesting the absence of a former peat digging. At the base of Core 2.8, a firm fibrous and well preserved brushwood peat was contacted.

The water table is highest in the main peat fen, where it is maintained by the alluvium aquaclude, with inputs from the river. Water tables decline precipitously from the landward margin of the marine alluvium towards the catch dyke. The catch dyke, with a deep plug of dense dyke-bed silt, effectively extends the alluvium aquaclude, so that the deep trough in the water table is located on the upslope side of the dyke (c.f. Transect 1), maintaining wetness in the fen edge. Were the dyke silt removed, the fen margin would likely be dewatered. The upslope water table flattens at around 0m AOD. The point where the hillslope water table rises again was not reached, the dotted blue line on Figure 5 being speculative. Clearly, no upslope ground water is reaching the wetland surface.

Transect 3

Transect 3 shows many similarities to the first two transects. A cross-section is presented in Figure 6.

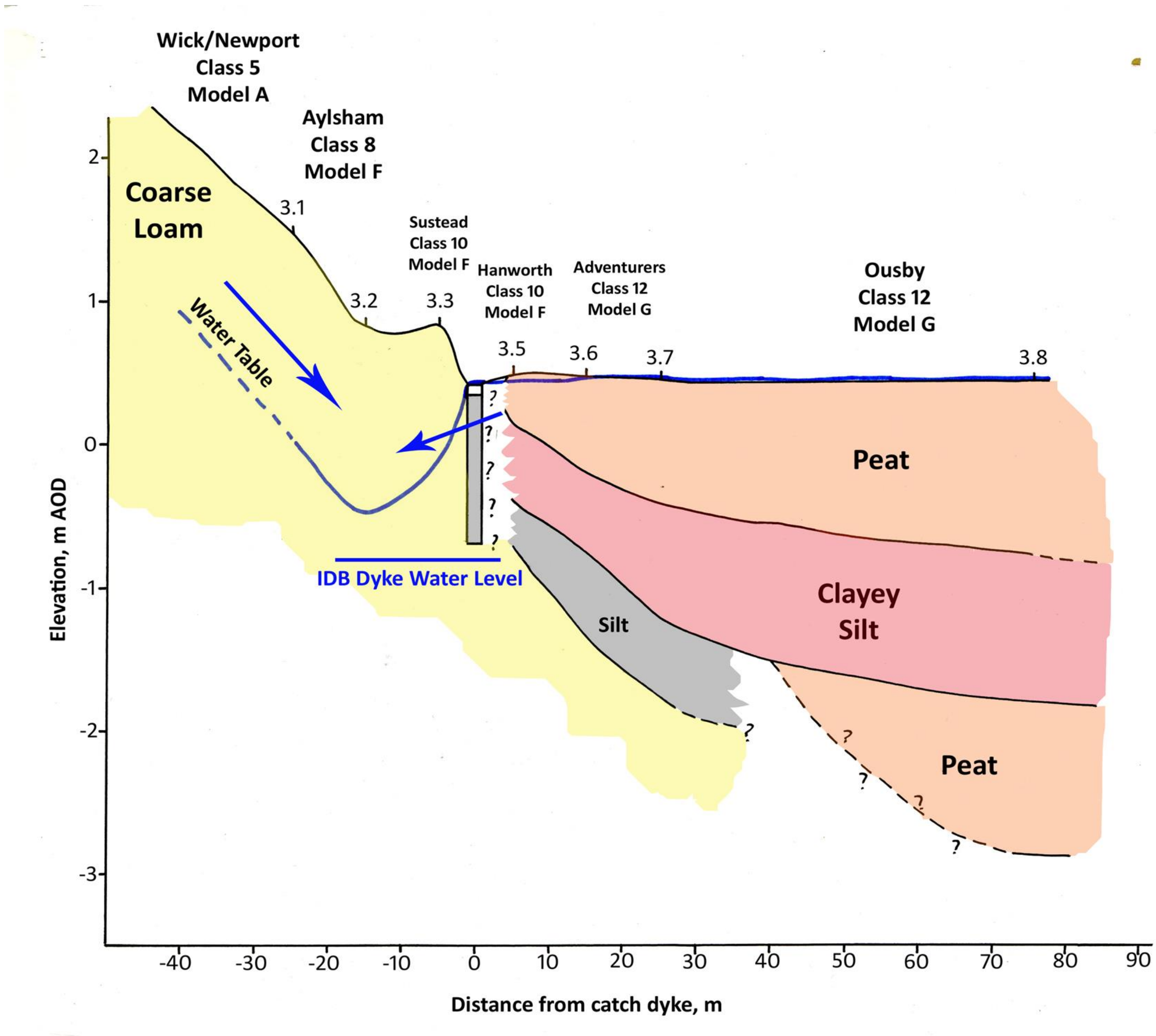
Upslope of the dyke, the profiles are stoneless, with a deep surface layer of sandy silt loam in the lower two profiles, indicating a deepening of the cover of Loess. Gleying affects 0.75-1.0m of the profile, indicating substantial variation in the water table. The more elevated profiles are gleyic brown earths of the Aylsham Series, while the soil next to the dyke is a groundwater gley of the Sustead series. All three profiles are underlain by coarse sands which can be orange-brown.

The catch dyke, which retained 12cm of water at the time of coring, sits over the coarse sand. Above this there is about 1m of dark brownish organic silt, presumably dyke silt, topped by leaf mould.

Downslope of the dyke, the cores are very consistent. The surface layer is peat, thickening towards the river. The top layer of fibrous fresh peat again suggesting recent growth of the fen surface. There is humified peat in the middle cores, but fibrous peat in the last core at 75m from the catch dyke. It is not watery and loose as it is in Transect 1, but still unhumified and suggests infill of a peat digging. Below the peat is a thickening layer of clayey silt and fine sandy silt which may both be alluvium. Under all but the distant Core 3.8 is the base layer of coarse, grey, running sand.

As with Transect 2, the final core contacts a dense layer of brushwood peat underneath the first alluvium stratum. The peat varies from part to fully humified.

Figure 6: Cross Section at Transect 3 showing Water Table and Shallow Stratigraphy



The water table here shows a similar overall pattern to Transect 2 with a deep trough recorded upslope of the catch dyke. In Transect 3 the alluvium aquaclude is thicker and closer to the catch dyke than in previous transects. The plug of dense organic silt under the dyke is also thicker and may be contiguous with the alluvium. The catch dyke bed may even run through the landward margin of the alluvium. Hence, the water table gradient on the catch dyke/alluvium margin is steepest and deepest of all of the transects. Once again, no groundwater is able to enter the wetland.

3.3.3 Behaviour of the Water Table

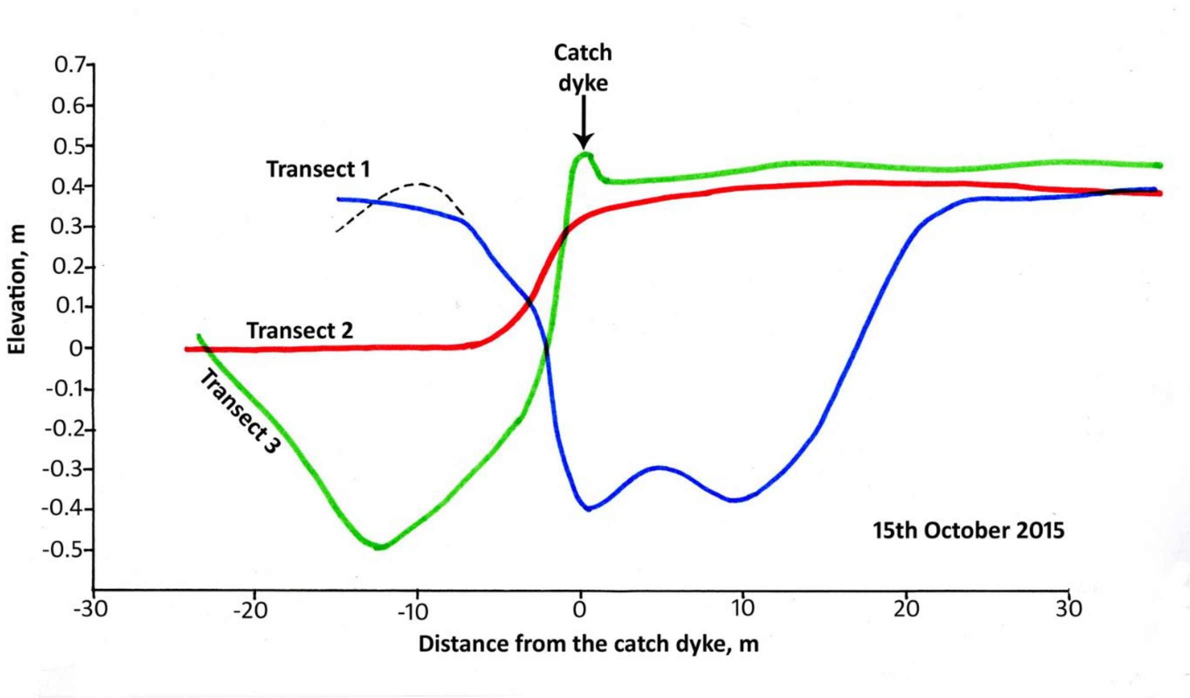
It is clear that the alluvium aquaclude is maintaining a high fen water table, supported by the river whose water is circulated by dykes and porous peats. The upland drift aquifer contributes nothing to the fen water balance, being cut-off by a deep trough in the ground water along the catch dyke or just upslope of it.

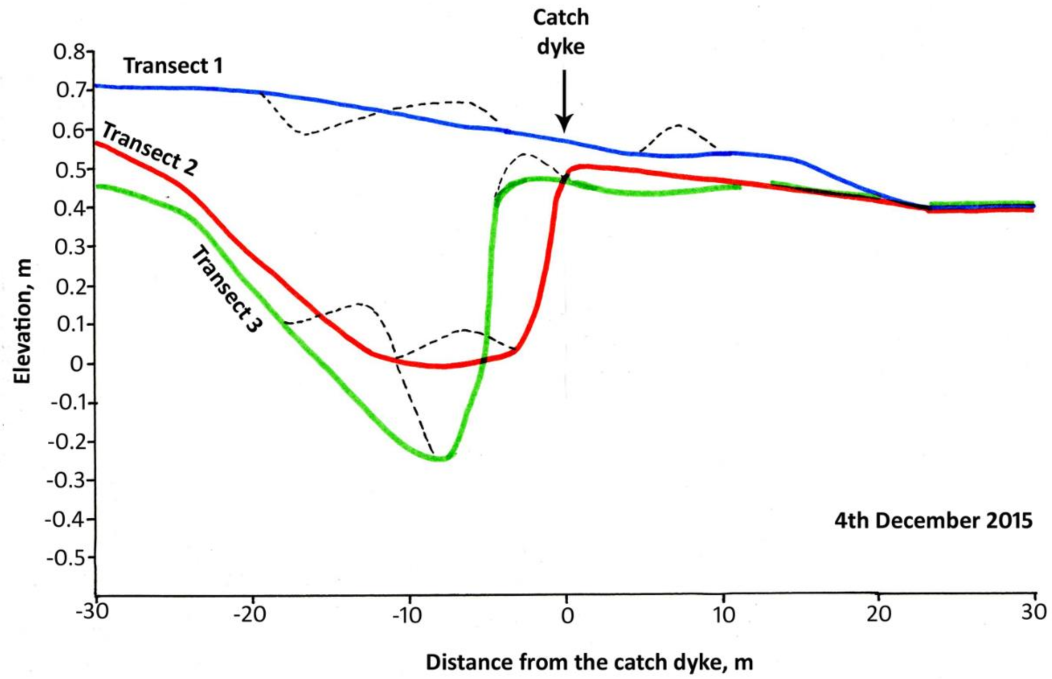
However, the catch dyke cannot be directly responsible for the deep trough because it is not centred on the dyke, and is much deeper than the bed of the dyke (which often has water perched in dyke bed silts). There is no mechanism for water to rise from the trough into the dyke. Somehow, groundwater is being continually drained from this trough.

Further investigations were undertaken on 4th December 2015, when all three transects were re-drilled with a soil auger after significant autumn rains, when it was expected the hydrology would be more active. Figure 7 overlays the ground water table recorded in the three transects, for October 2015 (first graph) and then December 2015 (second graph).

Figure 7: Water Table Profiles Across the Catch Dyke, 15/10/15 and 04/12/15.

Profiles are smoothed; dashed black line indicates level recorded in the field.





The graphs show that in both periods, the water table of all three transects equalise over the aquaclude, reflecting the overriding influence of the river and alluvium on surface water levels. Water tables further than 10m downslope from the catch dyke show only a very modest increase in level (up to 10cm but usually much less) between October and December. The increase in water table level in the coarse loams upslope of the catch dyke is by contrast very marked, 30.5cm on average but closer to 40cm for T1 and T3. The rest level in December was well within the mottled zone of the toe slope soils. The data suggests water levels are relatively stable in the peat fen but dynamic along the catch dyke corridor and the toe slope.

In October, the position of the trough is closely aligned to the upslope edge of the aquaclude. In Transect 1, the aquaclude lies further into the fen, hence the trough underlies the dyke and extends into the fen. In Transects 2 and 3, where the aquaclude more or less reaches the catch dyke, the trough is pushed upslope of the dyke.

Within the coarse loams upslope of the catch dyke, the water table declines in elevation from Transect 1 through to Transect 3, indicating a water table gradient from west to east along the corridor of the catch dyke and toe slope. Hence it appears likely that the trough flows along this gradient from west to east, under and adjacent to the catch dyke. This flow must be sufficient to maintain the trough against groundwater moving into the trough from upslope.

The profiles are anachronistic in October in a number of places. Suspecting potential error, the profiles were re-examined in December when more cores were drilled per transect. The profiles of Transects 2 and 3 again show the marked trough just upslope of the catch dyke. There is a much clearer sequence of declining elevation from T1 to T2 to T3. Perhaps the most surprising feature is the near-naturalisation of the groundwater profile in Transect 1, sloping down gently through the bed of the catch dyke - where the water table was only around 0.15m below the bed – and without a marked trough.

In conclusion, the two sets of curves confirm the presence of a groundwater trough under and upslope of the catch dykes, and that there is a west to east gradient in the groundwater trough.

The low point of the trough in Transect 3 was minus 0.50m AOD in October. The water level in the catch dyke downstream of the sluice located at the eastern boundary of the site was minus 0.75m AOD (see Figure 6). This drain, which is part of the pumped IDB system, is well below river level which at the same time was around +0.40m AOD (depending on tide). Hence the IDB Main Drain is the lowest drainage point for the system. As a pumped system, it is likely to be drawing water at all times (water was passing over the sluice on 15th October). Hence it is suggested that the pumped IDB drain is drawing water westward below the catch dyke, causing the observed pattern in the water table, and depleting the fen of groundwater inputs.

This may explain why Transect 1 showed such a marked flattening following autumn rains. It is furthest from the point of drainage, providing a lag before the "trough" is drained once more.

It is emphasised that these conclusions are speculative with the current data, and that pumping-induced flows along/beneath the catch dyke bed have not been directly observed or measured.

3.4 Topography

Levelling of the northern part of the floodplain and catch dyke corridor was undertaken with a digital DGPs. LIDAR data was used to provide contouring of the upland slope. Results are presented on Figures 8a-c.

The site has a simple topography. A ridge separates the Bure valley to the south from the Ant valley to the north. The interfluve at around 11.50m AOD lies between the west-east track and the A1062. A convex slope descends south to the valley margin where a short toe slope grades into the valley floodplain. The catch dyke lies in the toes slope, but a little above the level of the flat peat surface. The dyke is asymmetrical, with the upslope dyke edge being markedly higher than the downslope.

The Bure meanders across the floodplain, with Ebb and Flow forming within one large meander loop on the left bank of the river.

The northern half of the fen is remarkably flat. The level averages between around 0.35m AOD to 0.40m AOD. There is great micro-topographic variation in the marsh surface around this range, +/- 5cm. Micro-topography has been generated by the organic growth of the peat surface together with cattle and deer poaching low trackways. There may be some variation caused by past peat diggings. Otherwise the fen presents as a flat peat plain. The fen surface

Figure 8a. Topography Overview.

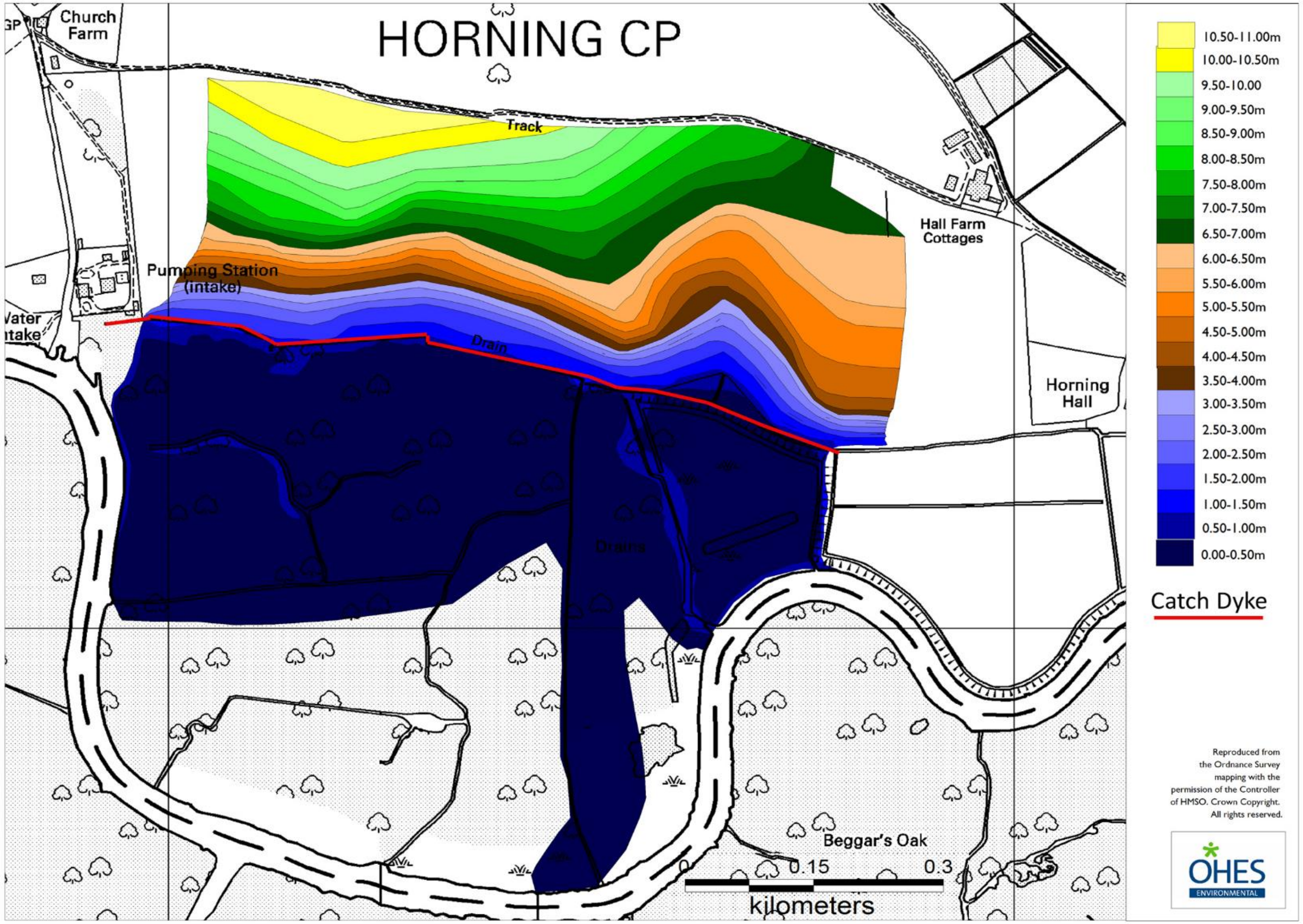


Figure 8b: Topography: Detailed Levels West Side

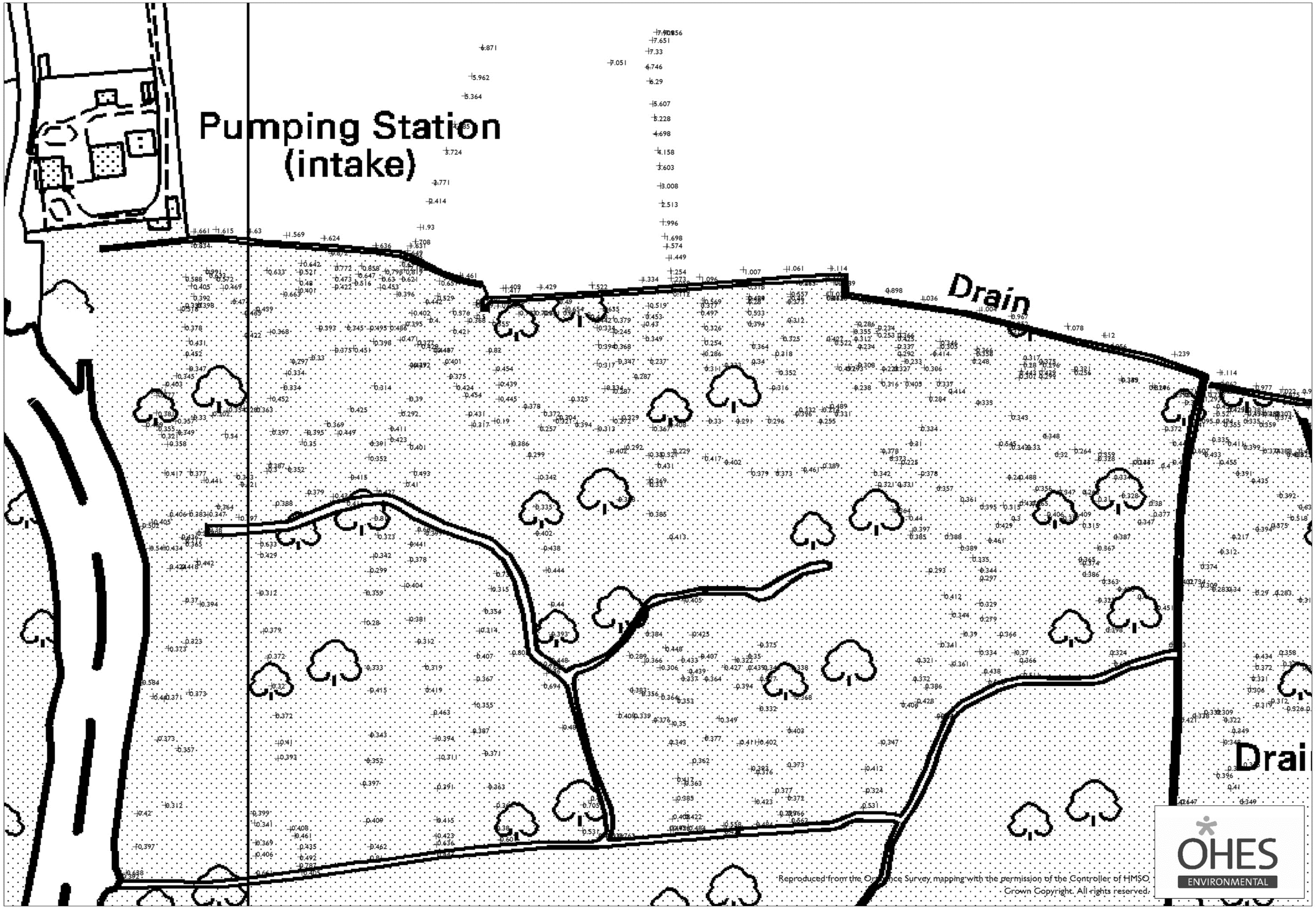
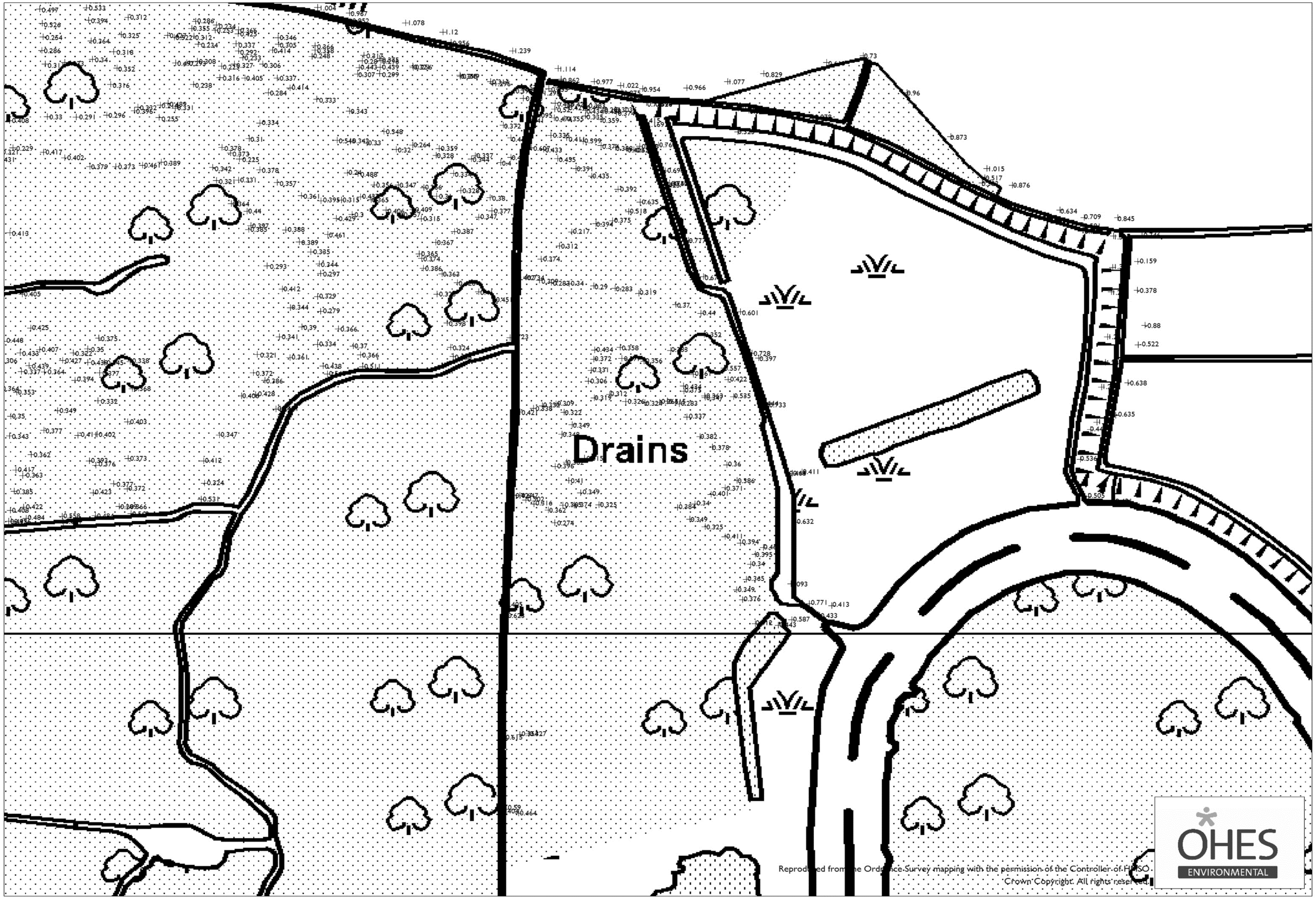


Figure 8c: Topography: Detailed Levels East Side



towards the river was not comprehensively levelled as it is distant from catch dyke. Levels taken flanking the north-south dyke suggest the peat surface remains around 0.40m AOD.

Many of the open dykes have a raised margin on at least one side. This may have arisen from deposition of dyke slubbings, and/or because the dyke margins were not dug for peat to the same degree as the adjacent internal compartment areas. The river, too, appears to have a low levee which is breached where dykes have open outfalls.

There is also a significant down valley gradient to the toe slope. Levels on the track on the upslope side of the catch dyke decline from around 1.60m AOD at the east end to 1.0m AOD in the central section, and then to around 0.65m AOD at the eastern end. By contrast the peat floodplain seems rather level from west to east. The grazing marsh just to the east of the fen is significantly lower, at around minus 0.50 to minus 0.60m AOD. This low-lying land is within a floodbank which runs the length of the east margin of the Fen, and is part of the IDB pumped system.

3.5 Vegetation

3.5.1 Plant Communities

Vegetation recorded in 2007 (ELP 2010) is provided on Figure 9, overlaid on the OS 1885 map showing areas of peat cuttings. The main communities recorded are given in Table 1. In all, 138 samples were taken with a mean species-richness of 14.8 (BA 2013). The majority of the vegetation is composed of variants of the main Broadland fen community, S24 *Phragmites australis-Peucedanum palustre* tall-herb fen. There is a fringe of species-poor, eutrophic and slightly salinity-affected reed fen (S26) around the river margin. The fen along the northern margin is relatively poor mixed reed fen.

The central areas support the fen communities of greatest conservation interest. The acid fen (BS5 *Dryopteris cristata-Sphagnum* spp. fen), the calcareous *Cladium* dominated fen and the calcareous pools (all three being SAC features) are away from the marginal areas. This may reflect edge effects such as ingress of nutrients and salinity. Table 1 and Figure 9 both make clear there is also a correlation between the turbaries and the better quality fen. The majority of SAC features and the better quality communities such as S24f, S24g and to an extent S24d are concentrated in former turbaries. Poorer fen types are mostly outside. Maps of fen species richness in BA (2013) also show a correlation between species richness and location of turbaries.

Ebb and Flow is the only site recorded in the Fen Resource Survey in the Bure Valley for the uncommon BS5 *Dryopteris cristata-Sphagnum* species fen[1]. This acid transition community is more common in the Ant and Thurne valleys. It is thought to be rainwater-dependent, maintaining its hydrochemistry by having an elevation which prevents irrigation by eutrophic and/or base rich fen waters (ELP 2010).

[1] Rick Southwood notes it is recorded in very small quantity in the Bure Marshes Reserve south of the River.

Figure 9: Vegetation Communities Recorded During the Fen Resource Survey (ELP 2010). It is overlaid on the 1885 OS 1st Edition Six Inch Map, with peat diggings coloured blue.

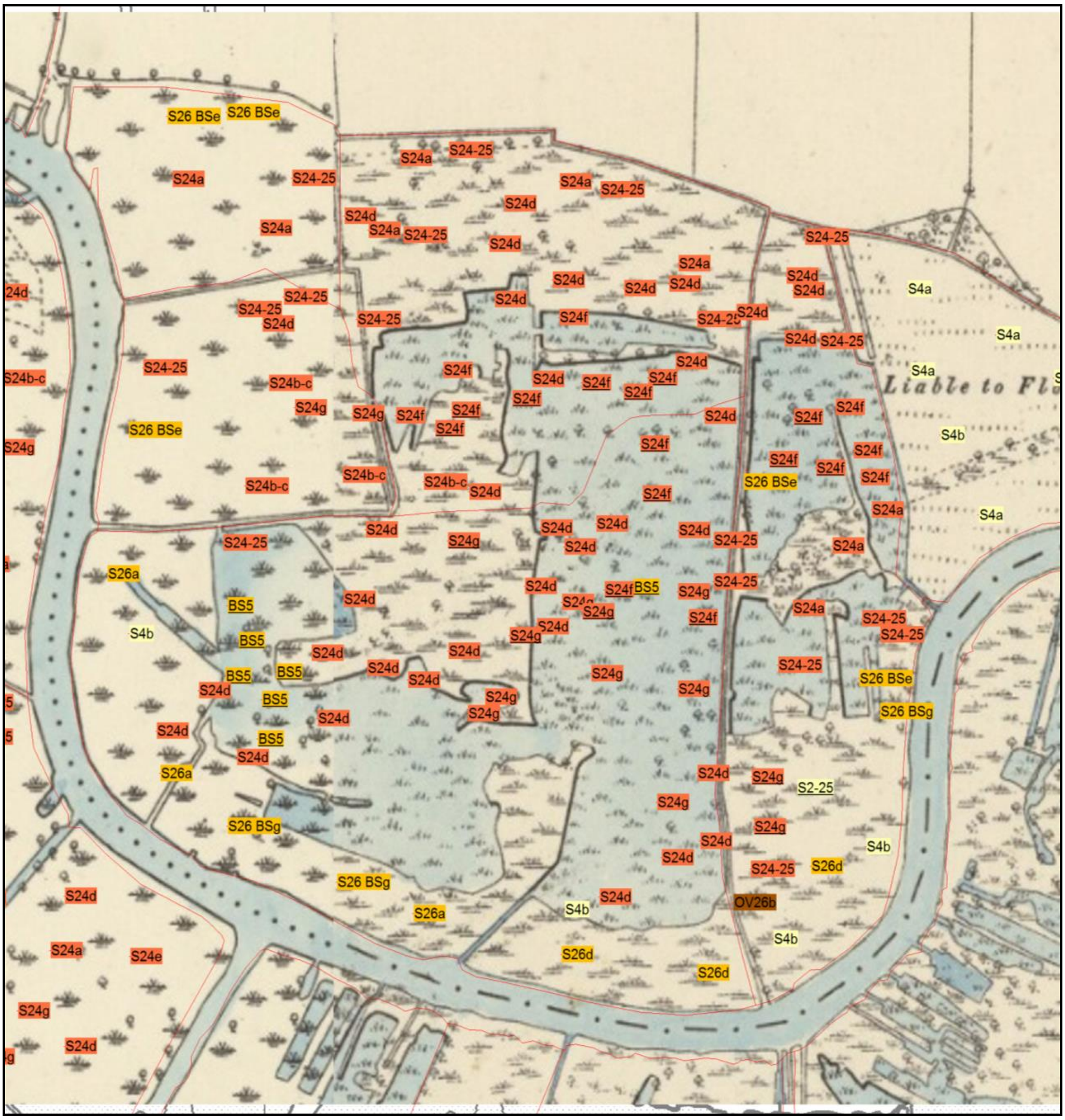


Table 1: Principle Plant Communities At Ebb And Flow, With Numbers Of Samples Located Inside And Outside Of 1885 Mapped Turbaries

NVC Community	No. samples		
	Turbary	Non-Turbary	Total
SAC Feature – *Cladium*-rich fen (also assigned to one of the below NVC types, mostly S24f and S24g).	13	6	19
SAC Feature - BS5 *Dryopteris cristata-Sphagnum* species fen	7	0	7
S24a *Phragmites australis-Peucedanum palustre* tall-herb fen, *Carex paniculata* sub-community	2	7	9
S24b-c *Phragmites australis-Peucedanum palustre* tall-herb fen, intermediate between (b) *Glyceria* and (c) *Symphytum officinale* sub-communities	0	4	4
S24d *Phragmites australis-Peucedanum palustre* tall-herb fen, Typical sub-community	19	17	36
S24f *Phragmites australis-Peucedanum palustre* tall-herb fen, *Schoenus nigricans* sub-community	17	2	19
S24g *Phragmites australis-Peucedanum palustre* tall-herb fen, *Myrica gale* sub-community	9	4	13
S26 *Phragmites australis-Urtica dioica* tall-herb fen, various sub-communities	0	14	14
S4 *Phragmites australis* reedswamp	1	9	10
Intermediate between S24 *Phragmites australis-Peucedanum palustre* fen S25 *Phragmites australis-Eupatorium cannabinum* fen (most records in turbaries are on the boundaries)	6	12	18

Aquatic habitats are poorly represented. The dyke network is modest and often occluded and overgrown. There is no data on aquatic plant communities. Within the fen, there are some shallow fen pools arising from scrub clearance, but these are of small extent and are likely to progress to dense fen rapidly. Nevertheless, they support a wide range of aquatics and semi-aquatics and a good proportion of the uncommon species described above. BA (2013) suggest Ebb and Flow is one of the best sites in the Bure for extent and diversity of bryophytes. None of the wet scrub qualifies as SAC feature floodplain woodland.

3.5.2 Plant Species Records

Historically, Parmenter (1994) has also documented an extensive list of uncommon to rare species recorded in the fen.

Pre-1796 *Drosera rotundifolia, Narthecium ossifragum, Parnassia palustris, Carex dioica, C. pulicaris, Potentilla palustris, Menyanthes trifoliata,*

Pre-1804/5 *Carex lasiocarpa, C. limosa, C. hostiana, C. diandra,*

1831	*Hypericum elodes, Drosera intermedia, Drosera anglica.*
1832	*Carex flava*
1836	*Dactylorhiza praetermissa*
1842	*Eriophorum latifolium*
1855	*Cirsium dissectum, Epipactis palustris, Stellaria palusttis, Osmunda regalis, Ophioglossum vulgatum, Vaccinium oxycoccus.*
1861	*Blysmus compressus, Carex rostrata, C. panicea, C. echinata*
1871	*Carex vesicaria.*
Pre-1887	*Utricularia minor*
1910	*Sphagnum imbricatum var affine, S. subsecundum*
1914	*Viola palustris, Carex curta*
1977	*Sphagnum flexuosum*

Parmenter (1994) records an area of "acid seepage fed mire or raised bog in the Horning area…" but could not trace the location. The range of plants listed above associated with acid conditions, together with the only locus for the BS5 *Sphagnum-Dryopteris* community in the Bure valley, suggests Ebb and Flow could be the former location for the acid mire.

3.6 Hydrological Data Including Water Chemistry

3.6.1 Water Levels

EA installed some water level monitoring data in the fen (see Figure 14 for location) including a gauge board on the main west-east dyke. Note that all equipment is south of any influence of the catch dyke. Data for the period January 2007 to March 2011 were available and are plotted on Figure 10. Mean water for the whole period are given in Table 2.

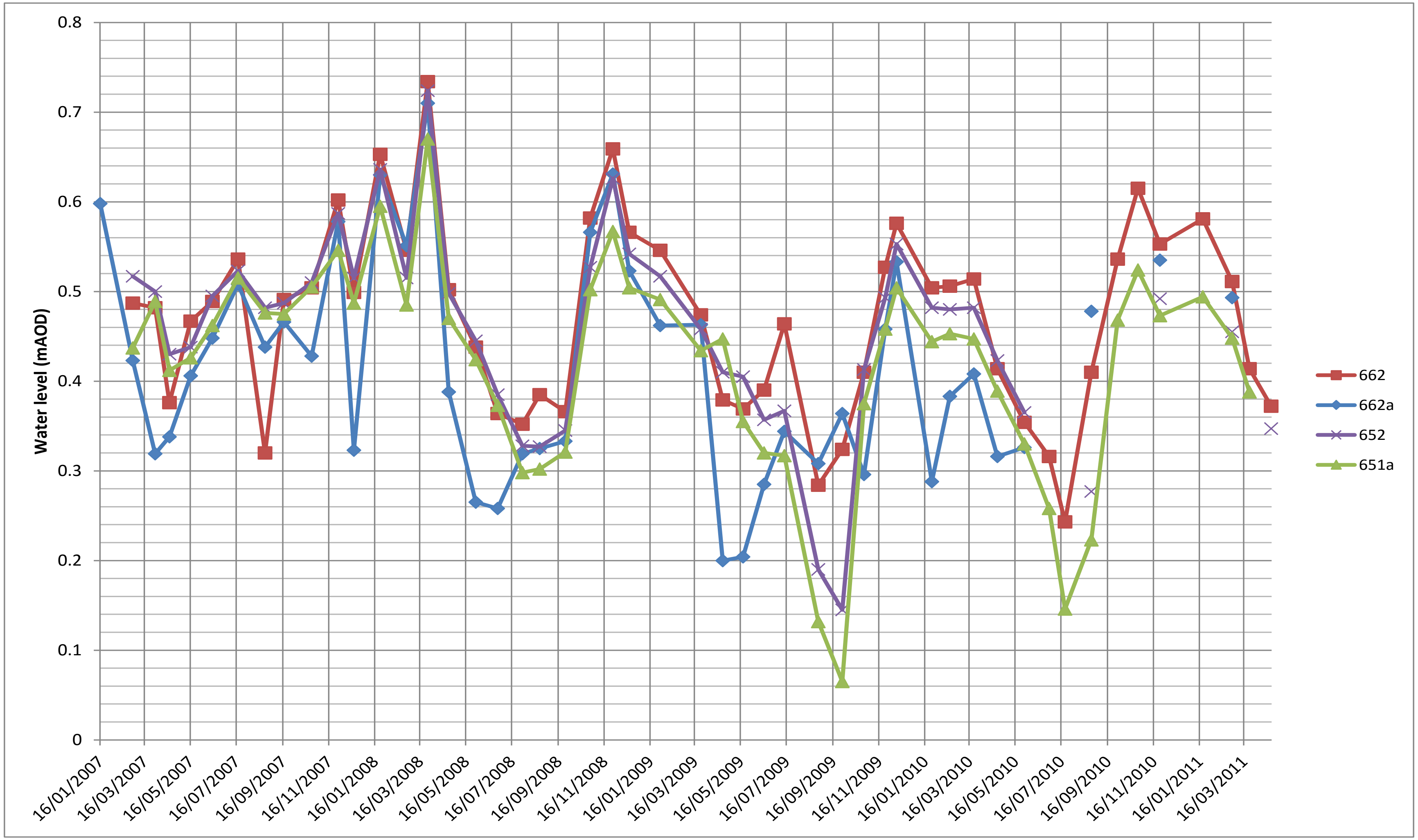
Table 2: Mean Water Levels in Dipwells and Gaugeboard

Recorder	Distance from dyke, m	Water level, mAOD		
		Mean Summer	Mean Winter	Mean Annual
Gauge board 662a	0	0.37	0.49	0.41
Dipwell 662	43	0.39	0.65	0.47
Dipwell 651a	67	0.32	0.49	0.42
Dipwell 652	110	0.35	0.52	0.45
Mean Dipwells		0.36	0.52	0.45

The data suggests:

- Mean fen water table (all three dipwells) is 0.45m AOD. This is consistent with observations made during fieldwork for this report. It is around or slightly above fen ground level, at least for the area north of the dipwells.

Figure 10. Water Level Data For the Gaugeboard (662a) and Three Fen Dipwells. See Figure 14 for locations. Data courtesy of EA.



- Mean summer water level in the fen is around 0.16m below mean winter level, a remarkably stable level. The summer level is around 10cm below average ground level but because of topographic heterogeneity, a wide range of water level heights relative to ground is provided for.
- Mean fen water levels in winter are above that of the dyke network, suggesting the dyke drains the fen. In summer, mean fen water levels are the same or slightly lower than the dyke, suggesting there may be some marginal movement of water from dyke to fen. This appears to keep pace with evapotranspiration.
- However, there is not the expected straight line relationship between water level and distance from the dyke. The middle dipwell has the lowest levels in both seasons, the dipwell nearest the dyke the highest. The range however is generally very small. Comparison with historic maps shows that the transect line crosses a turf pond boundary. Varying hydraulic properties of dug and undug peat *may* account for variability in water table levels.
- Maximum water levels (Figure 10) are around 0.5-0.55m AOD and minimum levels around 0.3m AOD. The higher water levels would leave the fen shallow flooded across the whole site. The lower level would be a little below average marsh surface, but still leave hollows with water.
- There are significant peaks and troughs but these are irregular in occurrence and not sustained.
- The fen dipwells appear to track the ditch water level, suggesting the ditch and river are the main control. All traces are generally quite closely bunched.
- Overall the water table appears rather flat across the site with damped, muted fluctuations.

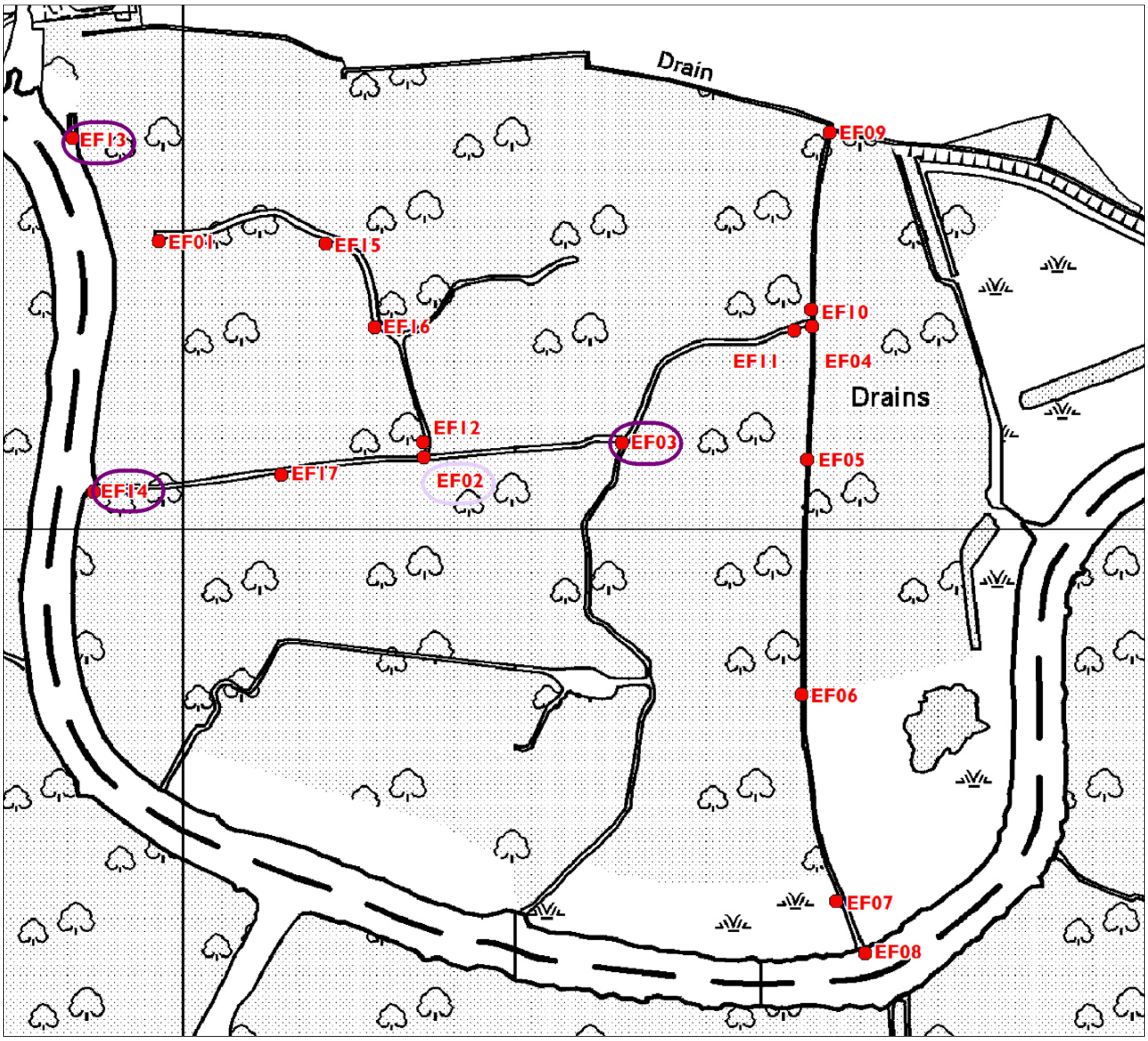
At Horning Marsh Farm, a similar fen area just upstream, water level monitoring data from ESW (2009) showed a strong positive correlation between river and marsh dyke water levels, and a close correlation between marsh ditch water levels and the groundwater table level in the peat. River level appears to control fen ditch and peat water tables, as at Ebb and Flow. Note however, ESW (2009) found the strength of correlation between ditch and peat water table levels diminished with distance from the dyke. It is not clear whether this is because (a) hydraulic conductivity in the peat changes in the compartment interiors because for instance an area of peat digging is encountered, or (b) peat hydraulic conductivity is sufficiently low to cause a distance decay effect to reduce exchange with dyke water or (c) the influence of evapotranspiration on groundwater tables overrides transmission of dyke water into the peat.

3.6.2 Water Quality

The only water quality data available is for salinity. The monitoring stations are shown in Figure 11.

EA recorded 23 salinity readings between January 2003 and April 2008, with inconsistent periodicity. The data do provide some overview across the marsh however. Figure 12 shows that mean readings throughout the dykes vary between 1000-2000 µScm[1].

Figure 11. Water Quality Monitoring Locations



The WFD standard (UK Gov 2015) for freshwater lakes with no natural saline influence is 1000 µScm[1]. Hence, salinity does not meet WFD standards, although the degree to which the saline surges can be viewed as a “natural influence” is debatable. Overall, salinity is likely to be adversely impacting dyke aquatic communities. The extent to which this affects the fen vegetation is not certain, although section 3.5.1 notes salinity-influenced vegetation around the river margin of the site.

Mean salinity in the river is no worse than in the marsh dykes (Figure 12). Locations with means approaching 2,000 µScm[1] (and therefore a concern) are EF01, EF07, EF016 and EF17, all internal dykes. The sampling station nearest to the catch dyke (EF09) has similar mean salinity as the Bure. There is no clear relationship between mean salinity and proximity to the river, and there is no clear spatial pattern in mean readings.

Figure 12: Salinity Readings at Ebb and Flow. Courtesy of EA.

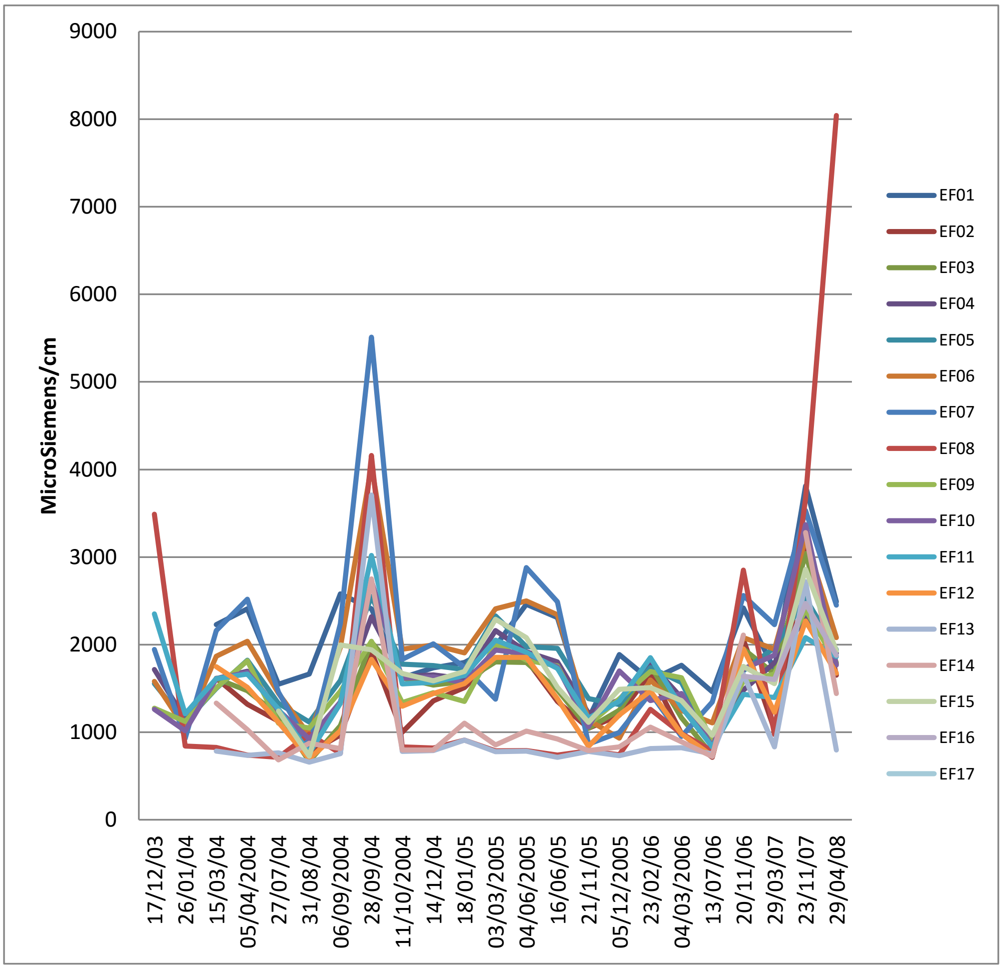
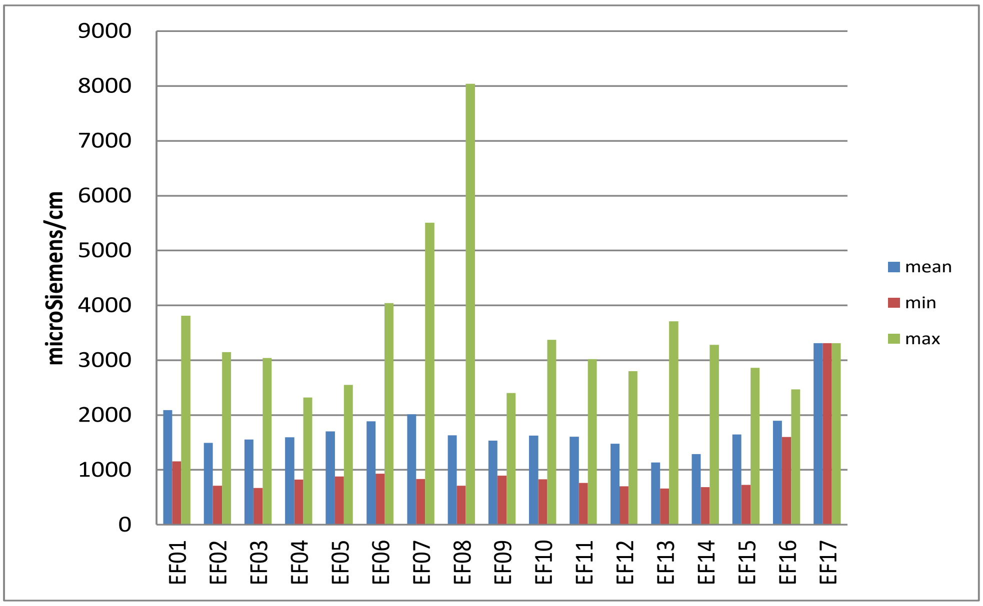


Figure 13. Mean, Maximum and Minimum Salinity Readings For All Stations. Courtesy EA.

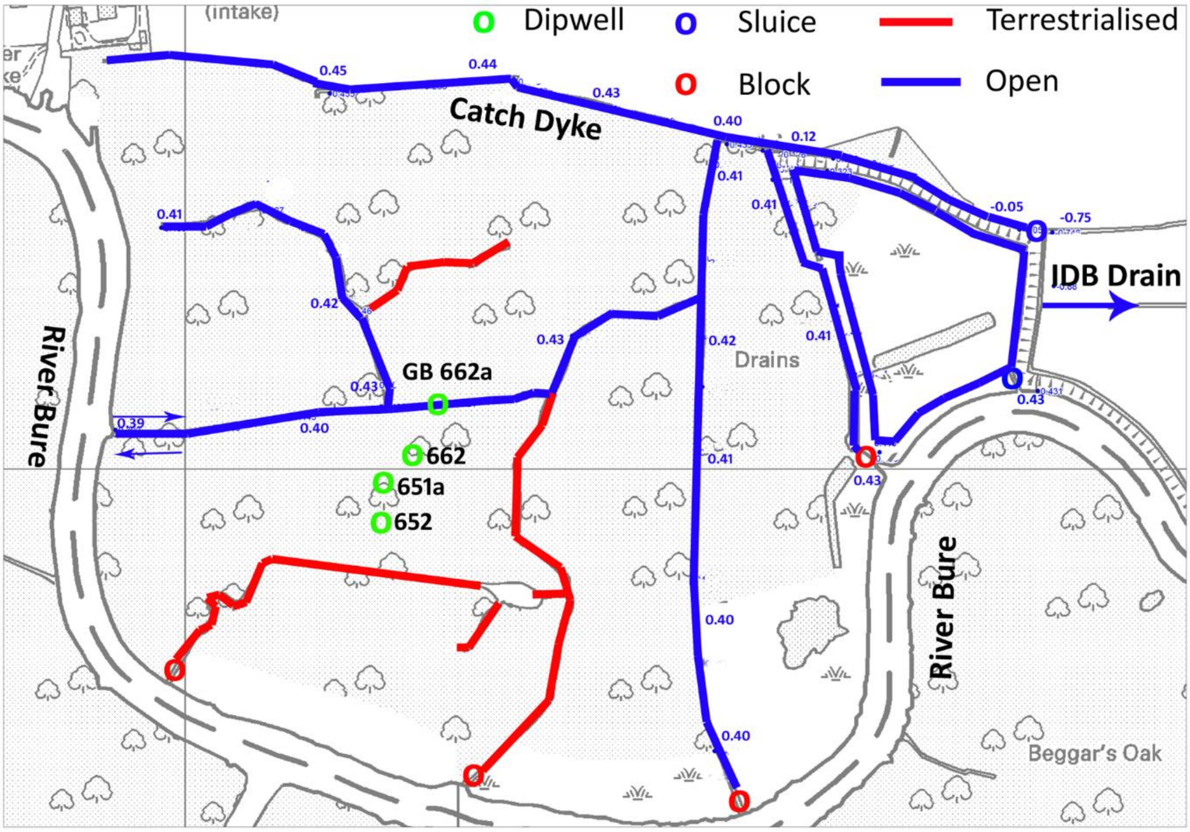


Peaks are more easily understood. The three biggest peaks in Figure 12 are the river at the south-east point (EF08) and the two sample points in the north-south dyke directly behind, especially EF07 but also EF06. These two internal stations record higher spikes than the sampling points on the Bure (EF13 and EF14). As salt water travels upstream from the east, the north-south dyke will receive the water first. Exposure will be more prolonged and more intense. The west-east dyke mouth is oriented to receive freshwater flowing down the Bure from the west, and to avoid salt water moving upstream. These data support NWT's decision to seal the north-south dyke from the river, leaving the west-east connection open to the river (Figure 14).

3.6.3 Surface Water Flows

Figure 14, derived from fieldwork and confirmed by published sources (AW 2006, ESW 2009, Entec 2005, NWT 2015) shows surface water flows at Ebb and Flow. The site is undrained and un-embanked, with no flood defences.

Figure 14: Dykes and Water Flows



Many of the dykes are terrestrialised and assumed to be non-functional, although some river water could ingress through loose dyke infill. The main extant dykes are closed to the river by bunds except the main west-east dyke which is open. The river is freshwater tidal, making comparisons of water levels taken over a day difficult. Water levels in the Bure were recorded at about 0.39m AOD at the east side and around 0.43m AOD at the west side. Levels in the fen dykes were 0.40-0.43m AOD confirming the close relationship between river and dyke.

Because there is only one point of free river connection, it might be assumed that sections of dyke more distant from the Bure connection have lower rates of river water penetration, although salinity data showed the river and dyke waters were well mixed. The open dyke network is not sufficient to circulate water around the whole site. Large areas remain isolated other than during significant river flooding events.

Compartment 58, the reedbed at the eastern edge of Ebb and Flow, is largely enclosed with a sluice controlling water levels, evacuating to the River Bure in the SE corner of the compartment.

The catch dyke is connected to the floodplain dyke system via the main north-south dyke, and then to the river. In autumn 2015, some sections of the catch dyke had no water or intermittent water. Recorded water levels were very irregular and those shown on Figure 14 are selected. The catch dyke has not been maintained for some time. Direct flow into the fen was only observed near to the main north-south dyke. Otherwise, the catch dyke flows west-east along the upland toe slope. The water levels are similar to floodplain dykes for most of the length but drop by around 0.3m along the margin of the reedbed compartment at the eastern end. This suggests that there is no culvert under the track at this point, or if there is, it is blocked.

At the eastern perimeter of the site, the catch dyke flows over a sluice or high level culvert (not visible at the time of survey) whose retention level is not known. Downstream of the sluice, the dyke becomes part of the pumped IDB drainage system. At the time of survey, the water above the sluice was minus 0.05m AOD, while below it was minus 0.75mAOD. The IDB pumped system discharges to the Ant via the Horning Grove Pump in the Horning Marshes (Harpley 1998). The Water Level Management Plan (Harpley 1998) did not describe further any water level management relevant to the site.

3.7 Site History and Management

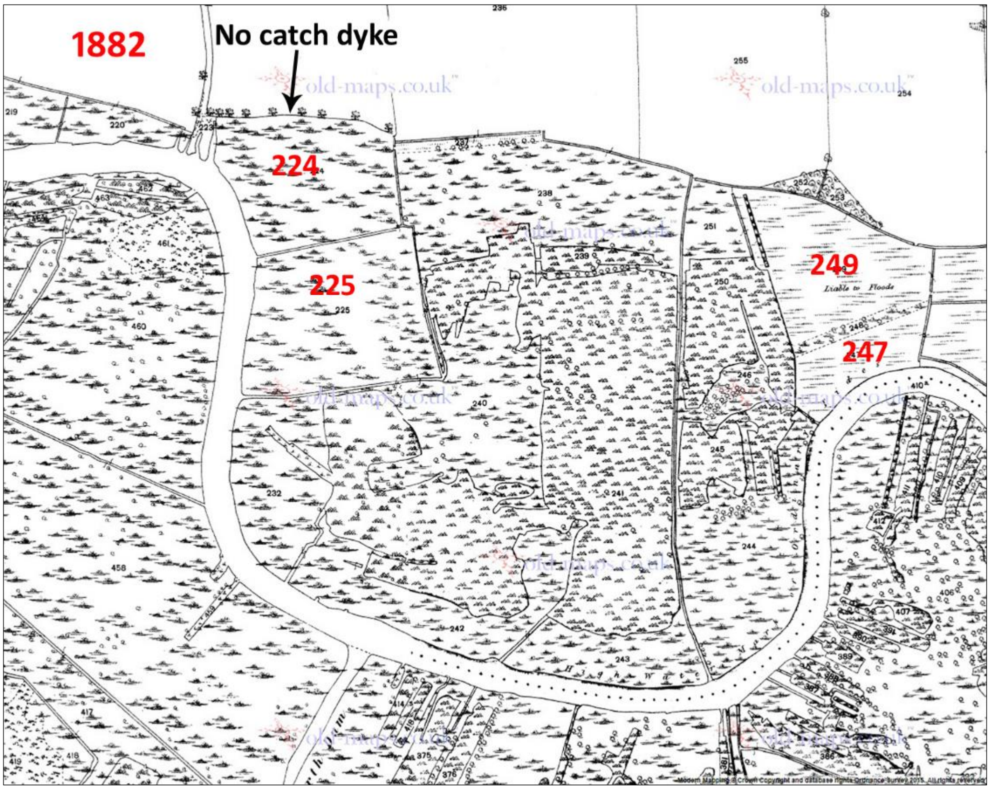
3.7.1 Historical Development

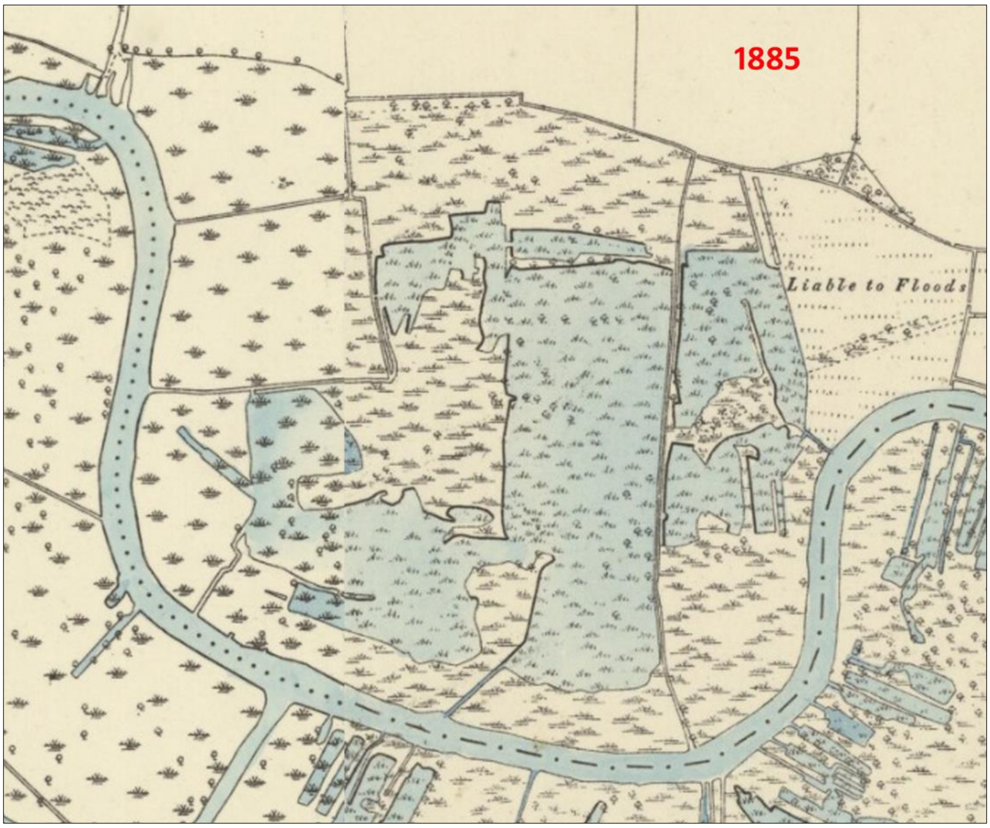
A series of historic maps are reproduced in Figure 15.

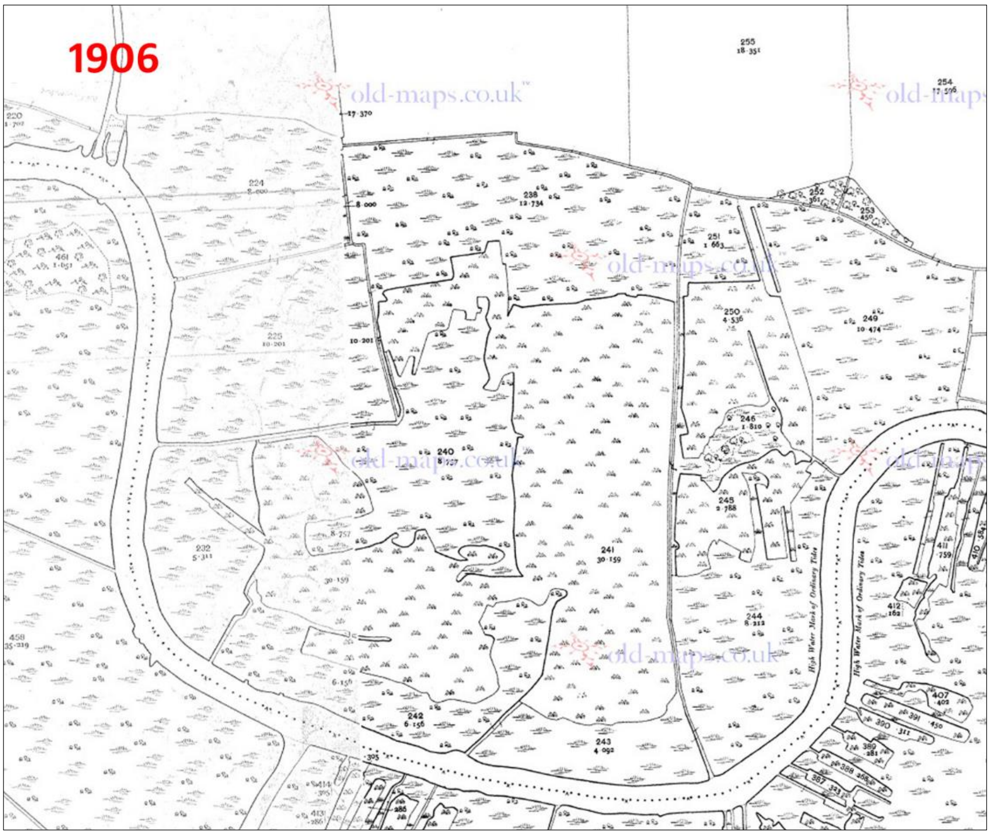
Fayden's Map of 1797 has little site detail but shows it as part of a fen area that continued westwards nearly to the village of Horning. The strip of fen connecting Ebb and Flow to the adjacent fen was very narrow.

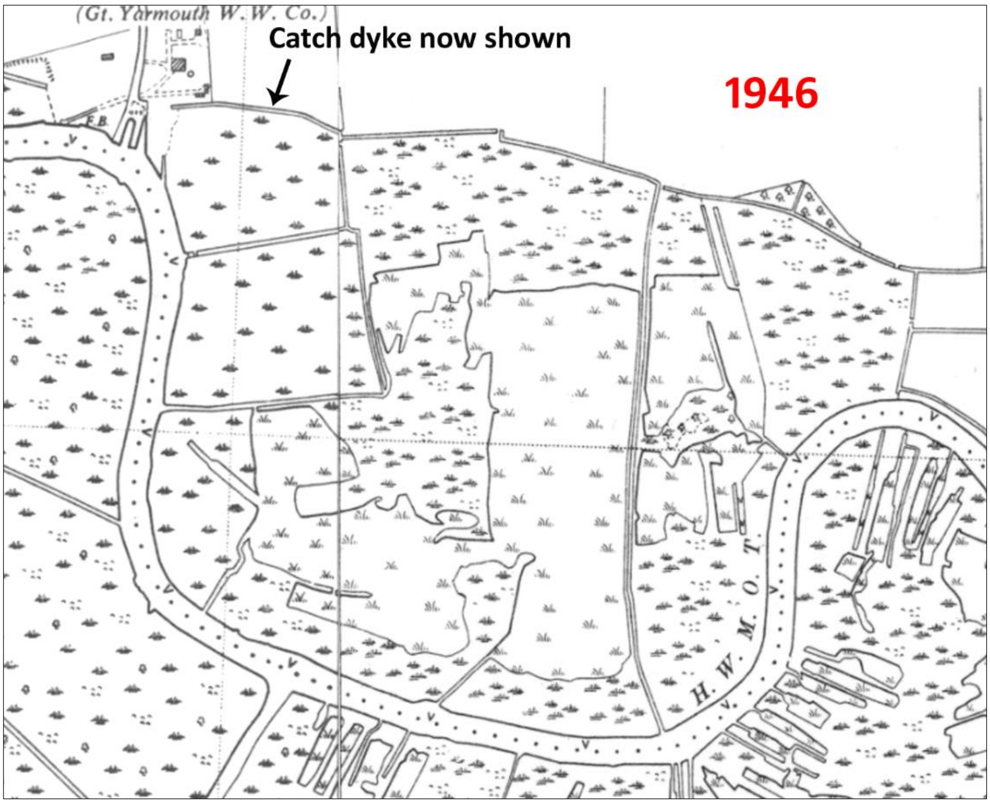
Parmenter (1994) records that the 1812 OS 1st Edition one inch map shows the site as open fen with no peat diggings. The Tithe map of c.1840 gives no indication of peat cutting in the area.

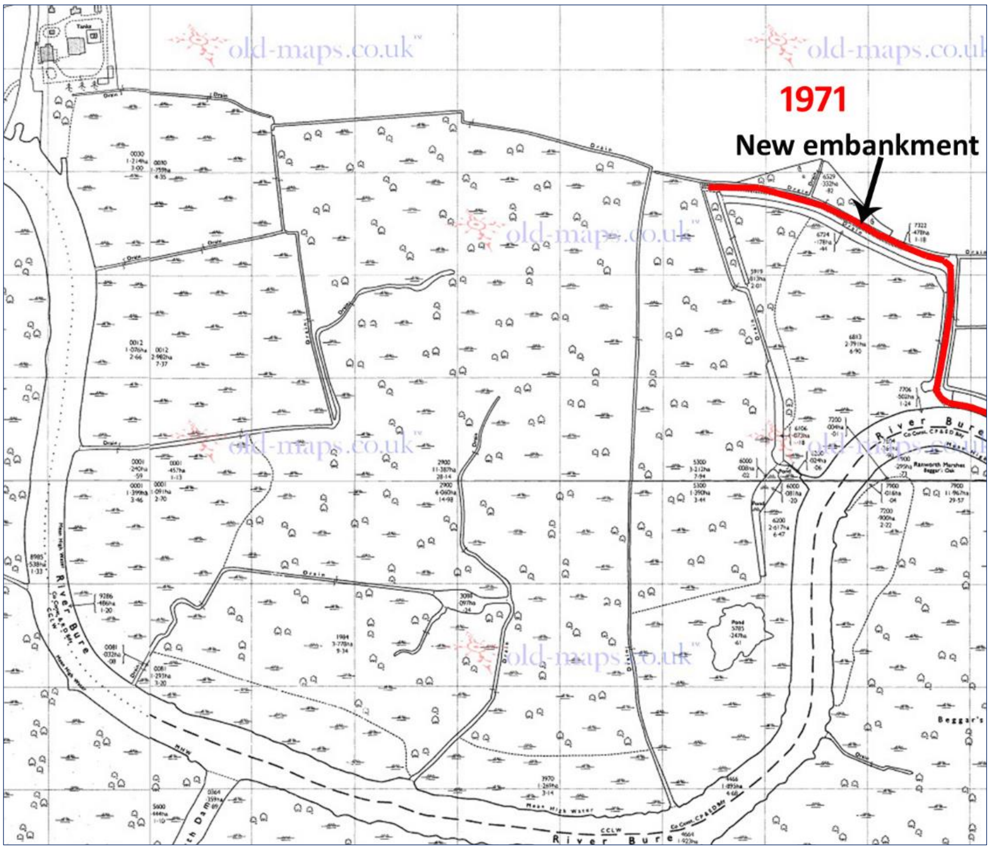
Figure 15. Ebb and Flow Historic Maps. See text for sources.



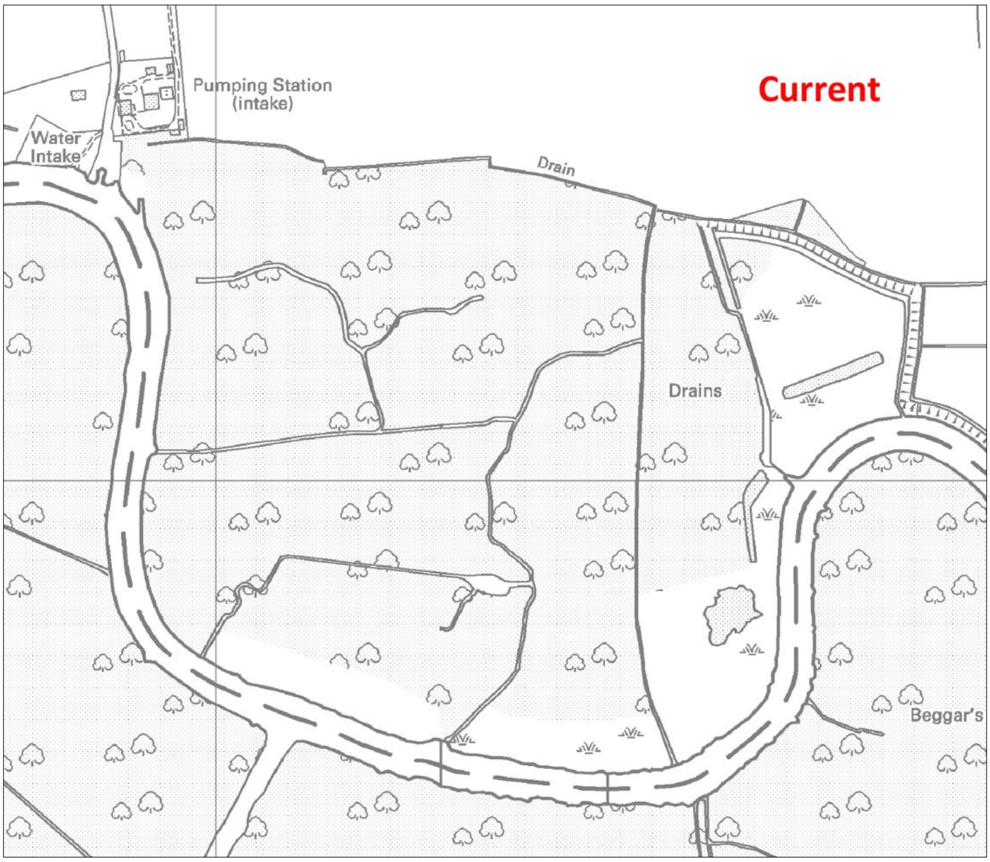



1906
old-maps.co.uk


(Gt. Yarmouth W.W. Co.)
Catch dyke now shown
1946



1971
New embankment
old-maps.co.uk
River Bure
Beggar's



Current
Pumping Station
(intake)
Water
Intake
Drain
Drains
Beggar's

On the 1882 OS 1st edition six inch map[2] , the catch dyke line is similar to that of 2015, although the dyke does not extend along the northern margin of the western-most marsh. The only other dykes on the marsh are the main north-south dyke from the highland to the river, and the dykes which provide boundaries to OS Fields 224 and 225 (see Figure 15) in the north east. These may have been used for rough grazing. OS Fields 247 and 249 (the reedbed) have a different mapping symbol consistent with fields further east, and the legend "liable to flood", indicating their lower topographic level and different wetland nature, even then. Close inspection of the map indicates a range of sub-compartments across the site with highly irregular boundaries which are not dykes and presumably are peat cuttings.

The 1885 map[3] has the same general confirmation and looks to be based on the same base map as 1882. Some tinting of the map suggests water bodies which conform to the irregular boundaries of those on the 1882 map, and must surely be terrestrialising former peat cuttings. Parmenter suggests these were dug between 1840 and 1885. The map shows small ditches cut from the excavations southwards to the river, presumably originally for drainage but perhaps acting to re-flood the cuttings.

The 1906 OS Second Edition six inch map[4] still shows the presumed turbaries, now more clearly delineated but without tinting. They are mapped with a different symbol suggesting a different vegetation type. Little else has changed. The eastern reedbed area are still mapped with different symbols, again suggesting a different wetland type, but the fields further east outside of the site are now shown plain white and presumably improved, although there is no embankment between. The 1946 map[5] again shows the turbaries (still showing a different mapping symbol) but with little further change, other than the extension of the catch dyke westwards.

By 1971 (OS Plan 1:2,500), the old diggings were no longer mapped. The dyke system has significant new additions in the south of the compartment. They trace the line of the dykes that connected the turbaries to the river and trace parts of the perimeter of the excavations. The dykes around the two western marshes remain, with a small irregular extension east which marks the northern edge of a small turbary. The eastern-most reedbed compartment has a new dyke along its west margin separating it from the rest of Ebb and Flow. An embankment has been built along the east margin, separating Ebb and Flow from the marshes to the east. The embankment with a borrow dyke runs along the north margin below the catch dyke. This section is not maintained but the north-south embankment is now a major floodbank. Construction of this embankment prior to 1971 provided for the drainage of the marshes to the east in what was presumably a major capital scheme leading to the installation of the pump in the Horning Marshes.

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2 OS County Series: Norfolk sheets. 1882. 1:2500

3 OS Six-Inch England and Wales. Norfolk LIII.SW and LII SE, 1885

4 OS County Series: Norfolk sheets LIII.SW and LII SE, 1907 (second edition). 1:2500

5 OS County Series: Norfolk sheets LIII.SW and LII SE, revised 1946, Published 1950, 1:2500

The current OS maps shows the familiar dyke network with the boundary ditches around the north-western marshes now reduced and their lines more irregular. These and the southern dykes have been connected to the main north-south drain. The drainage map (Figure 14) shows that much of the mapped dyke network has become terrestrialised. It also shows NWT have blocked most of the exits to the River Bure.

3.7.2 Site Management

Norfolk Wildlife Trust acquired their site in 1997. Prior to this there was occasional commercial sedge and reed harvest. The Broads Authority undertook scrub clearance and dyke work, but areas worked on are not known.

Major restoration scrub clearance was undertaken in 2002/3. This created pools and early successional habitat.

Reed is harvested on a two year rotation in the eastern compartment and on a 5-10 year rotation elsewhere on the site. Sedge continues to be cut on a 3-4 year rotation in the central areas. Restoration mowing was undertaken in 2012. Ditch sides are managed on a 2-year rotation.

Grazing was introduced in 2003 following restoration works. Current grazing is undertaken in the northern compartments, where the catch dyke fence was renewed in 2015. In 2014, 95 grazing days June-August were completed with 11 Dexters and 4 ponies. The ponies were not used in 2015 because of concerns from NE about their impact. The current Management Plan (NWT 2015) proposes extending grazing to all of the northern part of the site.

Ditches were cleared out in 2006 with a light slubbing (40cm) in 2013. Five new culverts were installed at that time.

3.8 Natural England's Conservation Objectives

3.8.1 Conservation Objectives

The Conservation Objectives are stated by Natural England as:

> The Conservation Objectives for this site are, subject to natural change, to maintain the following habitats and geological features in favourable condition (or restored to favourable condition if features are judged to be unfavourable), with particular reference to any dependent component special interest features (habitats, vegetation types, species, species assemblages etc.) for which the land is designated (SSSI, SAC, SPA, Ramsar) as individually listed in Table 3." NE (2008).

3.8.2 Designated Features

Natural England have assessed the SSSI and Natura 2000 features present on Ebb and Flow (Table 3). Not all of the species in the plant assemblages are known on the site – some relate

Table 3. SSSI and Natura 2000 site features at Ebb and Flow. Courtesy Natural England.

BAP Broad Habitat Type	**Specific designated features**	**Explanatory description of the feature for clarification**	**SSSI designated interest features**	**SAC designated interest features**	**SPA bird populations dependency on specific habitats**			**Ramsar criteria applicable to specific habitats**			
					Annex 1 species	**Migratory species**	**Waterfowl assemblage**	**1a Wetland characteristics**	**2a Hosting rare species &c**	**3a 20000 waterfowl**	**3c 1% of population**
Standing Open Water and Canals	**SSSI -** Lowland ditch systems **SAC -** Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation	Freshwater ditch systems	*	*				*			
	Lutra lutra	Otter		*					*		
	Vascular Plant Assemblage: *Myriophyllum verticillatum* *Najas marina* *Potamogeton coloratus* *Potamogeton friesii* *Stratiotes aloides*	Plant assemblage: Whorled water-milfoil Holly-leaved naiad Fen pondweed Flat-stalked pondweed Water soldier	*						*		
Fen, Marsh and Swamp	**SSSI -** S2 *Cladium mariscus* swamp	Swamp and sedge-beds	*								
	SSSI - S24 *Phragmites australis Peucedanum palustris* tall-herb fen **SAC -** Calcareous fens with *Cladium mariscus* and species of the *Carex davallianae*	Tall-herb fen	*	*				*			

BAP Broad Habitat Type	Specific designated features	Explanatory description of the feature for clarification	SSSI designated interest features	SAC designated interest features	SPA bird populations dependency on specific habitats			Ramsar criteria applicable to specific habitats			
					Annex 1 species	Migratory species	Waterfowl assemblage	1a Wetland characteristics	2a Hosting rare species &c	3a 20000 waterfowl	3c 1% of population
	Vertigo moulinsiana	Desmoulin's whorl snail		*					*		
	Botaurus stellaris	Bittern			*						
	Circus aeruginosus	Marsh Harrier			*						
	Lowland open waters and their margins assemblage	Assemblage of breeding birds	*								
	Vascular Plant assemblage: *Carex appropinquata* *Cicuta virosa* *Dactyloriza traunsteineri* *Dryopteris cristata* *Lathyrus palustris* *Peucedanum palustre* *Sonchus palustris* *Sium latifolium* *Thelypteris palustris*	Plant assemblage: Fibrous tussock-sedge Cowbane Narrow-leaved marsh orchid Crested buckler fern Marsh pea Milk parsley Marsh sow-thistle Great water parsnip Marsh fern	*						*		
	Invertebrate assemblage (see Criteria Sheet for list of species) Broad Assemblage Type: W31 permanent wet mire Specific Assemblage Type**:** W313 mesotrophic fen and W314 rich fen	Invertebrate assemblage Fenland	*						*		

to the broader Bure Broads and Marshes SSSI. Conversely, some important features now known to occupy the site are missing from the table – in particular, the B5 *Sphagnum spp-Dryopteris cristata* transition fen, which would now qualify as an SAC and SSSI feature. NE are currently reviewing features for sites (Adrian Gardiner, *pers comm*) so the table will evolve.

All of the identified features would benefit from catch dyke restoration either through improved water balance, improved water quality or development of seepage and transition habitats. In-fill of the catch dyke should not be damaging to the SSSI features as the catch dyke does not support any of the aquatic communities or plants listed.

NE (2008) provides very detailed information qualifying conservation objectives for each feature (e.g. relating to extent of the feature) and also the parameters which define favourable condition for each feature.

3.8.3 Site Condition Assessment and Related Issues

The site is Unit 5 of the Bure Broads and Marshes SSSI. The Condition Assessment history is as follows:

1998	Unfavourable - Recovering
2000	Unfavourable - Recovering
2010	Favourable
2015	Favourable

BA (2013) report that 81% of the plots recorded were in favourable condition. Key findings of the report in terms of management are:

- Much of the site is in good condition having benefitted from recent scrub clearance, mowing and grazing.
- The role of the catch dyke in removing groundwater is not understood and is a concern. Although structural diversity at the macro-scale (i.e. between relatively large patches) is diverse, the patches themselves tend to be relatively even-structured.
- There is an absence of mire and fen meadow communities.
- There are still extensive stands of dry, undermanaged and species poor fen representing latter stages of the fen succession, and significant areas of accumulating fen scrub and woodland.
- There is a paucity of aquatic habitats and the early successional and wet fen stages are under-represented.
- Overall, the site still leans towards the later stages of the fen succession.

3.9 Existing Vegetation and Hydrological Monitoring

There is currently no fixed plot monitoring on Ebb and Flow. The Broads Authority started *Cladium* monitoring to assess potential impacts of grazing in 2003, but this was not continued (NWT pers comm). Hydrological monitoring is restricted to EA dipwells as part of the review of consents process.

3.10 Conceptual Eco-hydrological Model of Current Functioning

3.10.1 Overview

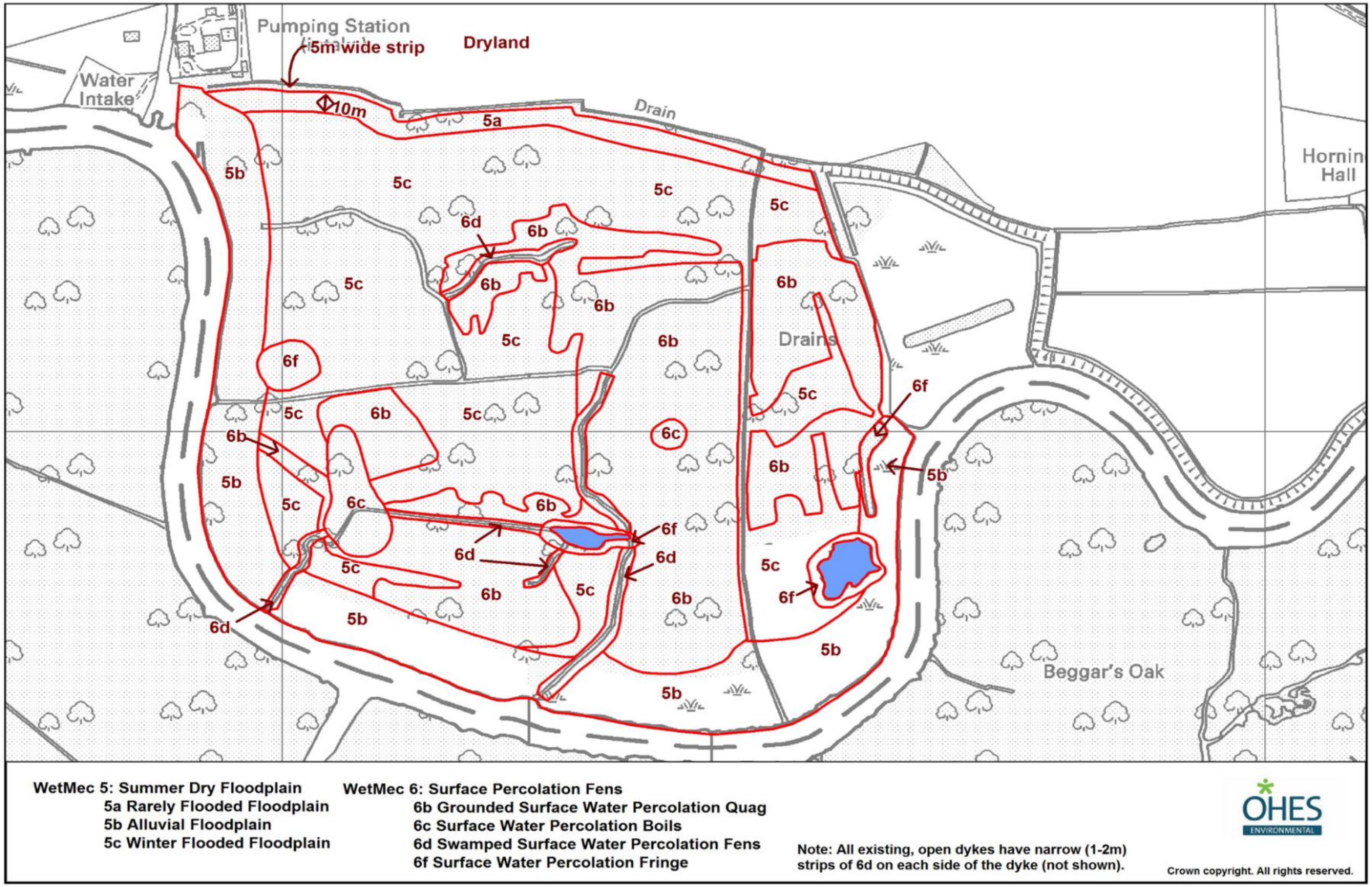
Figure 16 summarises the probable arrangement of eco-hydrology of the site, adopting the Wetland Mechanism (WetMec) framework developed by Wheeler et al (2009). Boundaries between WetMec types are diffuse and are tentative on the diagrams.

The main fen area is a complex of the various sub-types of the two classic Broadland floodplain ecohydrologies. Both are topogenous, supplied by rainfall and river/dyke water and without substantive groundwater inputs:

> **WetMec 5, Summer-Dry Floodplains**: Floodplain fens on solid, generally humified peats with relatively low hydraulic conductivity, such that water distributed by dykes does not penetrate far into fen compartments. Consequently, summer water tables can decline in response to evapotranspiration. These declines are mitigated by rainfall, but not groundwater or dyke water. Water levels in summer are therefore quite low. They are usually on uncut peat surfaces.
>
> **WetMec 6, Surface Water Percolation Floodplains**. Floodplain fens where the upper peat layers are open and loose, probably of more recent origin and usually associated with recent in-fill of old turbaries. This transmissive peat allows fen water tables to be readily recharged from the dyke network, maintaining high water tables during summer. For the mechanism to operate there must be free contact with river/dyke margins, with no barriers of low transmissivity peat such as undug baulks or compacted access tracks. It is possible that this kind of eco-hydrology can develop where whole sites have become wetter and the whole surface is growing upwards with fresh peat. The depth of loose surface peat required to foster lateral flow is uncertain, but the layer must be thick enough to make substantive contact with summer dyke water levels. Although the stratigraphy section above notes just such a layer in the sampled peat cores, it is likely to be too thin to accommodate this WetMec.
>
> True hover, a fen floating fen surface wholly detached from the underlying substrate, was not encountered at Ebb and Flow. Many areas were spongy and unstable but were not hover. However, southern areas were not investigated as part of this study, where true hover (WetMec 6e Wet Surface Water Percolation Quag) may occur.

Apportioning different areas of the fen between the two WetMecs is difficult because stratigraphical evidence is restricted geographically to a small number of cores, and peat water tables are known only for the area around the three EA dipwells. Consequently, the approach taken is to map areas known to be old turbaries, or where significant depth of loose peat was recorded, as WetMec 6, and to assign remaining areas to WetMec 5. Further coring could assist better definition of the map.

Figure 16. WetMec Zones At Ebb and Flow, Likely Existing Condition



3.10.2 Components of the WetMec Model

Dryland Edge

The toe slope and the immediate downslope flank of the catch dyke is non-wetland. The drainage effect of the catch dyke has reduced water tables along the fen margin. The dryland edge has no WetMec type. The zone on the fen side is often covered in scrub, quite often with *Quercus robur*.

WetMec 5: Summer Dry Floodplain

WetMec 5a: Rarely Flooded Floodplain: The extent of flooding from the Bure depends on topography. The margins of the site, which are still on the toe slope, are inundated only in the highest flood. The peat is recharged less often and this zone is therefore dryer, providing a transition to wetter WetMec types. Fieldwork suggests that the water table comes close to the surface relatively rapidly as the toe-slope declines to mean floodplain level, so this zone is narrow. It is wider at the east end, around 20m, narrowing to 10m by the centre. Its vegetation is transitional, rather dry fen communities, relatively species poor and often dominated by reed, *Carex acutiformis* and *Calamagrostis canescens*.

WetMec 5b: ***Alluvial Floodplain***. This WetMec is characterised by alluvial deposition where river flooding is most frequent and intense. Silt, along with immersion in more eutrophic (and in this case, occasionally saline) waters, raises fertility in the substratum. The band of eutrophic, slightly saline and species-poor fen vegetation around the river margin is good evidence for this WetMec.

WetMec 5c: ***Winter Flooded Floodplain***: This type encompasses undug peat that shallow-floods in winter (Table 2 indicates 10-15cm above mean marsh level). It is sufficiently far from the river margin to be out of the 5b Alluvial Floodplain zone, and sufficiently low in surface elevation not to be 5a Rarely Flooded Floodplain. It is characterised by wet, mixed tall herb fen of S24, but generally the less species rich stands.

The areas at Ebb and Flow probably have higher summer water levels than typical for the WetMec (Wheeler et al 2009). Areas that have thin surface transmissive peat may be transitional to WetMec 6a Solid Surface Water Percolation Fens, which typically has a mean summer water table 12.3cm below ground (Wheeler et al 2009).

WetMec 6: Surface Water Percolation Fens

WetMec 6b: Grounded Surface Water Percolation Quag: Where a loose and transmissive peat infill of turf ponds has become grounded on the uncut underlying surfaces, and does not form a hovering, buoyant mat during the summer, it falls within WetMec 6b. This is the characteristic eco-hydrology for the majority of the old turf ponds at Ebb and Flow. Water tables are supported by lateral flow through the substantive transmissive peats, although bands of undug or compressed peat could interrupt this flow. In winter, complete saturation of the peat mass may cause inflation of the peat surface and apparent sponginess under foot. This is not true buoyancy and should not be confused with true “hover”. However, an expanding peat mass greatly increases water storage and buffers the fen vegetation against evapotranspiration losses, maintaining wet fen conditions. Summer water levels recorded by the piezometers, c.10cm below ground, are higher than typical for this WetMec which Wheeler et al (2009) record as 18.2cm bgl.

This is a preliminary classification. Areas to the south which were not explored in detail during this investigation may contain true hover and then be assigned to WetMec 6e Wet Surface Water Percolation Quag.

WetMec 6c: Surface Water Percolation "Boils". These are quite localised areas of fen over loose infill of old peat diggings, which have buoyancy and/or the vegetation surface has grown above the surrounding peat surface through, most typically, growth by *Sphagnum*. These raised "boils" host the transitional acid mire (BS5 *Sphagnum-Dryopteris* community). Their elevation prevents flooding by base-rich and mesotrophic surface water. Such areas may expand through upward and outward growth of the *Sphagnum* carpet and hence they can be a later successional phase to the base-rich fens. They may then develop to true ombrotrophic fen and bog habitats.

WetMec 6d: Swamped Surface Water Percolation Fens. These are past surfaces that have become significantly wetted by a change in management that has flooded (or "swamped") the ground surface. At Ebb and Flow these conditions have been promoted by dereliction of the dyke network which has flooded and then infilled with fen vegetation. The fen is "swamped" and often characterised by swamp species. These features are too shallow to maintain open water (true aquatic) conditions. Instead they have developed very wet fen types that can be buoyant and/or treacherous to walk on. At Ebb and Flow, WetMec 6d forms narrow corridors through other WetMecs. Because they occupy much of the dyke network with loose transmissive infill, they may provide important water supply mechanisms, transmitting river and dyke water around the site, albeit slowly.

The aerial photographs show many small linear features that have not been mapped as dykes. They may be old terrestrialised footdrains associated with past fen management or peat digging. A proportion of these may also be swamped and hence form a denser network across the fen than the WetMec map implies.

WetMec 6f: Surface Water Percolation Water Fringe: This WetMec occupies the fringe of larger water bodies. It has a high water table and is often dominated by swamp species. There is a topographically mediated transition to the adjacent WetMec type. This WetMec has clear similarities between this and the previous WetMec. While the origin and development of the stand, and the operating water supply mechanism, may differ between the two, the resulting swamp vegetation may be very similar. It is not extensive on the site. There is a broad fringe of this WetMec around the larger pools shown on the maps. There may also be very narrow strips of WetMec 6f along open dykes if the margin has a shallow profile.

4. STAGE 2 : DEFINING THE PROBLEM

4.1 Catch Dyke Characteristics

Using the data and assessment tables in the pilot catch dykes study (OHES 2014), this dyke is a **Type 1**: **Groundwater Dykes With Significant Direct Drainage.**

It is atypical as the dyke is essentially derelict (Type 7 Redundant or Derelict Dykes), and is connected to floodplain dykes whose level is controlled by the Bure. It is also sluiced at the eastern end (suggesting Type 2 Groundwater Dykes With Minimal Direct Drainage). However, the low-level IDB dyke, part of a pumped system downstream of the sluice, is a controlling influence on the dyke and the shallow ground water table. The sluice is not effective in maintaining groundwater levels. Hence, when considering the broad grouping of characteristics associated with the seven types described in Table 3 of OHES (2014), the dyke best fits into Type 1.

4.2 Catch Dyke Risk Assessment

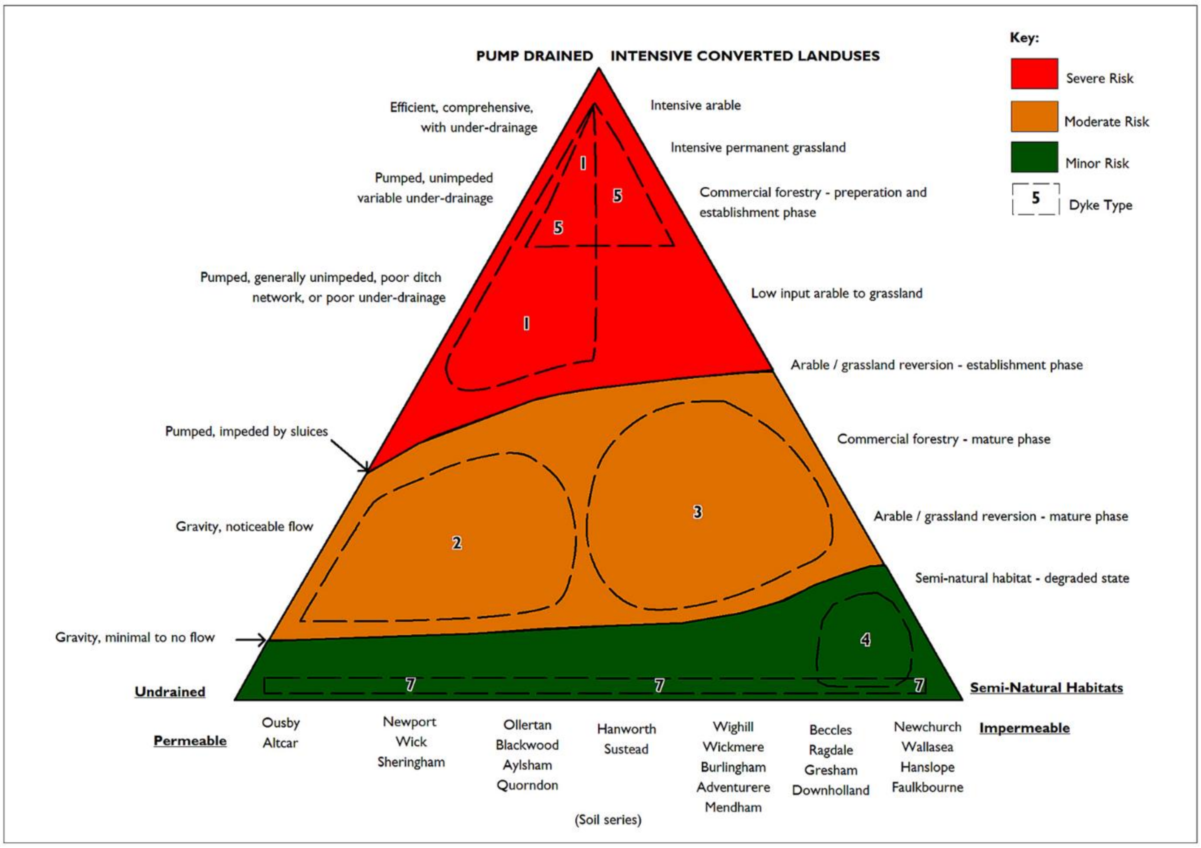
Type 1: Groundwater Dykes With Significant Direct Drainage are rated by OHES (2014) as **Severe Risk of Impact**. The following summary of this risk category is provided:

> "Because of the context, they are likely to be in locations where groundwater plays a significant role in water budgets and water quality in the floodplain. The adjacent floodplain may also be the locus of wetland types most closely associated with low nutrient conditions, with characteristic natural chemistries vulnerable to disruption. Because of their direct drainage, they are likely to severely interrupt groundwater movements and also to directly draw down water tables. Because of the permeability of the catchment they are likely to be significant vectors for upland pollutants."

The current report confirms that this characterisation is accurate for the Ebb and Flow catch dyke. The wetland may potentially receive agro-chemicals from the arable land on the permeable fields to the north.

In terms of the Risk Triangle presented in OHES (2014) (Figure 17), the area occupied by Type 1 is located in the red **Severe Risk** zone.

Figure 17: Risk Triangle. Type 1 Dykes are in the Severe Risk Zone.



4.3 Likely Impacts of Catch Dykes on Habitat Features

4.3.1 Mechanisms

The following uses information on potential impacts summarised in Table 2 of OHES (2014) to identify broad impacts:

Change of ground water quality. Groundwater affected by the catch dykes arises from Drift deposits and possibly Crag. NSRI (2014) indicates Drift water would be low nutrient under natural conditions, supporting acid to neutral grassland and woodland. The Crag would supply a calcareous and base-rich element. The net effect is difficult to determine, because the precise contribution of each is not known. Being soligenous water flushing down and through the surface soils, it is likely to have high redox. These characteristics have been altered by the catch dyke, such that the margin of the fen is dependent on rainwater, with a potential supply of river water via the dykes and through the peat. The hydrology is no longer soligenous but topogenous, and is likely to have less favourable redox conditions. Clearly the presence of the catch dyke has had significant impact on the fen soil water quality. The exact shift in chemical composition is, however, impossible to define with precision.

Depletion of Water Balance. The drainage of groundwater depletes the water balance. The wetland will experience lower groundwater levels (especially at the highland margin) and will be less buffered against drought stress. Soil moisture deficits will increase within fen compartments in terms of degree and duration.

Direct Draw Down of Water Table. This effect has been demonstrated and quantified in the stratigraphy survey. The degree of impact seems to depend on the proximity of the aquaclude to the catch dyke. At the west end where the alluvium is more distant, impacts of the catch dyke extend to 25m downslope. In the centre and east sections this reduces to 10-15m as the aquaclude moves landward.

Generation of Nutrients: The land upslope of the catch dyke has a long history of arable and is likely to remain so. The crops are managed conventionally and are therefore fertilised with mineral fertilisers. Because of the coarse loams, high permeability and ready drainage downslope, nutrients not absorbed by the crop are likely to be routed into the floodplain. All of the plant communities of high conservation value are damaged by eutrophication of the peat. Delivery of agro-chemical nutrients is therefore an issue for the site.

Truncation of the Wetland to Dryland Transition at the valley margin: the cutting of any catch dyke facilitates land use change up slope, drawing a line in the landscape, upslope of which semi-natural habitats rarely survive. Hence the full wetland to dryland transition at the valley margin is extremely rare in the Broads. At Ebb and Flow, what was a gradual topographically determined gradation to dryland habitats has been comprehensively transformed and is now arable.

4.3.2 Impacts on WetMec

Figures 16 and 18 compare the arrangement of WetMec types existing now with WetMecs which may exist without the catch dyke. Comparison of the two shows that the catch dyke is likely to have transformed the eco-hydrology of the site. It may have removed entirely WetMec 10b Permanent Diffuse Seepage Slopes and the associated WetMec 17a/b Strongly/Weakly Groundwater Flushed Slopes. Impacts may only cease when WetMec types determined by river and ditch become dominant.

5. STAGE 3: DEVELOP SOLUTIONS

5.1 Eco-hydrological Model With a Remediated Catch Dyke

Possible eco-hydrological functioning were the catch dyke to be restored is shown in plan form and cross section on Figures 18 and 19 respectively. Because of the aquaclude and the controlling influence of surface water on the fen water table, change to current functioning is likely to be limited to the first 50-75m downslope of the catch dyke, and certainly by the first functioning west-east dykes. Note that with the current data the projections are somewhat speculative.

The new arrangements assume that the west to east groundwater flow to the IDB pump drained level is stopped, presumably by the construction of a sub-surface barrier across the toe slope.

If so, natural re-establishment of the groundwater from upland to floodplain is likely to occur. If so, the toe slope would be substantially wetted up. Because of the topographical slope, the aquaclude underlying the peat and the lack of alternative pathways, groundwater would be forced to the surface around the catch dyke location, creating a seepage zone all along the valley margin.

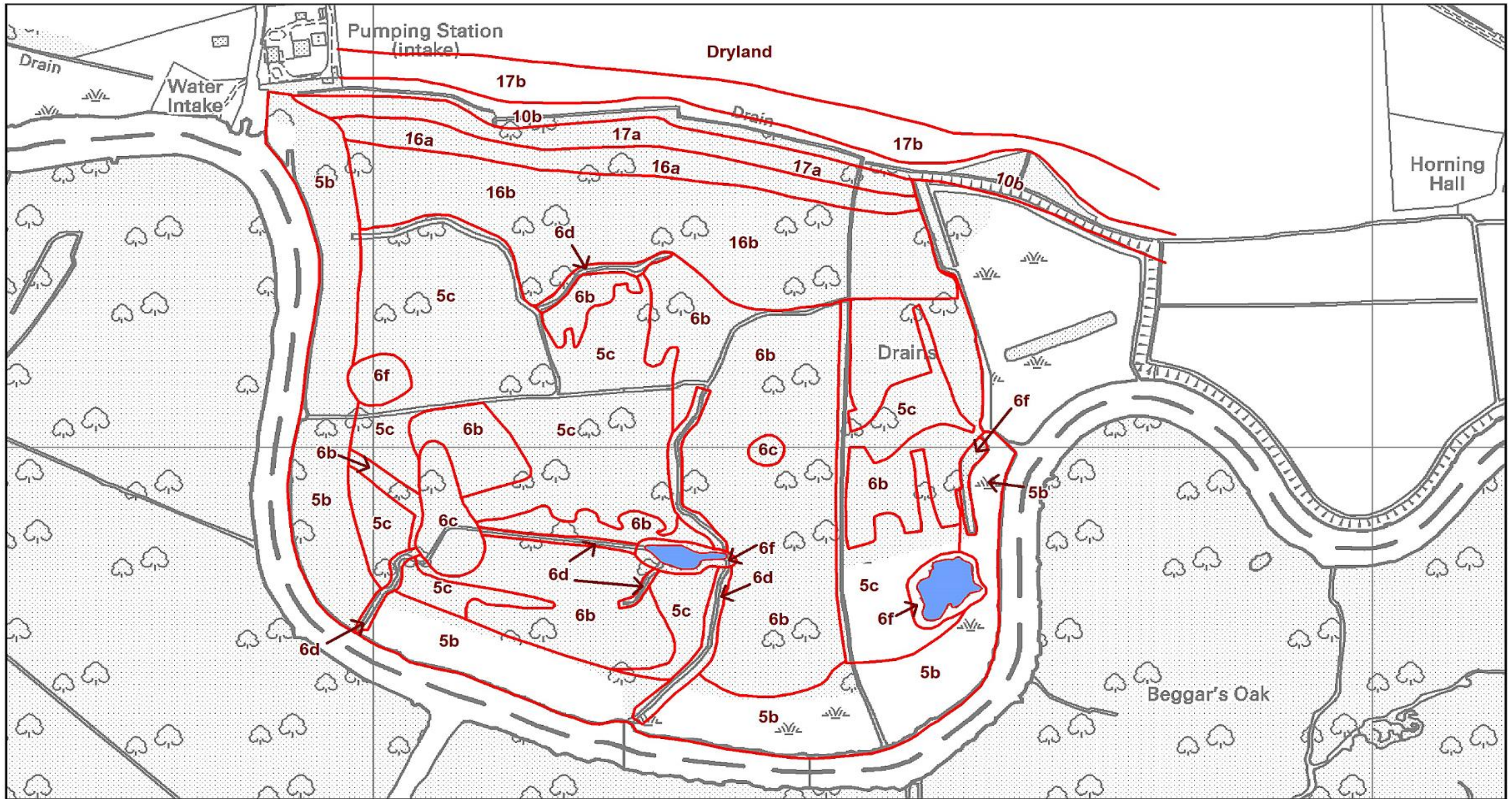
In summary the following eco-hydrological patterning may result:

The **dryland zone** would retreat upslope. It would be the terminus of a fully formed wetland to dryland transition, from dry grassland to the River Bure. The lower elevations would over time show mottling in the sub soil, changing from brown earth soils to gleyic brown earths. Figure 19 suggests the “dryland zone”, would start at around 1.5m AOD. The water table would be 1m below ground level at approximately the point where ground level is 2.50m AOD, although this distance depends on the actual slope of the water table.

Above the catch dyke (and upslope from WetMec 10b Permanent Diffuse Seepage Slope zone), would be a form of **WetMec 17b Weakly Groundwater Flushed Slopes.** Here, the narrow zone would be flushed by groundwater, most likely in the upper soil layers above the area currently showing evidence of mottling. It would over time develop elevated layers of mottling becoming true ground water gley soils. Because of topographic elevation, groundwater feed would be comparatively weak and dependent on lifting of the sub-surface water table during wetter winters. The soils would be largely mineral, but depending on the strength of flushing, good quality rush pasture communities could develop.

The seepage area, **WetMec 10b Permanent Diffuse Seepage Slope,** would lie immediately below this, forming a narrow zone parallel to the restored catch dyke. It would occupy the sloping ground where mineral profiles grade into the deep peat fen. The upslope division between this and the previous WetMec 17b would vary according

Figure 18: Possible Arrangement of WetMecs Following Catch Dyke Restoration: Plan View



WetMec 5: Summer Dry Floodplain
- **5a Rarely Flooded Floodplain**
- **5b Alluvial Floodplain**
- **5c Winter Flooded Floodplain**

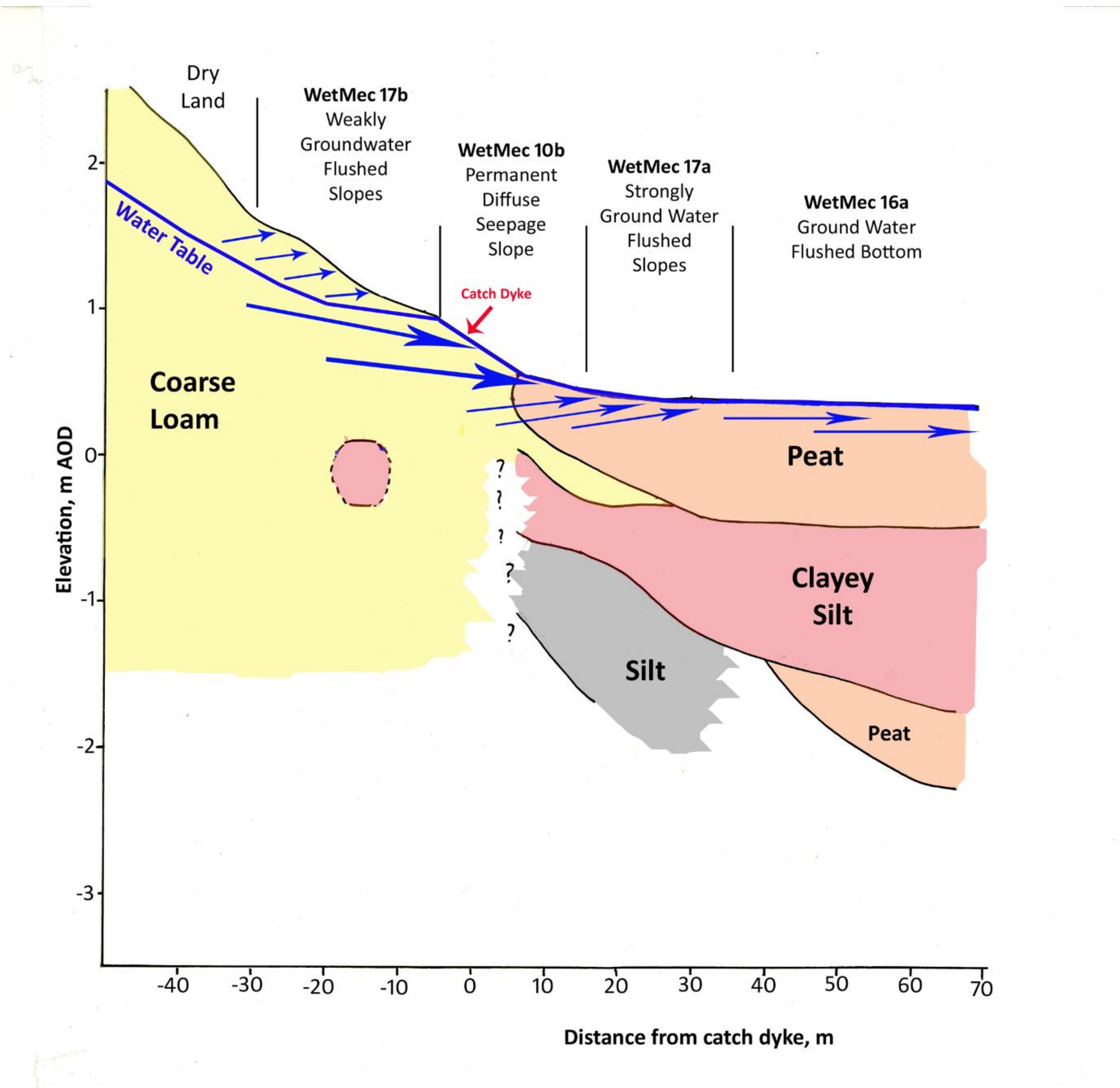
WetMec 17: Groundwater Flushed Slopes
- **17a Strongly Groundwater Flushed Slopes**
- **17b Weakly Groundwater Flushed Slopes**

WetMec 6: Surface Percolation Fens
- **6b Grounded Surface Water Percolation Quag**
- **6c Surface Water Percolation Boils**
- **6d Swamped Surface Water Percolation Fens**
- **6f Surface Water Percolation Fringe**

Wetmec 10: Permanent Seepage Slopes
- **10b Permanent Diffuse Seepage Slopes**

WetMec 16: Groundwater Flushed Bottoms
- **16a Groundwater Flushed Bottom**
- **16b Groundwater Flushed Bottom + Water course inputs.**

Figure 19: Possible Arrangement of WetMecs Following Catch Dyke Restoration: Cross Section At Location of Transect 2.



to the groundwater table height, moving upslope in wet years. In Figure 19, a nominal boundary is given by the upper height of mottling observed in Transect 2. The WetMec would end where seepage stopped expressing onto the floodplain surface. In practise, this will be a diffuse boundary, difficult to observe in the field. In wetter years, the seepage area would probably not move down slope because it is controlled by the intersection of the toe slope and the floodplain, and by the position of the aquaclude. Instead, the fen receiving the seepage at the margin of the floodplain would sit in ponded groundwater for longer and such groundwater would affect a broader surface area of the fen. This is a subtle but important functional difference.

Down slope of the seepage zone would be a second narrow zone parallel to the seepage, where groundwater enters the surface layers maintaining high groundwater conditions, but there is no permanent surface expression. This would be **WetMec 17a Strongly Groundwater Flushed Slopes.** It would be a soligenous supply mechanism, fed by lateral movement of groundwater from above. Being outside of the main seepage, the water table could drop below marsh surface in dry periods when evapotranspiration is high and groundwater conditions are low, but the water table would rarely be far from the surface. During heavy rainfall or periods of high groundwater levels, surface water may pond even on sloping areas. The zone occupies the very base of the toe slope and the first part of the flat peat fen. The substrate is generally thin peat.

Where the peat thickens up and is underlain by the substantial aquitard, and the hydrology becomes topogenous on the flat valley bottom, there is a transition to **WetMec 16a Groundwater Flushed Bottom.** Water levels would not necessarily be increased compared to now, but the zone would be more robust to summer drawdown (i.e. water levels would be sustained for longer into late summer, and/or in dryer years), because in this WetMec the peat mass is constantly replenished by groundwater from upslope as well as water laterally from the dykes. The absolute water level would still be determined by river/dyke levels.

South of WetMec 16a, there is likely to be a zone of **WetMec 16b Groundwater Flushed Bottom + watercourse inputs**. A distance-decay is expected to operate for marginal groundwater contributions to the fen, to the point where lateral inputs from the dyke reach some kind of equilibrium or balance.

Thereafter, it is assumed that any influence of the catch dyke restoration is extinguished. South of the first west-east dyke line, the eco-hydrological zonation remains the same as the current “before restoration” arrangement.

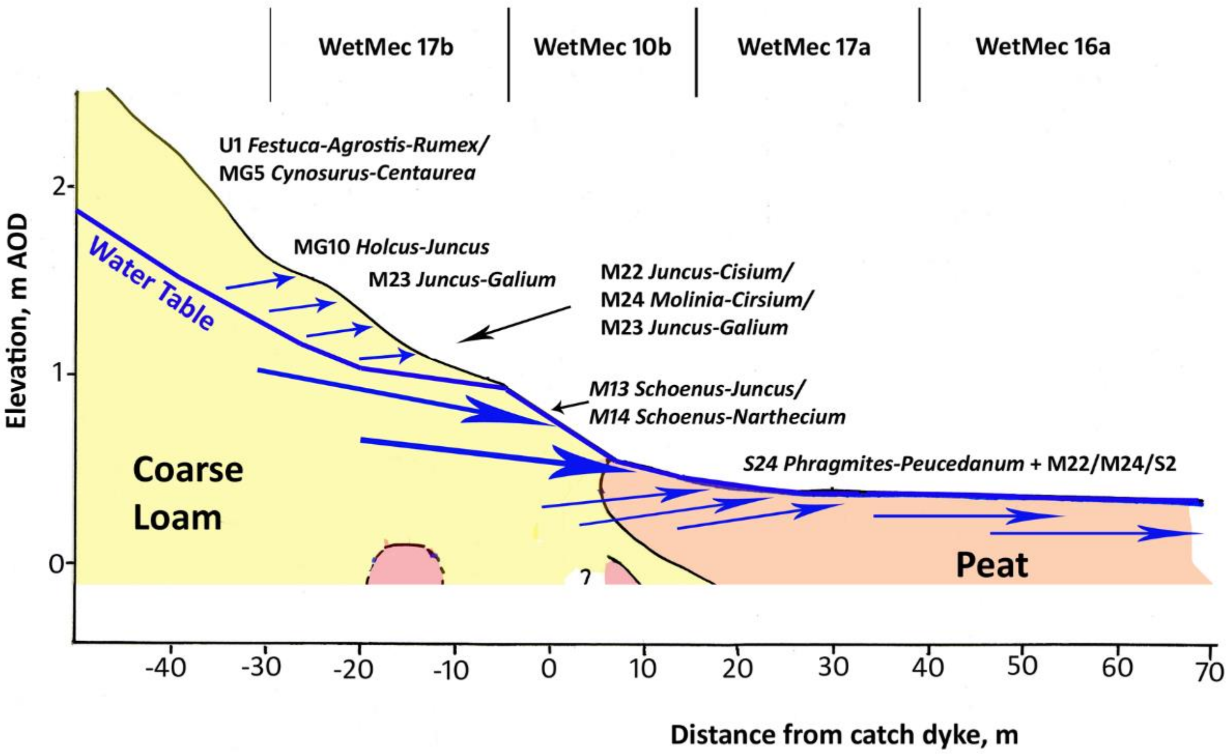
The boundaries between WetMecs 17a, 16a and 16b are speculative and difficult to observe in the field. They are also likely to be dynamic, depending in any given year on antecedent rainfall, the drift water table and the flow regime of the river. The diagram is therefore conceptual.

5.2 The Vision for Ebb and Flow: Optimal Site Condition

If the eco-hydrological functioning outlined in Figure 19 can be restored, the full wetland to dryland sequence of habitats could be recovered.

The succession of plant communities is shown in Figure 20. Wheeler et al (2009) indicate that WetMecs 10 and 17 can support many of the same communities, with some being more frequent in one type than another but most being possible in all the eco-hydrologies. Hence Figure 20 is simplified, and patterning is expected to vary laterally as well as down slope.

Figure 20: Potential Arrangement of Habitats Following Catch Dyke Restoration



The dryland habitats, being restored on former arable, would take time to re-establish. *Calluna* heath has not been suggested. The soils are too fine-textured, lacking coarse gravelly-sandy soils typical of natural heather heath. Instead, a grassland somewhere between U1 *Festuca ovina-Agrostis capillaris – Rumex acetosella* acid grassland and MG5 *Cynosurus cristatus-Centaurea nigra* mesotrophic grassland would likely develop. The U1 acid grassland would favour coarser sand soils, the MG5 more likely on profiles with siltier topsoils. The more mesic acid grassland types – such as the *Anthoxanthum odoratum-Lotus corniculatus* sub-community – and the more low-nutrient mesotrophic grassland – such as the *Danthonia decumbens* sub-community – would be most likely, reflecting the intermediate nature of the soils.

There would be a narrow zone of rush pasture where soils are water logged in winter and summer dry. At higher elevations, the MG10 *Holcus lanatus-Juncus effusus* rush pasture would most likely develop, while further down the toe slope in wetter situations, there would be a transition to a form of M23 *Juncus acutiflorus/effusus- Galium palustre* rush pasture where ground water flushing is more reliable and raises the water table close to the surface in summer. Communities on the acid side of neutral are expected on the coarse loams with groundwater derived from the Happisburgh Formation decalcified drift.

The sequence thereafter is difficult to determine and may vary across the toe slope depending on local soil and groundwater conditions. True mires could start develop where groundwater flushing is strong but elevation prevents permanent seepages developing. M24 *Molinia caerulea-Cirsium palustre* and M22 *Juncus subnodulosus-Cirsium palustre* fen meadows are both possible, the former in slightly dryer, less swampy and perhaps less mesotrophic conditions. Both fen meadow communities would express as more base-poor sub-communities due to the likely dominance of groundwater derived from decalcified drift. As a consequence, there could be considerable overlap with M23 *Juncus-Galium* mire, with mosaicking and intermediates common.

Initially, because of the arable legacy, all of the new communities would be relatively nutrient rich, even after a period of nutrient-stripping through cropping. If nutrient-depleting management is employed, the communities should move to more mesotrophic communities.

In the core areas of permanent seepage, the M22, M23 and M24 mire communities could also be recorded. However, the core communities could include M13 *Schoenus nigricans-Juncus subnodulosus* mire if calcareous groundwater was expressed, or M14 *Schoenus nigricans-Narthecium ossifragum* mire if the groundwater pH were circum-neutral or lower. Both mires require very low nutrient conditions, hence may take substantive timescales for their development. Wet heath is not expected in the groundwater zone, just as dry heaths are not expected on the parched soils.

Downslope of the seepage area, on peat soils which are strongly flushed with groundwater (WetMec 17a), the communities progress to floodplain habitats. They would include wetter variants of all those now found on the site (see Table 1 above), with S24 *Phragmites australis-Peucedanum palustre* fen perhaps being most extensive, as at present. In swampy hollows where fertility is low and conditions base-rich, *Cladium* communities could thicken up to dense stands of S2 *Cladium mariscus* swamp.

Outside of WetMec 17a, where the current eco-hydrology is controlled by topography and river levels, the current plant community arrangement would largely continue. Because of buffering of the water balance by groundwater from upslope, these communities are likely to sustain higher water levels in dryer periods. Species which benefit from dryer conditions are likely to decline, while those dependent on wetter or more stable conditions will increase within a community largely remaining within the same NVC type.

Once the transition to current eco-hydrological conditions is complete, south of the first west-east dykes, further change in plant communities will cease.

Management could play a key role in determining the arrangement of plant communities. The mowing-mediated relationship between tall herb fens (S24/S25) and fen meadows (M22/M24) is very well understood (e.g. Rodwell 1991). Other communities such as S2 *Cladium* swamp and S4 *Phragmites australis* swamps have similar management dependencies and clear relationships with other fen communities. The above sequence assumes that there are no sump type communities associated with fen pools and recent peat diggings, but were these created by management, it is possible communities such as M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire might develop if the hydrochemistry were appropriate. If suitable arable land were available for incorporation of excavated peat, considerable turf ponding could be considered to provide primary hydroseral stage communities, which are currently under-represented on the site.

5.3 Constraints, Project Stakeholders, Consultations and Scope of Permissions Required.

5.3.1 Constraints

A review of constraints using Table 2 of OHES (2014) shows that the main catch dyke and working corridor is relatively unconstrained, having arable to the north and fen to the south. There are no known records for protected species around the dyke or immediate working corridor. The dyke is in poor ecological condition. The dyke corridor supports no SSSI or Natura 2000 features. It has no significant aquatic flora and is unlikely to support water voles. Although the dyke feeds eventually into an IDB pumped system it is not Main Drain or Main River. Remedial works are not likely to affect flooding or land drainage other than for the fen and immediate arable land upslope. There are no third party or economic assets within the area likely to be affected, no utilities and no wayleaves or easements other than the access track. Infrastructure is relatively unconstrained. There are unlikely to be significant social constraints as the project land is private, outside of any settlements and away from established rights of way or recreational areas. Remaining potential constraints are therefore:

- Agreement to the works of the landowners. As the project is included in the NWT Management Plan and will benefit their site, the main issue will be with the landowner farming the arable to the north. This land is not under-drained but the toe slope at least will be wetted up. To restore the full wetland to dryland transition, a significant area of arable will need to be reverted to grassland.

- Funding. Currently there is no funding for the project. Securing funding would take some time.

- Old Trees. There are a number of mature oak trees along the bank of the catch dyke. They have high value for landscape and wildlife. Their removal may be difficult to agree with stakeholders.

- The access track. This would be made wetter and potentially impassable. Alternative arrangements would be required.

- EA maintain an engineered floodwall along the eastern boundary of the site. Any works which affect the engineering properties of this floodwall (including direct interference or changes to hydrology of the footings) would be an issue for EA.

Table 4: Summary of Stakeholders, Consultations and Scope of Permissions Required. Under Stakeholder, the principal contact(s) are listed – others may be involved in discussions.

Stakeholder and Contacts	Response to Initial Plans	Permissions Required	Information Required to Assess Proposals
Landowner: Upslope of Catch Dyke: Mr Robert Kittle, Grove Farm	Mr Kittle is not supportive of the plans as proposed because of the impact on his arable operations of raising water levels on the toe slope. He is however willing to look at reports and information and to discuss possible financial measures which were favourable to him.	Formal written agreement to proceed including understanding of implications for the toe-slope arable operation.	This report.
Landowner: Downslope of Catch Dyke. Norfolk Wildlife Trust.	Positive to the current plans, both on-site and for the toe slope and upland areas. Raising the finance would be a concern.	Approval required by Chief Exec and Reserves Officer.	This Report.
Essex and Suffolk Water have one marsh managed by NWT, also the river abstraction works adjacent.	NWT will undertake liaison on behalf of the project.		
Broads IDB. Caroline Labourne, Conservation Officer, Kettlewell House, Austin Fields Industrial Estate, Kings Lynn, PE30 1PH. caroline@wlma.org.uk, 01553 819600, 07880 728389. Mathew Philpott, Matthew@wlma.org.uk. Alan Goose, Alan@wlma.org.uk, Giles Bloomfield, giles@wlma.org.uk.	"The Board would need to be consulted for work to be carried out within the Boards area and a Byelaw assent be completed. This consultation would need to be sent to Matthew and Giles, but it would be helpful if you could copy Alan and myself in. I have attached the link below. I think you will require the Consent for "altering a watercourse" for any works taking place within the district, i.e. if works fall within the red line on the map.", email CL, 04/01/16	Consent to Alter a Watercourse. http://www.wlma.org.uk/uploads/BIDB_Application_to_alter_a_watercourse.pdf	Full specifications for proposals and description of purpose.
Broads Authority, Yare House, 62-64 Thorpe Road. Norwich NR1 1RY 01603 610734. Andrea Kelly, andrea.kelly@broads-authority.gov.uk.	"Regarding Planning permission, I need to advise you to send in a prior notice to gain a position from the Planners to advise if permission is required. To help give you an indication of the likely judgement I have looked at the 'Town and Country Planning General	Most likely Planning Permission. Initially a "Prior Notice".	Full specifications for proposals and description of purpose.

	permitted development Order 2015', Part 6. Unless the operation is 'agricultural development', it does not come under permitted development. Agriculture is defined as that which is 'productive', rather than for environmental benefit. The fence for livestock is unlikely to require planning permission. If the water control structures are for agricultural benefit these may come under permitted development. N2K sites are not exempt from Planning permission. ………. I am aware that Planners have been happy that water control structures in the middle of nature reserves that will not affect any other parties do not need permission." Email AK 04/01/15		May be further requirements as application assessed, in particular protected species surveys and possible flood risk assessment.
Natural England, Adrian Gardiner (Lead Adviser - SSSIs), Norfolk & Suffolk Area Team, Natural England, 2 Gilders Way, NORWICH Norfolk NR3 1UB/ Tel: 0300 060 1967. Adrian.Gardiner@naturalengland.org.uk	Site meetings including with NE Lead Specialists have been positive. NE wishes to the proposals progress.	SSSI Consent. At least initial scoping required under the Habitat Regulations.	This Report. Full specifications for proposals
Forestry Commission, Santon Downham, Brandon, Suffolk IP27 0TJ eandem@forestry.gsi.gov.uk Tel: 0300 067 4574. Sid Cooper, Woodland Officer for the Broads. 0300 067 4573. 07826 914880.	According to the Forestry Commission web site (http://www.forestry.gov.uk/forestry/infd-6dfkw6), a Felling License could be required to clear all scrub exceeding 8cm diameter at 1.3m height. To present a case not to re-stock, Environmental Impact Assessment (Forestry) Regulations 1999 pertain and an assessment and submission may need to be made. Mr. Cooper advises that an EIA Opinion Request Form should be submitted so FC can assess whether an EIA will be needed and thereafter a Felling Licence. He suggested works to support restoration of SSSI/SAC normally do not progress to full EIA unless the case is complex or a	Uncertain, depends if the tree works form part of a planning application, and FCs opinion on the initial inquiry.	Full specifications and proposals for the trees.

	large area is involved. A License is not required for pollarding and tree surgery (applicable to the oaks). The web site also indicates that a license is not required if the work forms part of an existing Planning Permission.		

6. STAGE 4: PROPOSALS AND CONSENTS

6.1 Consideration of Management Solutions

The five issues/impacts of the catch dyke identified in Section 4.3.1 are:

- Change of ground water quality.
- Depletion of water balance.
- Direct draw down of the water table.
- Generation of nutrients
- Truncation of the wetland to dryland transition at the valley margin.

Figures 10 and 11 in OHES (2014) provides a decision tree for identifying remedial solutions for these issues. As the site constraints are manageable, the decision trees suggest the following remedial solutions:

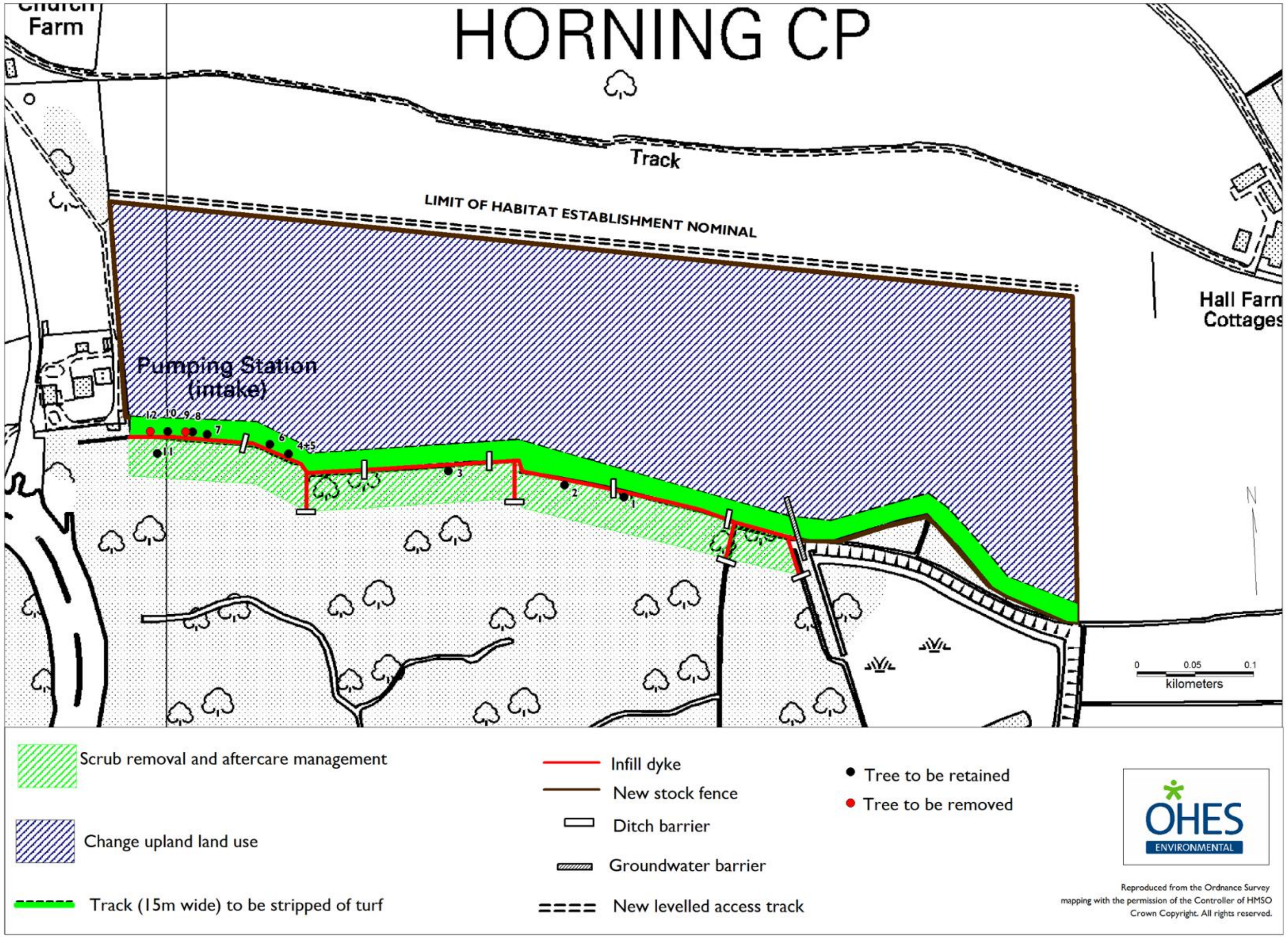
1. Comprehensive infill of the catch dyke. Because groundwater is being depleted underneath the dyke and eastwards to the low-lying IDB drained land, cross-barriers at depth will be required in addition to infill.
2. Change upland land use to reduce runoff, increase infiltration, improve water quality and restore the wetland to dryland transition.
3. Improve farm practises (where land use change is not feasible) to reduce runoff, increase infiltration and improve water quality as far as possible.

6.2 Remedial Measures Adopted

Solutions 1 and 2 will be progressed in full. Improving farm practises (Solution 3) is only needed if full upland land use change cannot be achieved. It would be a partial contribution to solving some hydrological issues and generation of nutrients in particular, but would not restore the wetland to dryland transition at the valley margin.

Remedial measures (summarised on Figure 21) start from the west end near the ESW works, stopping at the fen track west of the reedbed compartment. The reedbed area is commercially cut and has its own independent hydrological management, including an internal perimeter dyke which isolates the reed from upslope hydrology. There would be little benefit in terms of fen and habitat features in restoring this section of catch dyke. Stopping upstream of the reedbed prevents any interference with the EA flood wall (along the east margin), removing a potential constraint.

Figure 21: Summary of Remedial Measures at Ebb and Flow



Solution 1 : Comprehensive Infill of the Catch Dyke (Figures X and Y)

There are four components to this solution:

Removal of scrub along the catch dyke corridor: All scrub and trees will be removed within 30m of the catch dyke, retaining only significant oak trees as marked on Figure 21 and summarised in Table 5. Two oaks – numbers 9 and 12 – are to be removed. All scrub roots need to be removed (either pulled or ground) and all arisings taken from site. The retained oaks will remain as markers of the former catch dyke. Where possible they will be pollarded or receive tree surgery to maintain longevity.

Table 5: Significant Oak Trees in Scrub Removal Belt, Including Recommended Treatment.
TS = Tree Surgery aimed at balancing canopy and prolonging life where pollarding is not practical.

No.	Description	GPS (all TG)	Size (dbh, m)	Treatment
1	Fen bank, stubby, gnarled	36389 16345	1.55	Pollard or TS
2	Fen bank, Good, straight.	36342 16348	1.30	TS
3	Fen bank, young, leaning, stag-headed	36242 16361	1.40	Pollard
4	Upslope side, large, leaning straight, stag-headed	36104 16366	2.80	TS or pollard
5	Upslope side, leaning, stag-headed.	36104 16366	2.40	Pollard or TS
6	Upslope side, large leaning, very divided stem.	36091 16369	2.80	TS
7	Upslope side. Large, heavy leaning, stag-headed.	36034 16383	3.15	TS
8	Upslope side. Large, tall and straight (mild lean).	36021 16386	2.30	TS
9	Upslope side. Crowded, split trunk, crooked.	36016 16387	2.57	**REMOVE**
10	Upslope side. Tall, straight trunk, stag-headed.	36000 16388	2.95	TS
11	Fen side. Fine, straight, stag-headed.	35990 16377	3.80	TS
12	Upslope side. Collapsed and over-turned.	35984 16381	c.2.50	**REMOVE**

In-fill of the dyke: The aim is to allow movement of the groundwater back into the wetland in shallow layers, creating a seepage slope along the catch dyke corridor. The dyke should therefore be in-filled with permeable material, coarse loams typical of the toe slope. Vegetation and dyke silt should be removed to hard bottom, or if no hard bottom is found, to leave a mean dyke depth of 1.5m, measured from fen side bank. This represents an approximation of the probable original dyke profile when excavated. The in-fill should be set aside while the dyke is back filled from locally-won coarse loam from upslope. Dyke margins which have become blinded by silt should be scraped off by 0.2m. The resulting perimeter should be fluffed out immediately prior to infill using tined digger bucket or similar implement. The in-fill should not be compacted but laid loose, and should be left 15% over-filled to allow for settlement. Figure 22 shows the design.

Figure 22: Cross-section of Ditch Infill and Cross-barrier (NOT TO SCALE). Dyke silt and the ditched margins should be removed (hatched brown) and the dyke infilled with coarse loam to 15% above the finished (settled) level. The sheet pile barrier should be driven though the infill to Finished Level (piling in loam not shown below for clarity).

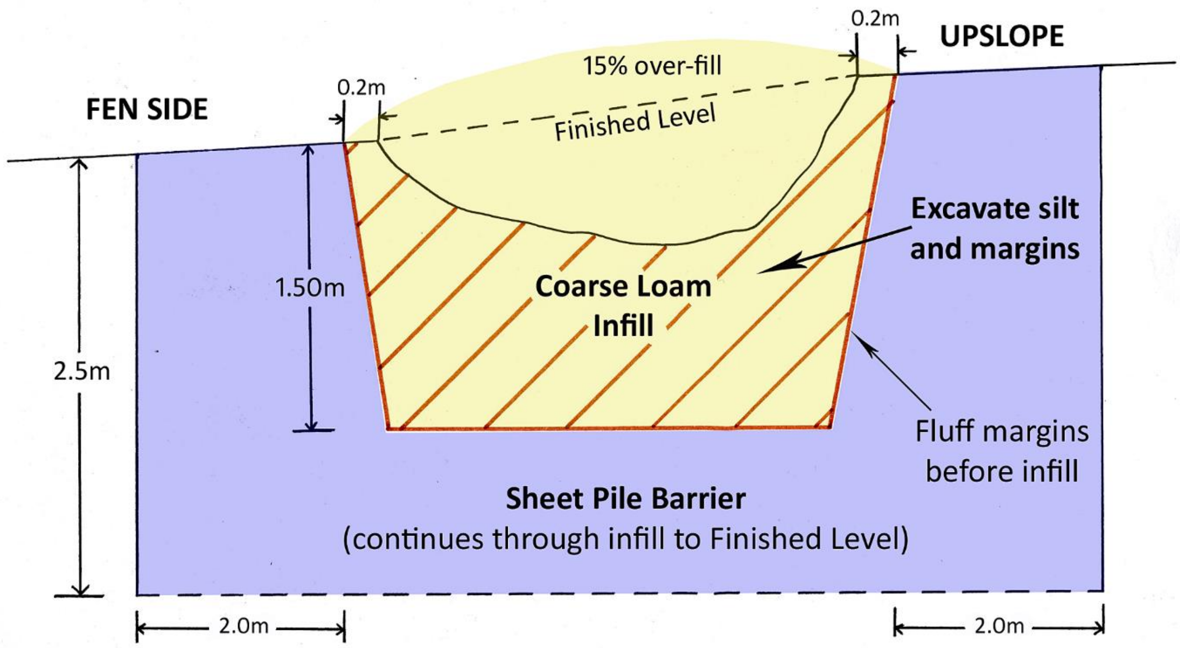


Figure 23 shows representative cross sections of the existing dykes, with a generalised red line showing the approximate desired finished profile. The silt in the dykes is firm and therefore the cross-sections show the top of the dyke silt. The sections were constructed using levels taken every 1m and are diagrammatic, with the elevation not to Ordnance Datum.

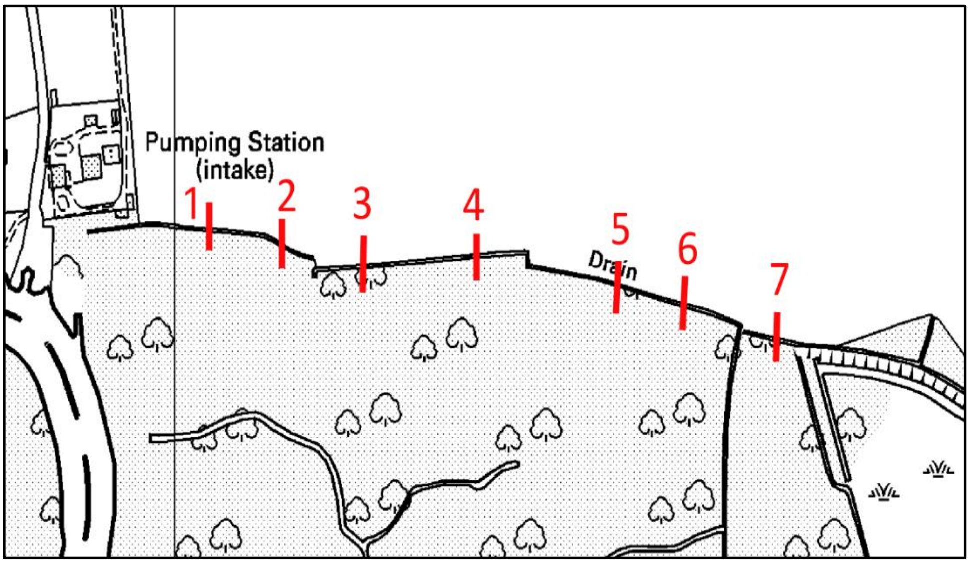
The silt and ditch slubbings should then be spread upslope on the surface and the whole slope graded to a smooth natural surface. Ideally the slubbing should be removed from site but the high cost and carbon footprint of doing so means a long term view of stripping the contained nutrients needs to be taken. The upslope area where slubbings were spread or where vehicles have trafficked should be sub-soiled and then ploughed to mix the enriched layer before Solution 2 is undertaken. Post-restoration cutting will also assist control ruderals and reduce nutrients.

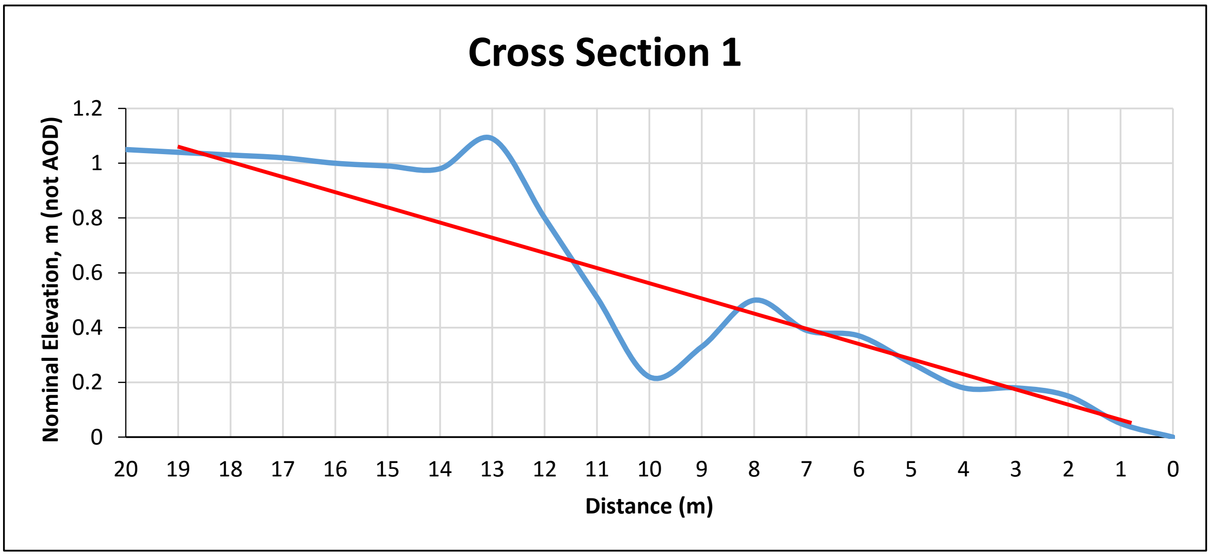
In four locations, the catch dyke is joined to dykes trending north-south which connect (or used to) to marsh dykes. These ditches could drain the toes slope area and hence should also be infilled for the first 30m. To prevent through-flow in the loose fill, there should be a ditch barrier at the end of the infill.

Prevention of west-east groundwater flow. Even the in-filled ditch, with loose coarse sediments, could form a preferential flow line from west to east. In order to force water to move down slope and across the in-filled catch dyke into the wetland, cross barriers will be needed (shown on Figure 22). Every 100m or so, a cross-barrier should be inserted into the former catch dyke, 2.5m below fen side ground level and keyed 2m into each bank. The final barrier width will vary by location, with the seven sections in Figure 23 providing an indication of the range. Interlocking trench sheet should be used and should be laid flush to the ground level expected after settlement. Ideally, the trench sheeting should be driven through the fill material.

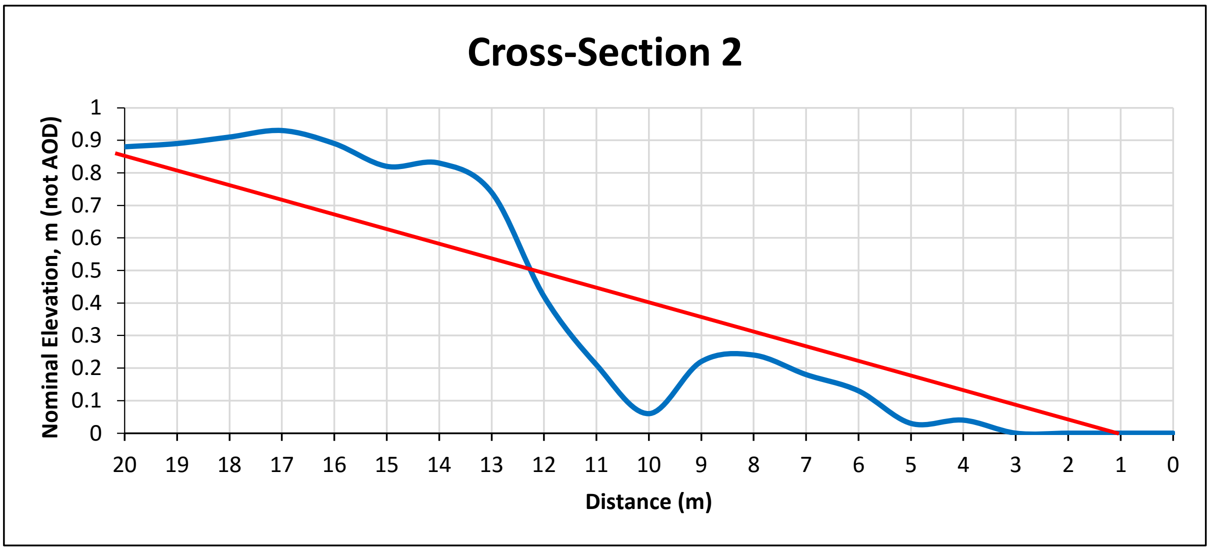
Five barriers in the catch dyke are needed, plus four in the spur of infill in the north-south dykes.

Figure 23: Representative Cross-sections of the Catch Dyke. Blue line is the top of the silt which is firm. The red line is the approximate desired finished profile. A photo of the section follows each graph.

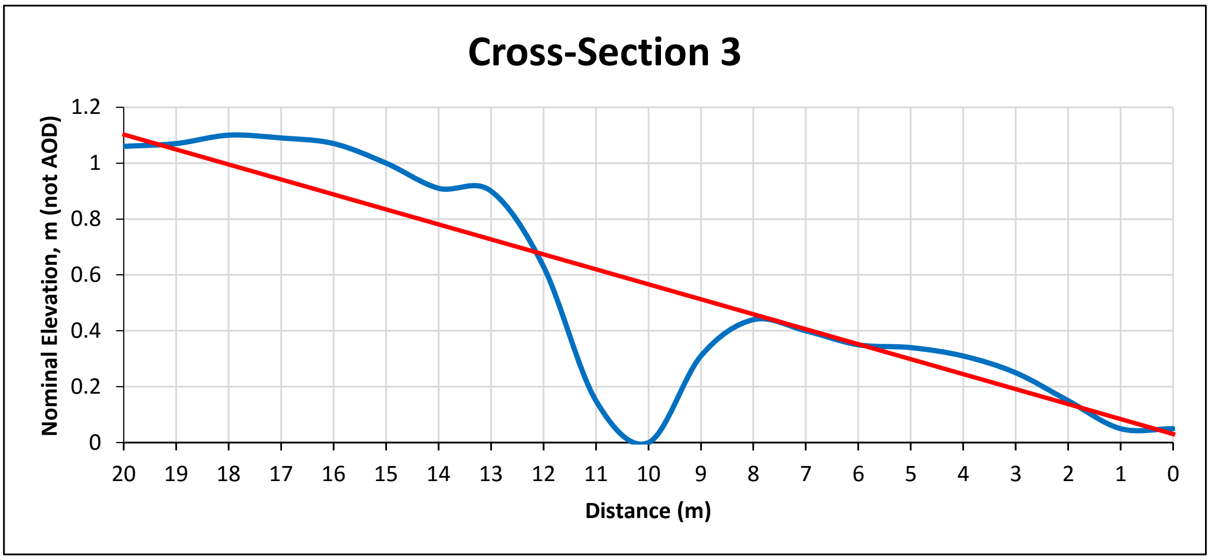



Cross Section 1
Nominal Elevation, m (not AOD)
1.2
1
0.8
0.6
0.4
0.2
0
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Distance (m)

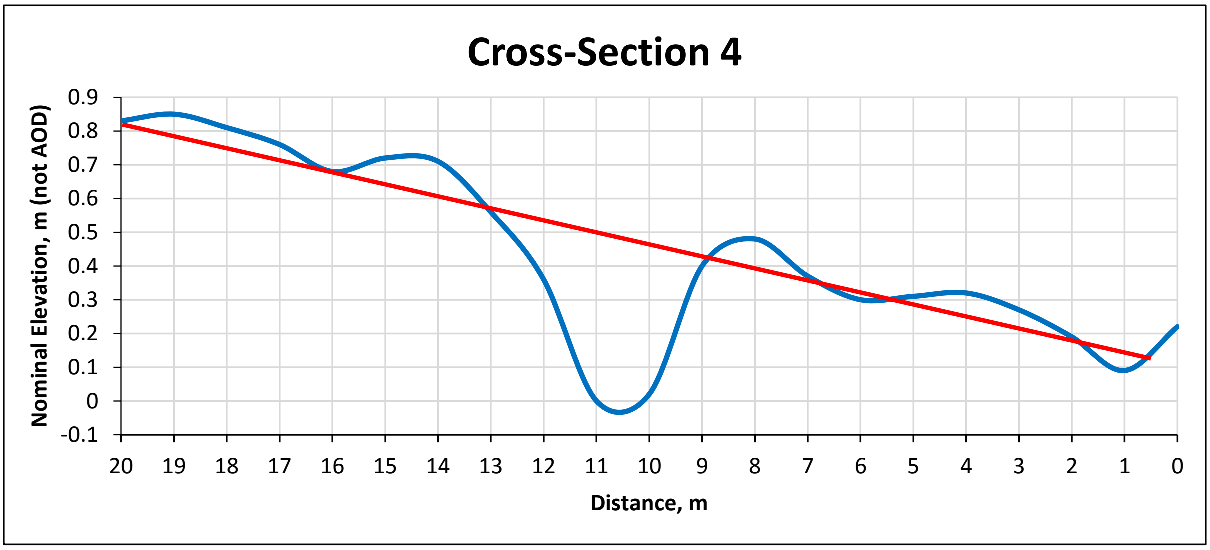

Cross-
Section 1


Cross-Section 2
Nominal Elevation, m (not AOD)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Distance (m)


Cross-
Section 2

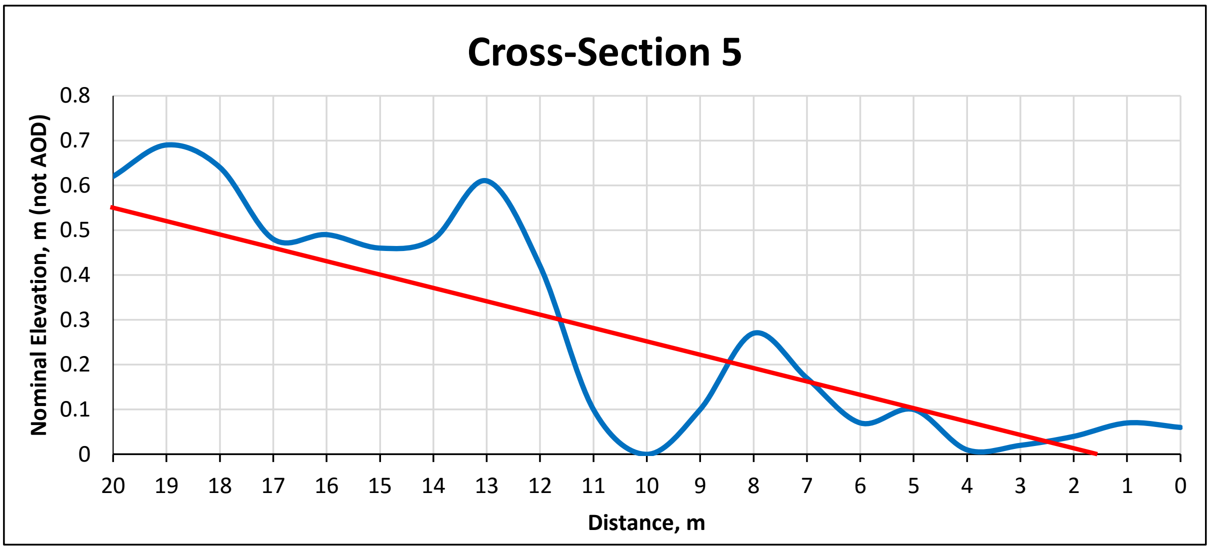

Cross-Section 3
Nominal Elevation, m (not AOD)
1.2
1
0.8
0.6
0.4
0.2
0
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Distance (m)


Cross-Section 3

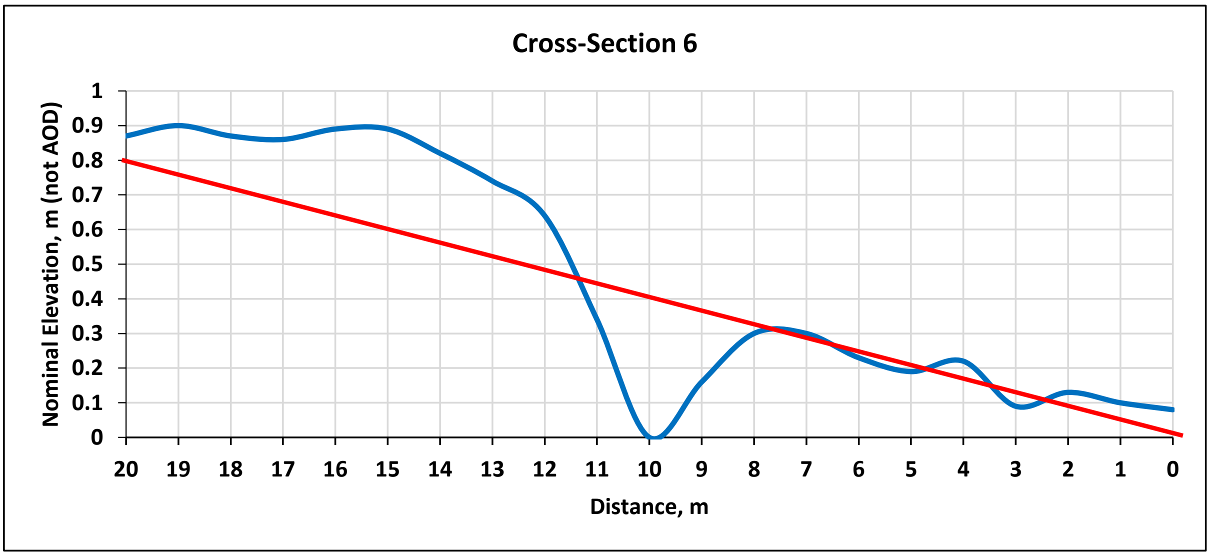


Cross-Section 4
Nominal Elevation, m (not AOD)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Distance, m

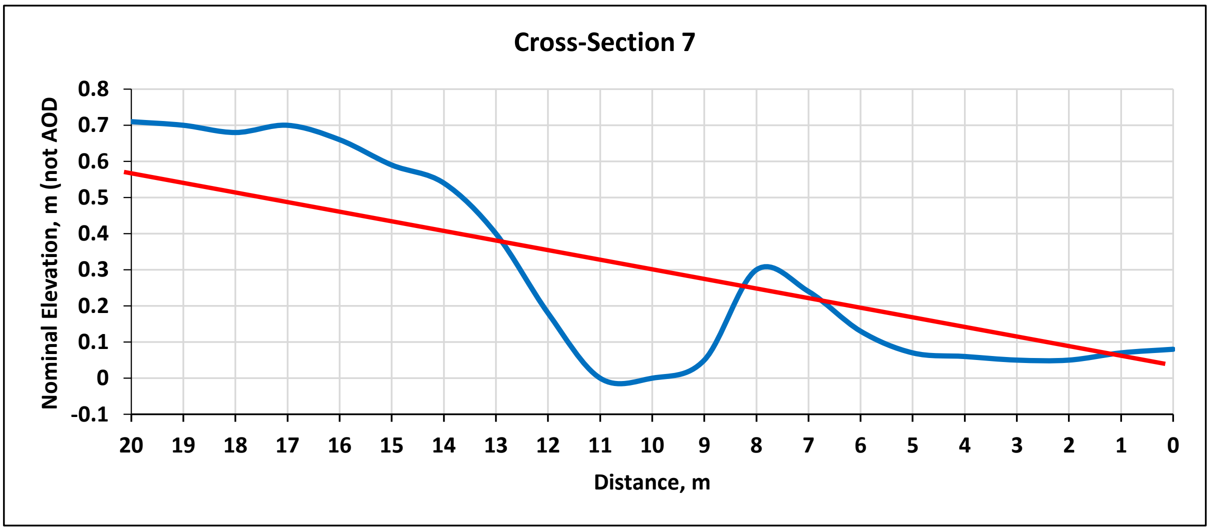
Cross-section 4


Cross-Section 5
Nominal Elevation, m (not AOD)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Distance, m


Cross-
Section 5


Cross-Section 6
Nominal Elevation, m (not AOD)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Distance, m


Cross-Section 6


Cross-Section 7
Nominal Elevation, m (not AOD
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Distance, m


Cross-
Section 7

One major cross-barrier is needed to prevent the proposed draw-down of the water table under or around the catch dyke at the east end of the valley. This will need to penetrate down to base drainage level, which is taken as the low level dyke east of the site. This was measured as minus 0.78m AOD in October 2015, but will be lower in summer. A design base depth of -1.50m is suggested for the barrier. Sealing should extend downslope of the catch dyke to meet the clayey alluvium. Transect 3 suggests this is close to the catch dyke at the east end of the site, hence 20m from the centre of the catch dyke. It should extend upslope from the centre of the dyke by 35m, a total of 55m. Interlocking trench sheeting should be used. It should be located at the track location at the east end of the marsh (Figure 21).

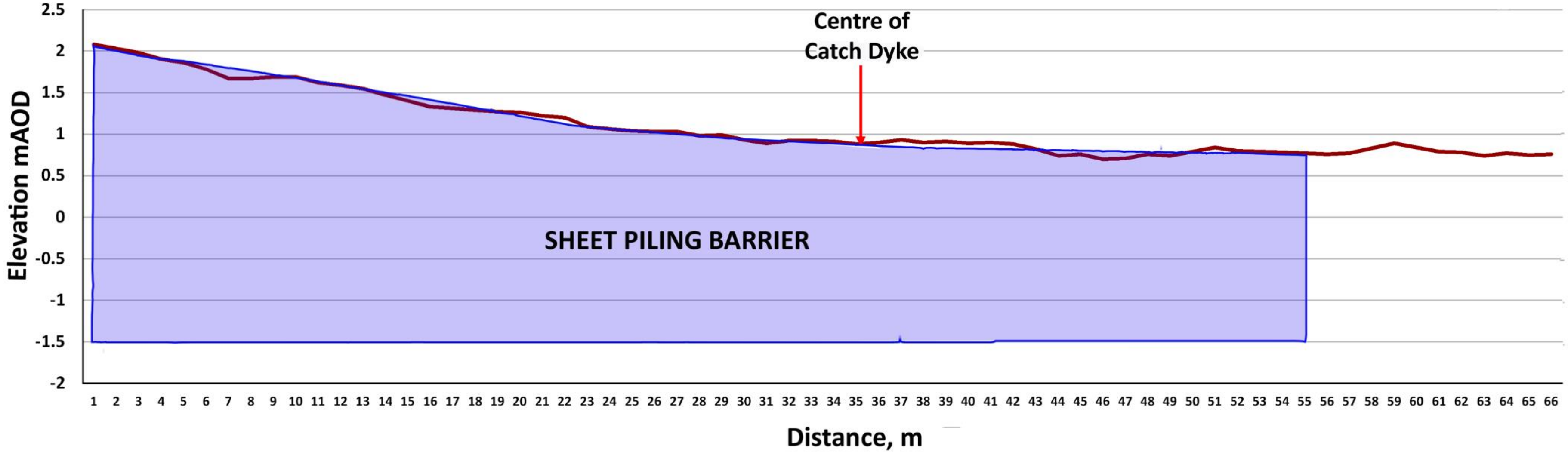
Figure 24 shows a topographic survey of the line of the barrier with a level to mAOD recorded every 1m from 35m upslope to 30m downslope of the centre of the catch dyke (culvert location). To reach design depth of -1.50m AOD, the piles will need to be longer upslope to account for the rise in land. From a point 10m upslope of the centre of the catch dyke to the downslope end of the barrier, a length of 30m, the piles will need to be 2.5m long to reach target level. From the upslope start point, the sheet piles need to be c.3.5m long diminishing to 2.5m to the point 10m upslope of the centre of the catch dyke.

Ancilliary Works: The existing stock fencing will need to be removed. A new stock fence will be needed at the upslope margin. The final extent of habitat creation and therefore the line of the fence is subject to agreement with the land owner and Norfolk Wildlife Trust and is shown nominally on Figure 21. Ancillary infrastructure such as gates will need to be added – five field gates with 2m associated post and rail wing fencing are suggested with locations to be agreed at the time.

Because the in-fill and scrub clearance work will create substantial areas of unvegetated ground, it is expected that scrub, bramble and ruderal regeneration in the following 3 years will be significant. An after care plan will need to be put in place which promotes establishment of target fen and meadow communities. This will require cutting and control of developing vegetation to supplement grazing. Costings assume 30m upslope and 30m downslope will be affected by the works, creating a 65m corridor, 6.68 ha in total. Initially, cutting of 30% of the area cleared of trees three times per year should be budgeted for.

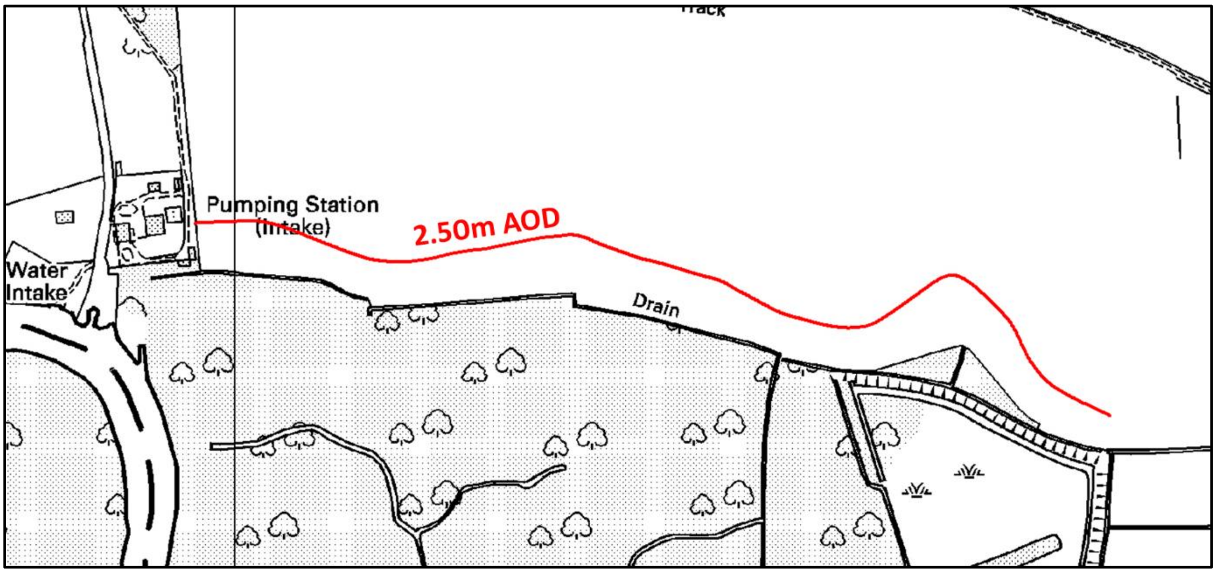
A new access track will be required. This should simply be a levelled width of 4m in the surface soils above the line of the stock fence. Because of the sandy/gravelly nature of the soils and the expected low level of trafficking, surfacing is not needed, but the finished track should be seeded with a hard wearing grass mix.

Figure 24: Cross-Dyke Sheet Piling Barrier To Prevent Eastern Flow of Groundwater. The red line is the ground surface. The barrier should extend from ground surface to -1.50m AOD. It should extend 35m upslope and 20m downslope of the centre of the catch dyke, 55m total.



Impact on Arable Land Use: Figure 19 (showing the likely water table profile following restoration) was used to estimate the point at which the groundwater table falls to below 1m below ground level. This would be at 2.50m AOD ground elevation. At lower elevations where the water table is less than 1m below ground, arable cultivation may be impacted. Figure 25 shows the 2.50m AOD contour, based on LIDAR data. It is assumed that land between this line and the catch dyke would be sub-optimal to unusable for cropping. The area equates to 4.224ha. It is acknowledged that this is an approximation.

Figure 25: The 2.50m AOD contour. Land between this and the catch dyke would have groundwater tables within 1m of ground level. Arable cropping would be affected.



Solution 2 : Change Upland Land Use

There are four aspects to this solution:

Reduce accumulated nutrients in top soils. This is best done by cropping the field using rye or barley in order to strip out nutrients. The crop should be grown without use of herbicides. Light applications of nitrogen can assist nutrient stripping by promoting growth and forcing plants to take up available phosphorus and potassium. Fertiliser with P, K or organic matter should not be used. Cropping should take place for five years, with applications of N stopping after the third year. If cropping is very poor after 5 years, habitat re-establishment can start. If growth remains lush, signifying residual fertility, cropping should continue.

Improve Farm Practises. Cropping should adopt measures in Solution 3 to reduce any impact on the developing fen margin. Cultivation should go as far down slope as wetness allows. Once the toe slope is wetted up, it may be that only hay cuts on developing fen vegetation can be taken.

Turf stripping. Once the new track is established upslope, the turf of the now redundant dyke side track should be stripped to reduce topsoil nutrients and promote regeneration by wetland plants. The track varies in width, but is 14m at the location of the long barrier. The turf can be removed and spread at the top of the slope ready for incorporation and then cropping.

Habitat Establishment: After decades of arable cultivation, there is unlikely to be a viable seedbank containing plants from species-rich acid, neutral or wet grasslands. Hence relying on natural regeneration may produce a weedy, species poor mesic grass sward of modest conservation value. It is therefore proposed that the ground be seeded with strewn hay from appropriate sites and with seed stripped from sites. Ideally sites from around the margins of Broadland should be identified for seed/hay harvesting. Seed harvesting is preferred as unlike hay spreading, it does not add organic matter and nutrients.

Solution 3 : Improve Farm Practises

This solution sees the land upslope of the catch dyke remaining in commercial farm management, but with management practises adapted to achieve as many of the benefits of land use change as possible. Key changes would include:

- Contour ploughing.
- Retaining winter stubbles.
- Reduced application of fertilisers.
- Extended uncropped headlands along the toe slope.

The measures will need negotiation and agreement with the farm manager each year according to cropping patterns and variations in farm economics.

7. STAGE 5: IMPLEMENTATION

7.1 Tendering

7.1.1 Form of Tender

All of the works should be let as a single tender package. The information in Section 6 and the soil coring and levelling maps would form the tender package attached to a standard contract such as NEC3 Short Contract which provides a standard set of terms and conditions for both Client and Contractor.

The Contractor should be required to undertake quantification in their tender as some of the quantities are can be subjective in the measuring (dyke silt, dyke dimensions and the quantities that arise therefrom). Some of the dimensions such as up slope restoration, are not definable until the final package is agreed with the landowner. Hence a nominal amount has been put into the tender for restoration of this area.

7.1.2 Selection of Contractor

Only contractors used to working on difficult terrain, including peatland and wet sites, should be engaged. The Contractor should demonstrate experience, ideally in the Broads or other wetland areas, and be used to working with conservation organisations on sensitive sites. Standard civils contractors often struggle with such sites and sometimes tend to pass costs of misjudgements or under-estimates on to the client through a “claims culture”.

In selecting the successful contractor, the decision should be weighted 50:50 cost/quality. Contractors who appear to have under-costed the project should be treated with caution as they may have misunderstood the requirement.

7.1.3 Health and Safety

Because of the scale of the works and the proximity to water and soft ground, the works may require oversight through the CDMC regulations.

7.1.4 Derivation of Final Tender Designs

There may be further iterations of design following comments by regulators and landowners to come to a final package of works. Hence it is recommended that tendering only take place after all permissions are resolved and a final scheme settled.

7.2 Preliminary Bill of Quantities

Table 6 provides an initial bill of quantities to allow for budgeting. This will change with further design iterations. It has been derived from GIS measurements and from the specifications contained in Section 6 but should be subject to final design and contractors measurement.

A contingency of 15% has been allowed because of the difficulty of the working conditions – this is for unexpected difficulties encountered during works and should not be used to meet the additional cost of inflation/high tender returns.

The Table do not include ecological oversight, permissions and design amendments, or other fees such as CDM. The costs do not include VAT or an allowance for inflation.

Finally, Table 6 does not include any costs associated with the land and any arrangements required with the upslope landowner.

Table 6. Initial Bill of Quantities. Subject to Contractors estimates of quantities.

Item	Quantity	
Scrub clearance	1.83 ha	
Tree work	Removal two oaks	
	High surgery on 10 oaks.	
In-fill catch dyke	720m	5.5m wide by 1.5 deep, 5940m^3 total, Assume 50% slubbing to remove silt (3,000m^3), 115% backfill (6,831m^3).
Restore toe slope by spoil spreading sub soiling and harrowing.	Infilled catch dyke: 720m	3,000m^3 spoil, 30m width along catch dyke margin.
Track Surfacing	835mm long, 4m wide, graded level seeded with hard wearing grass mix..	3340m^3.
Turf strip and disposal, lower track	1.343 ha	
Fence removal	720m	
New fence installed	1560m	Like for like replacement, pressure treated softwood, box strainers (double on soft ground), netting with two strands high tensile wire.
Field gates	5	Pressure treated standard wooden field gates plus 2m 4-rail post and rail either side.
Short dyke barriers	9	2.5m depth on fen side, width depending on location
Long barrier	1	55m total, 30m with 2.5m piles, 25m with 3.5m piles.
Aftercare of scrub clearance and catch dyke corridor	30% of 4.68 ha	1.4 ha, three times/year, 3 years, cut and remove.
Restoration of Upland habitats		Single sum
Contingency	15% of sub total	

8. STAGE 6: REVIEW: PROPOSED MONITORING

8.1 Proposed Monitoring

Monitoring will be in the form of two belts perpendicular to the catch dyke (Figures 26 and 27) and stretching from the dryland end of the hydrosere to the point in the wetland where the influence of the groundwater margin is extinguished, either by topography or other influences such as the river or dykes.

The belts are marked by a post at the start and end of the transect, up- and down-slope of the dyke, 4 posts in all. Because the arable is in active cultivation, the upslope post cannot be inserted until restoration work is complete. Each transect starts 2m from the edge of the catch dyke. The belt transect would be on the east side of the post line in all cases. Monitoring posts will be 3m 150mm top diameter pressure treated round straining posts. They will be sunk to 1.5m depth in peat, 1m in hard ground.

Figure 26: Location of Belt Transects

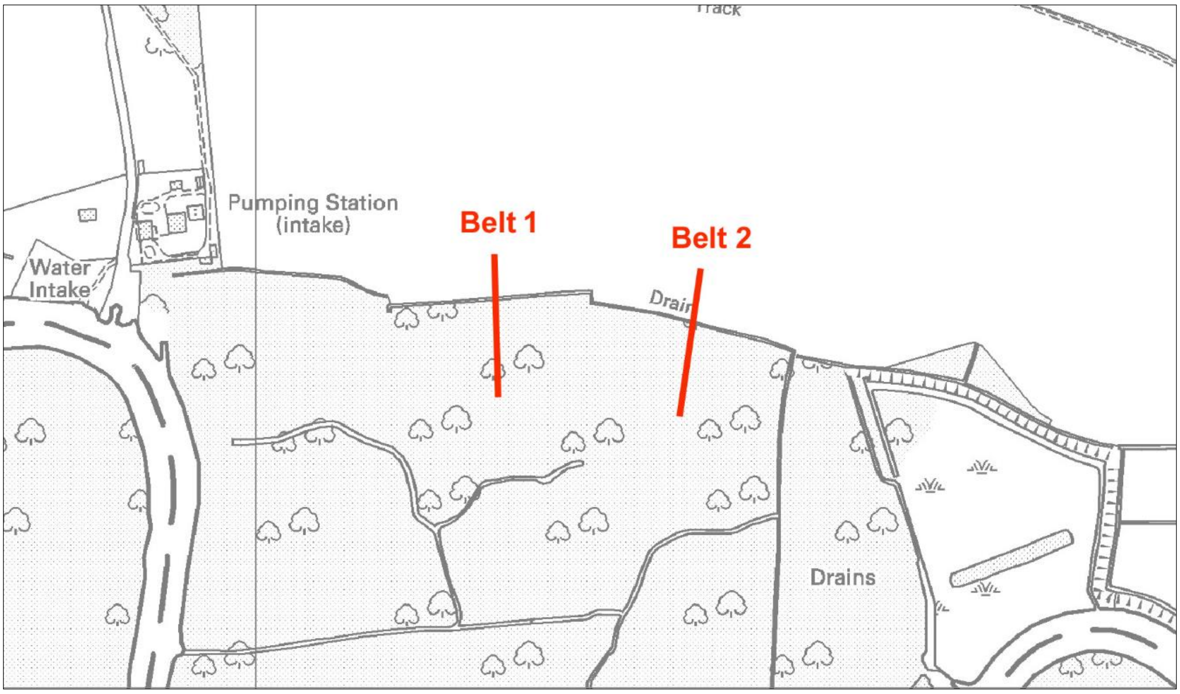


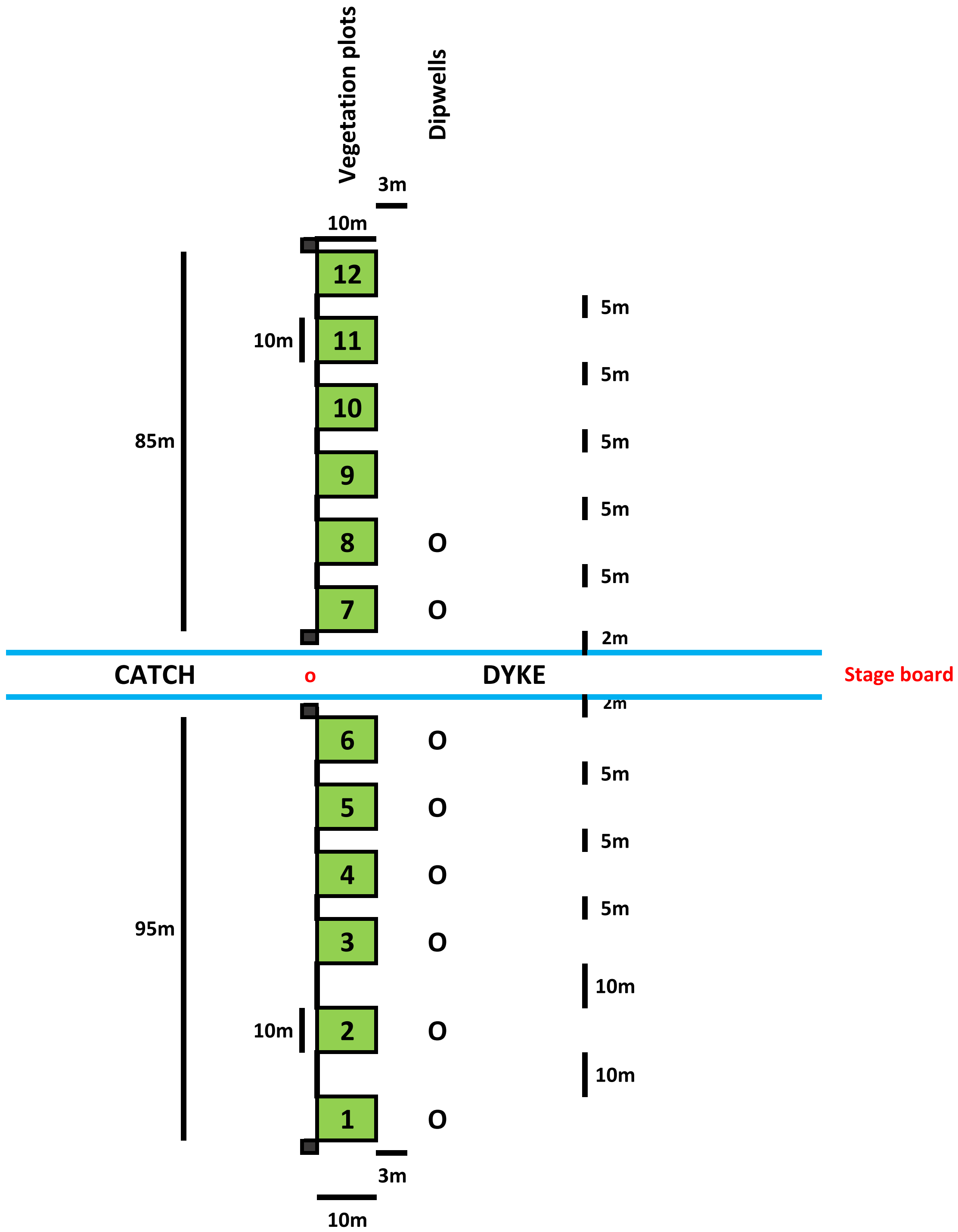
Figure 27: Belt Transect 1 (Left) and 2 (Right).

8.2 Vegetation Monitoring Plots

Along the belt, 10m square vegetation sample plots will be located upslope and downslope of the catch dyke (Figure 28). Such a large plot allows for the coarsely structured vegetation to be accommodated. It is the plot size used by Wheeler for his initial fen vegetation research – which formed the larger body of fen NVC samples – and the upper end of NVC sample size for tall herb fens. It also provides robustness to minor mis-registration of the permanent plots between repeat surveys. Because the upslope is still arable the upslope strainers have noy been installed.

There will be six plots each up- and down-slope of the dyke. Because the response of the water table is likely to show a marked distance-decay, the monitoring plots are densest nearest to the dyke. The plots themselves are not permanently marked. In Year 0, a long strand of baler twine is tied ***taught*** between the strainers. The plots are measured out cumulatively from the catch dyke strainer. Gaffer tape marks the start and end of a 10m plot along the line, and a permanent marker numbers the gaffer tape. When recording is completed, the line is wound back in on a wooden rod, from the far end first, back to the catch dyke. The wooden rod is labelled (Transect 1 Ebb and Flow etc.) ***and stored safely***. At the next monitoring round, the string is unrolled from the dyke edge strainer outwards to the far strainer. Allowing for minor stretching, the gaffer tape should mark reasonably accurately the locations of the vegetation plots. The process is repeated.

Figure 28 : Sketch of Monitoring Belt Transects. North is at the top of the diagram so monitoring plots are on the east side of the line.



Just to ensure against loss of the recording string, the four corner plots should be GPS recorded. However, as long as the strainers are retained and recording is always made to the east of the transect line, plots should be re-locatable with new strings.

Until the restoration work is complete and the long term future of the arable decided, only the track is available for vegetation and hydrological monitoring. Plots 9, 10, 11 and 12 will be placed when restoration is complete.

For each 10 x 10m plot, all species including bryophytes would be listed and an abundance given according to Domin. If a vegetation plot appears to overlay a vegetation boundary between two communities, or the edge of dominant stand such as a sedge bed, this will be included. A scale sketch of the vegetation boundary should be made. Remedial works could cause shifts in vegetation boundaries, so plots that include such boundaries could be sensitive indicators of change. Fen margins often exhibit small-scale vegetation patterning related to near-surface hydrology.

Plots should be recorded in July, with a photograph taken of each. Recording frequency is as follows:

- Year 0 - Summer prior to catch dyke restoration
- Year 1 – summer after catch dyke restoration
- Year 3 – third summer after catch dyke restoration.
- Year 5 – fifth summer after catch dyke restoration
- Every 5 years thereafter.

Those plots on the arable can be brought into the scheme once full hydrosere restoration is complete.

8.3 Water Table Monitoring

The ideal would be to have a single dipwell for each vegetation plot. However, twelve dipwells per belt would be expensive, and for the upland side, some would be redundant. Two dipwells will be used for the upland side, one for each of the first two plots, and on the margins of the track to avoid vehicle damage. There will be a dipwell for each plot on the floodplain. A stageboard will be inserted into the catch dyke itself.

Because of the need for a working corridor and the impact of the works, the stageboard and the first 1-2 dipwells up- and down-slope will need to be removed and replaced when works are completed. As long as they are levelled to OD at both installations, the data will not be affected. Dipwells are drilled 50mm diameter pvc pipe with a silt sock. They should have 2m of tube below the ground.

There should be a gap of 3m between the edge of the vegetation monitoring plot and the dipwell, so the dipwell will be 13m from the line between the two strainers. The dipwell should be as close as possible to the centreline of the 10m vegetation plots.

Because the fen compartments are grazed by cattle, the dipwells will need to be enclosed with a small fence, small enough to reach over to dip without climbing in, large enough to keep the cattle away and for installation not to disrupt the soil column or water table. Table 7 shows the locations and heights to OD of the dipwells.

Table 7: Dipwell Elevation and Location. Ground level is approximate.

Dipwell	Location	GPS Location (all TG)	Rim or GB "0", mAOD	Ground, mAOD
Belt Transect 1				
1.1	Fen	36211 16270	1.36	0.43
1.2	Fen	36209 16287	1.35	0.29
1.3	Fen	36208 16308	1.34	0.28
1.4	Fen	36207 16322	1.36	0.35
1.5	Fen	36205 16337	1.39	0.43
1.6	Fen	36205 16352	1.36	0.35
Gaugeboard	Catch Dyke		0.32	
1.7	Slope	36205 16363	2.03	1.16
1.8	Slope	36204 16372	2.34	1.48
Belt Transect 2				
2.1	Fen	36376 16248	1.37	0.46
2.2	Fen	36378 16267	1.36	0.43
2.3	Fen	36379 16287	1.34	0.43
2.4	Fen	36384 16304	1.35	0.37
2.5	Fen	36387 16318	1.46	0.38
2.6	Fen	36388 16332	1.35	0.44
Gaugeboard	Catch Dyke		0.40	
2.7	Slope	36389 16345	1.91	0.97
2.8	Slope	36390 16353	1.95	1.08

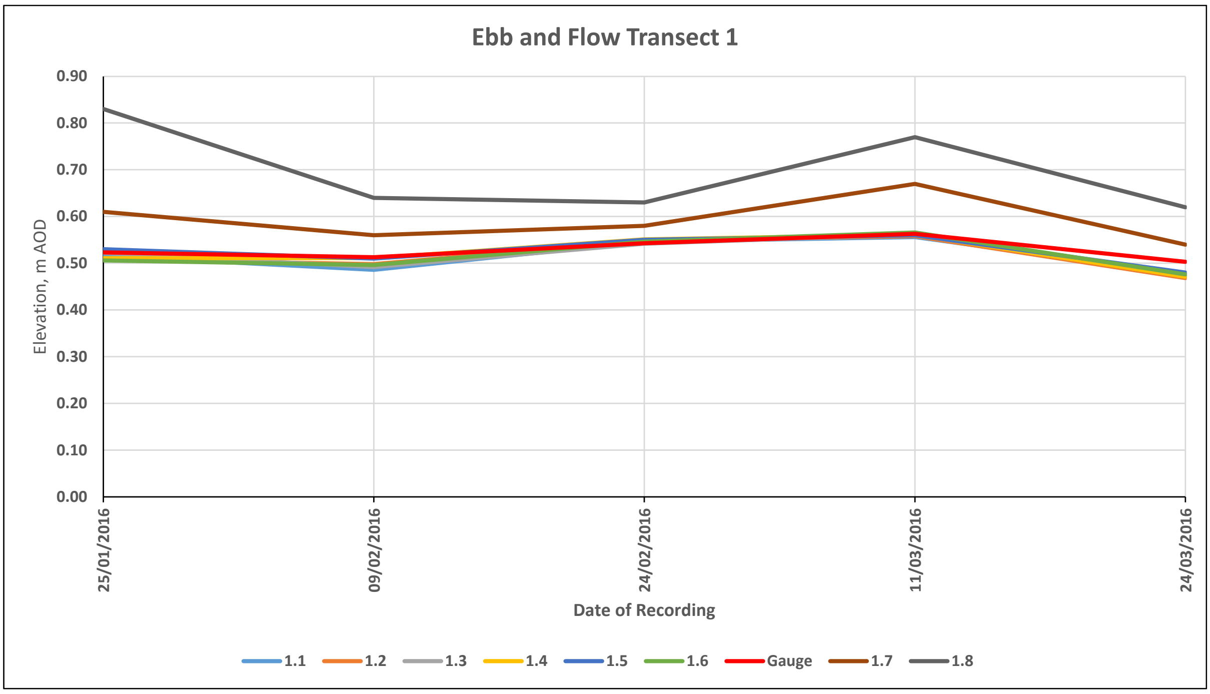
The dipwells should be recorded weekly, and on the same day and time each monitoring round. If this is not manageable, recording should be a minimum of fortnightly, again even spacing between recordings. Natural England have undertaken to do the recording, which should continue for as long as the vegetation monitoring continues. After Year 2, (i.e. with 3 full calendar years of data) it is expected the water table will have entirely stabilised and natural variation will be captured to a reasonable degree. Dipwell recording can be set back to monthly.

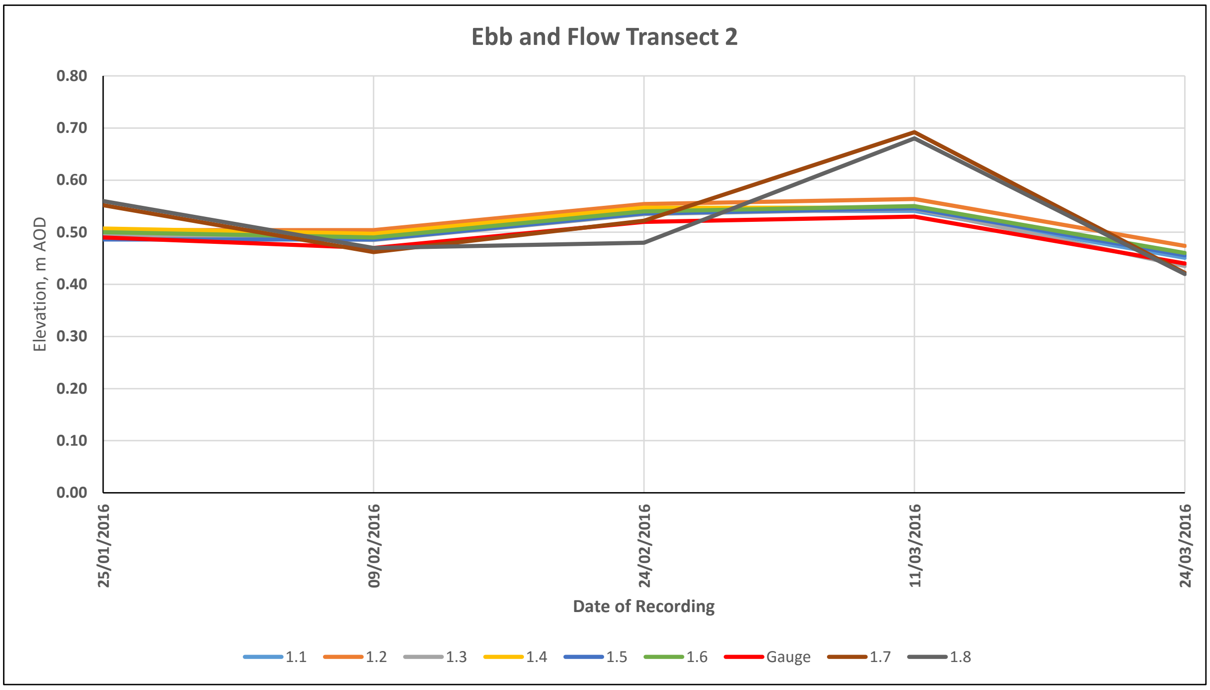
8.4 Data Storage and Analysis

8.4.1 Water Level Recording to 1st April 2016

Figure 29 shows dipwell recording up to 1st April 2016 for the two belt transects. All the dipwells show a broadly correlated trace – gradual declines other than a peak on 11 March presumably in response to rainfall.

Figure 29: Dipwell Records to 1st April 2016. First graph is Transect 1, the second Transect 2.





8.4.2 Ongoing Arrangemeents

Natural England will collect and collate the data.

Copies will be sent to the landowners and project partners.

Natural England will be responsible for data analysis and dissemination of the results.

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APPENDIX 1 : LOGS OF SOIL CORES

CORE	DEPTH	DETAILS
Pilot Phase 2014 Fieldwork		
1		**TG 36065, 16847**. Arable field. Rather clayey **Wick Series. 11.07m AOD**
	0 - 30	Light to mid-brown, fine sandy loam. Few small stones. Becoming silty at depth.
	30 - 70	Mid orange brown, sandy silt loam. Stones 1 – 2 cm. Firm, getting more silty with depth, stiffer.
	70-	Yellowy orange brown stiff sandy clay with frequent stones to 2cm. coring stopped 95cm
2		**TG 36081, 16606**. Bare arable crust with stones. **Newport Series. 9.89m AOD**
	0 - 30	Mid-light brown fine sandy loam, some gravel 1-2cm
	30 - 50	Orange yellow brown soft medium sand with occasional 1 – 2cm stones and much gravel with depth. Becoming reddish orange.
	50 - 70	Orangey brown coarse sand with gravel, becoming softer with depth, more stones
	70 -85	Yellow orange brown sandy clay with occasional gravel, stiff to very stiff
	85-	Orangey yellow brown slightly clayey sand. Stoneless, sandier with depth, becoming brighter orange, soft. Coring stopped at 100cm
3		**TG 36100, 16473**, arable field, same as above. **Newport Series. 5.48m AOD**
	0 – 40	Mid brown, slightly silty medium sand, becoming loamier with depth.
	40 - 65	Slightly yellowy mid brown coarse slightly clayey sand with some small gravel
	65 - 80	Slightly orangey brown soft coarse sand, slightly silty, occasional small stones, some large, up to 5cm. Structureless. Silt decreases with depth.
	80 - 105	Coarse orangey brown sand with stones, up to 3cm. Very weak and soft. Coring stopped at 105m.
4		**TG 36121, 16368**, grass margin, 10m wide. **Aylsham Series. 1.42m AOD**
	0 - 45	Mid brown sandy, slightly clayey loam. Stoneless. Damper with depth
	45 - 75	Slightly orangey mid-brown clayey fine sand. Occasional small stones. Small orangey-brown mottles.
	75 - 95	Grey to pale brown medium sandy clay, soft and moist, frequent small orangey brown mottles. Becoming clayey sand, paler grey-brown with

		depth, still mottled. Clay declining with depth, sand becoming orangey grey.
	95-	Pale grey orange, soft silty fine sand. Mottled, diffuse. Coring ends 115cm
5		**TG 36070, 16358** mixed reed fen. **Altcar Series**, but peat very shallow. **0.50m AOD**
	0 - 20	Humified loamy peat with reed rhizomes, dark brown, WT at 10cm
	20 - 40	Semi-humified dark brown peat, fibrous including fresh roots, firm
	40 -	Stiff grey clay, firm, wet, reed rhizomes, some black organic material. Some browny mottling around roots. Stoneless. Becoming stiffer and drier with depth – silty clay. Coring ends 100cm.
6		**TG 36064, 16313** 65m from catchdyke. Mixed reed fen**. Ousby Series,** again shallow profile. **0.40m AOD**
	0 - 60	Fresh peat, slightly humified, fibrous, lots of fresh roots, soft, difficult to pick up. **WT** at surface
	60 -	Grey clayey silt, soft and buttery, difficult to pick up, stoneless. Coring ends at 110cm
7		**TG 36058, 16257** 120m from catch dyke. Fen. **Altcar Series. 0.47m AOD**
	0 - 50	Dark brown / black humified loamy peat, some fresh roots. Quite silty. Reed rhizomes. **WT** at surface.
	50 – 120	Mid – dark brown firm fibrous peat with reed rhizomes, sloppy and difficult to pick up with depth.
	120 –	Grey, silty, stoneless soft clay, very wet and weak. Coring stopped at 140cm
Second Phase		
Transect 1		
1.1		**TG36080 16388**, 15m upslope of catch dyke, upside edge of grass track. GPS pt 29, **1.63m AOD.** 5.4.3 Gleyic brown earth, **Aylsham Series**, soils in coarse loamy stoneless drift.
	0-15	Top soil. Mid to dark brown, very sandy stoneless loam (overall sandy loam). Grass cover.
	15-30	Mid-brown very sandy silty loam, stoneless, stiff.
	30-70	Mid- to light-brown, very sandy loam, a little silty, stoneless.
	70-135	Pale brown coarse sand, some silt, small brown mottles occasional to 20%, silt content variable within the horizon (overall sandy loam).
	135-	**WT**. Wet to saturation, coarse, orange-brown sand. Structureless, sloppy with depth. Running at 180. Coring stopped at 190 when impossible to pick up.

1.2		**TG 36081 16383** Middle of grass track 10m upslope of catch dyke. GPS pt 30, **1.65m AOD.** 5.4.3 Gleyic brown earth, **Aylsham Series**, soils in coarse loamy stoneless drift.
	0-20	Topsoil**.** Mid- dark brown**.** Very sandy, coarse angular, loam (Overall sandy loam). Stoneless. Grass surface.
	20-40	Mid-brown coarse loamy sand, variable silt content. Stoneless.
	40-70	Mid- to light-brown, very sandy loam, a little silty, (overall sandy loam). Stoneless.
	70-125	Pale brown silty coarse sand (overall sandy loam), brownish mottles occasional then becoming frequent, with variable silt content. Stoneless.
	125-	**WT.** Wet, coarse orange to orange-brown sand, very little silt, becoming sloppy and structureless and increasingly difficult to pick up. Stoneless. Running at 165cm, coring stopped at 180cm.
1.3		**TG 36079 16381** Edge of grass track 5m from centre of catch dyke. GPS pt 31. **1.51m AOD.** 5.4.3 Gleyic brown earth, **Aylsham Series**, soils in coarse loamy stoneless drift.
	0-20	Top soil. Mid to dark brown sandy silty loam (overall sandy silt loam), becoming stiffer with depth. Mostly stoneless, <1%.
	20-90	Mid-brown coarse silty sand (overall sandy loam) with variable amounts of silt but generally little. Mostly stoneless, <1%.
	90-140	Pale grey-brown coarse sand with variable silt and a little clay, overall sandy silt loam. Browny-orange mottles occasional becoming frequent. Very wet at 120cm.
	140-165	**WT**. Coarse orange-grey sand, very little clay. Very soft, stoneless becoming sloppy.
	165-	Coarse orange sand, sloppy and structureless. Running at 185cm. Coring stopped at 195cm.
1.4		**TG 36078 16377** Bed of catch dyke. Bed dry and with pond sedge vegetation. GPS pt 32. **0.69m AOD**
	0-10	Peaty, fibrous, dark brown sandy loam.
	10-30	Sandy, organic, very silty loam. Overall silt loam. Orange-brown mottles occasional.
	30-100	Orangey-grey, mottled, sandy silt to silty sand, (overall sandy silt loam), proportions variable, moist, coming coarser at depth.
	100--	Grey-brown coarse sand with some silt (overall loamy sand) very soft, becoming wetter with **WT** at 110cm. Some clayey layers c.5cm thick. . Coring stopped at 200cm.
1.5		**TG 36080 16372**. 5m from centre of catch dyke, fen side. GPS pt 33. **0.82m AOD.** Grassy/sedgy vegetation. 8.7.1 Typical humic

		groundwater gleys **Hanworth Series,** soils in coarse loamy stoneless drift.
	0-10	Humic-peaty, fibrous with roots, dark brown sandy loam. Stoneless.
	10-30	Sandy, organic, silty loam (overall sandy silt loam). Orange-brown mottles occasional. Stoneless.
	30-100	Orangey-grey, colour variable, mottled, sandy silt, and silty sand, texture also variable, (overall sandy silt loam), moist, becoming coarser textured with depth. Stoneless.
	100-	Grey-brown coarse sand with some silt, (overall loamy sand), very soft and wet. Stoneless. **WT** at 110cm. Some clayey layers c.5cm thick. Coring stopped at 200cm.
1.6		**TG 36077 16369**. 10m fen side of catch dyke, edge of S24. GPS pt 34. **0.62m AOD.** 8.7.1 Typical humic groundwater gleys **Hanworth Series,** soils in coarse loamy stoneless drift.
	0-10	Dark brown, loamy organic peaty topsoil. Grassy mixed fen vegetation. Stoneless.
	10-35	Dark brown, organic, stiff, slightly fine sandy, clayey silt (silty clay loam). Stoneless. Frequent brownish distinct mottles.
	35-40	Orangey-brown to grey, sandy silt, quite stiff (overall sandy silt loam). Stoneless. Colour variable with brown mottle to 30%.
	40-110	Pale grey-brown slightly clayey silt with fine sand (overall sandy silt loam). Texture quite variable. Black inclusions, roundish, less than 2cm, possibly old roots or rhizomes. Mottled to 80cm with diffuse brownish large mottles. Becoming uniform grey with depth, and sandier. **WT** at 100cm
	110-	Grey coarse silty sand, wet. Becoming very sloppy, structureless and difficult to pick up. Coring stopped at 180cm.
1.7		**TG 36074 16359**. 20m from catchdyke. True fen, S24. GPS pt 35. **0.40m AOD. Not assigned to soil series.**
	0-5	Dark brown and fibrous peaty loam topsoil with dense roots. **WT** at 5cm. (perched?).
	5-20	Mid-brown, fresh peat with root fibres. Firm. Not humified, Von Post 3.
	20-110	Mid blue-grey silt with some clay and fine rounded sand (overall silty clay loam). Blue colouration declining after 40cm, becoming clearer mid-grey, soft and buttery. **Alluvium?** Very stiff and dry in middle of the layer. Becoming increasingly coarse and sandy at the base of the layer.
	110-150	Mid-grey to pale brown, coarse sandy silt, stoneless, stiff. (Overall sandy silt loam).
	150-	Grey silty coarse sand (loamy sand), rapidly becoming coarse orangey sand with variable amounts of silt. Running at 185cm. Coring ends 200cm.

1.8		**TG 36068 16336**. 35m from catch dyke. True fen S24. **0.38m AOD. Ousby Series**, but with shallow peat
	0-40	**WT at 0cm**. Mid-brown fresh peat with fresh roots. Firm, fibrous.
	40-130	Mid to pale grey, with some black inclusions, fine clayey silt (overall silty clay loam). Moist and firm to begin, becoming very wet at 60cm, to saturated, soft and very difficult to pick up. Greasy to runny at base.
	130-	Stiff, dryish sandy silty clay, becoming silty clay soon (overall silty clay loam), At 170cm, a layer of small (<5cm) gravel encountered, very hard. Coring stopped at 180cm.
1.9		**TG 36064, 16313** 65m from catchdyke. Mixed reed fen**.** 10.1.2 Raw Eu-fibrous pea**t, Ousby Series,** shallow profile. **0.40m AOD** (CORE 6 from Pilot Survey)
	0 - 60	Fresh peat, slightly humified, fibrous, lots of fresh roots, soft, difficult to pick up. **WT** at surface
	60 -	Grey clayey silt (overall silty clay loam), soft and buttery, difficult to pick up, stoneless. Coring ends at 110cm
1.10		**TG 36058, 16257** 120m from catch dyke. Fen**.** 10.2.2 Earthy eu-fibrous peat**, Altcar Series. 0.47m AOD** (CORE 7 from Pilot Survey)
	0 - 50	Dark brown / black humified loamy peat, some fresh roots. Quite silty. Reed rhizomes. **WT** at surface.
	50 – 120	Mid – dark brown firm fibrous peat with reed rhizomes, sloppy and difficult to pick up with depth.
	120 –	Grey, silty, stoneless soft clay, very wet and weak (overall silty clay loam). Coring stopped at 140cm
Transect 2		
2.1		1.50m AOD, 25m from centre of catchdyke. Under crop. TG 36255 14389. 5.4.3 Gleyic brown earth, **Arrow Series,** soils in coarse loamy drift with siliceous stones.
	0-20	Mid-brown very slightly silty fine sand (overall loamy sand) with occasional siliceous stones, 1-3%. Some organic matter and roots from grain crop.
	20-57	Mid-brown slightly clayey and silty, fine sand (overall sandy loam). Occasional stones to 2cm, c.3%.
	57-146	Initially pale beige-grey, becoming pale grey, slightly silty fine sand (overall sandy loam) with occasional siliceous stones 2-5cm around 3%. Initially fine mottling, rust brown, distinct, 10% of soil, up to 5mm. Becoming larger and denser at depth, 20mm and 30%. Soil becoming moist to wet. **WT 151cm.**

	146-	Orangey brown, coarse slightly silty sand with much stone, 0.5-4cm, up to 25%. Silt declining with depth, overall Loamy sand. Becoming very soft, difficult to raise. Coring stopped at 170cm.
2.2		1.09m AOD. 12.5m from edge of catchdyke. TG 3651 16376. Grass track. 5.4.3 Gleyic brown earth, **Arrow Series,** soils in coarse loamy drift with siliceous stones.
	0-18	Mid-brown stiffish, slightly silty and clayey fine sand (overall sandy silt loam) with small siliceous stones 1-3%, 1-2cm. Much root material and incorporated organic content. High macropores, 20-30%.
	18-53	Mid- to pale-brown stiff silty fine sand (overall sandy loam) 1-3% small siliceous stones, quite stiff. Similar to above but without clay and organics. Gradual transition to next:
	53-100	Initially beige but rapidly fading to pale grey, silty fine sand (overall sandy loam) with occasional small stones <1%. Prominent rust-brown mottling, initially fine <5mm, distinct, becoming larger with depth to 30mm and increasing to 30%. Stiff.
	100-124	Mid- to pale brown fine sandy, clayey silt (overall silty clay loam), firm, rather structureless to massive. Stoneless, no mottling. **WT 104cm**.
	124-167	Pale grey, silty coarse sand (overall loamy sand), slightly irregularly mottled in upper parts with brown, large (20mm) indistinct patches up to 20%, declining with depth and disappearing at 140cm. Variable silt content .
	167-	Orange-brown soft coarse sand, slightly silty, (overall loamy sand) not mottled. Becomes running sand. Coring stopped at 200cm.
2.3		0.98mAOD. 6.5m from catchdyke. Grass track. TG 36253 16369. 8.3.1 Typical cambic groundwater gley soils, **Quorndon Series**, soils in coarse loamy drift with siliceous stones.
	0-15	Dark brown, humous enriched, silty fine sand (overall sandy loam), soft. Stony, small stones 1-2cm, around 3%.
	15-30	Mid-brown, stiffish, fine sandy silt loam. Stoney with 2-5cm siliceous stones around 5%.
	30-70	Mid to pale brown sandy silt loam, becoming sandier with depth. Fine distinct rusty-brown mottles, to 5mm, 10% of soil. Siliceous stones 5%, 1-5cm.
	70-148	Soft, pale grey, silty fine sand (overall sandy loam) with large distinct mottles 30mm, orange-brown, to 30%. Stony, 1-3cm, 3%. At 110cm, mottles reduce to 5mm, still distinct, < 5%. Becomes slightly silty fine sand (loamy sand) with no stones. **WT 98cm**.
	148-180	Grey coarse sand, very slightly silty (overall loamy sand). Stoneless, no mottles.
	180-	Orange coarse sand, soon running. Coring stopped at 200cm.
2.4		0.31m AOD. **Catchdyke bed**. 2cm water over. Reed and pond sedge infilled with scrub. TG 36256 16365.

	0-70	Dark brown humic, almost peaty, silt. Dyke silt. Much plant fibre and roots.
	70-90	Mid-brown fine sandy silt (overall sandy silt loam), stiffish, stoneless, wet.
	90-170	Pale grey silty fine sand, silt fraction varies, but stiff, often dryish and friable, becoming moister with depth.
	170-	Grey coarse sand with little silt. Running sand very quickly. Core stopped 190cm
2.5		0.55m AOD. 7m downslope of catch dyke. Fen edge, in dryish reed. TG 36258 16360. 8.7.1 Typical humic groundwater gley soils. **Hanworth Series**, soils in coarse loamy stoneless drift.
	0-33	Dark blackish-brown humified peat, Von Post 8-9. Not earthy, very little sand. Abundant fresh roots, no stone or sand. **WT 17cm.**
	33-55	Pale browny-grey fine sandy silt (overall sandy silt loam), Firm, moist, gleyed with clear but small brown mottles, distinct, around 15%.
	55-90	Dark grey-brown fine sandy clayey silt (overall silty clay loam). Massive structure, some stones but <1%, very stiff. **Alluvium**?
	90-162	Mid-grey, fine sandy silt (overall silt loam), stiff but moist, stoneless (a few but <1%). No mottles.
	162-	Coarse, grey, slightly silty sand (overall loamy sand). Silt declines to leave Sand. Small stones <1cm, <5%. Becomes running sand at 180cm, coring stopped 195cm.
2.6		0.46m AOD. 14m from centre of catchdyke. Mixed reed fen. **WT 0cm**. TG 36256 16354. 10.1.2 Raw eu-fibrous peat. **Ousby Series,** grass-sedge peat. Note marginal peat depth.
	0-15	Fresh, mid-brown, only lightly humified peat, Von Post 2-3, many new roots, fibrous, rubbed c.80%. Sedge, reed, grass. New grown peat?
	15-46	Dark brown semi-humified peat with fresh roots, sedges and reed fibres. Von Post 5-6. Rubbed fibre 40-50%.
	46-75	Grey fine sandy silt (overall sandy silt loam) with many fine 5mm distinct brownish mottles15% of soil, stoneless.
	75-110	Blue-grey, stiff, massive, clayey silt, stoneless. (overall silty clay loam). **Alluvium?**
	110-	Grey fine sandy silt (overall silt loam), dryish and friable, stiff becoming hard lower down. Bed of gravel at 195cm, stones 1-5cm, jammed corer, stopped at 200cm.
2.7		0.38m AOD. 30m from catch dyke. Mixed reed fen. TG 36257 16339. **WT 0cm.** 10.1.4 Raw eutro-amorphous peat, grass-sedge peat. **Ousby/Adventurers Series.**
	0-20	Fresh, mid-brown fibrous peat, Von Post 3, much living and dead root fibre. Possibly growing. Peat is sedge and grass.
	20-80	Black-brown humified peat, Von Post 7-8, becoming Von Post 9, silty, at depth.

	80-157	Massive, grey clayey silt (overall silty clay loam), stoneless. **Alluvium?**
	157-	Grey, stiff, fine sandy silt (overall silt loam). Stony and hard at times. Coring stopped at 195.
2.8		0.35m AOD. Open fen. 65m from catchdyke. TG 36252 16296. WT +5cm. 10.1.4 Raw eutro-amorphous peat, grass-sedge peat. **Ousby/Adventurers Series.**
	0-20	Fresh mid-brown fibrous peat, with much fresh material. Actively growing? Very wet and sloppy and difficult to pick up. Von Post 2-3. Rubbed fibre 80%.
	20-86	Black-brown, firm, amorphous humified peat, VP 8. Very little rubbed fibre, <10%.Becoming silty toward the base.
	86-210	Pale blue-grey clayey silt (overall silty clay loam), massive structure, stoneless. **Alluvium?**
	210-	Mid-brown brushwood peat, dryish, part humified Von Post 5-6, very firm. Dense layer of brushwood. Coring stopped at 260cm.
Transect 3		
3.1		1.47m AOD. 25m upslope. In barley arable. TG 36396 16364. 5.4.3 Gleyic brown earth. **Aylsham Series**, soils in coarse loamy stoneless drift.
	0-22	Mid- to dark-brown fine sandy silt loam, stoneless, many macropores and roots to 30%. Firm, moist.
	22-54	Mid-brown, slightly orange tint, medium sandy silt loam (overall sandy loam) firm. Rare stones, <1cm, <1%.
	54-88	Pale brown silty coarse sand (overall loamy sand), rare small stones <1%, <1cm, Fine, diffuse mottles, orange-brown speckling, c.20% of soil, mostly <4mm. Transitional to;
	88-	Orange-brown soft, structureless (granular) coarse sand. Stones <1%, <1cm. Mottling continues but fades out at c.120cm**. WT 140cm**. Running sand at 160cm, coring stopped 180cm.
3.2		0.80m AOD. 14m upslope of the catchdyke. Grass margin. TG 36394 16352. 5.4.3 Gleyic brown earth. **Aylsham Series**, soils in coarse loamy stoneless drift.
	0-32	Dark brown fine sandy silt loam topsoil. Macropores of roots and worm holes at 20%+. Stones very rare, <1%, <1cm.
	32-53	Mid to pale brown fine sandy silt loam. Stones very rare, <1%, <1cm, but more stones with depth.
	53-86	Pale beige-grey fine sandy silt (overall sandy silt loam) stiff, sandier and coarser towards base. More or less stoneless. Distinct small mottles, to 5mm, 20% of soil – speckled effect – orange brown. Mottles becoming larger and more diffuse with depth.
	86-	Orangey-brown, then soon browny-orange, very coarse sand, very little silt and declining rapidly. Soft, granular structure. Moist, becoming saturated. **WT 130cm**. Running sand at 180cm, coring stopped 195cm.

3.3		0.85m AOD. 5m upslope of catch dyke. TG 36390 16341. Grass track. 8.3.1 Typical cambic groundwater gley soils. **Sustead Series.** Coarse loamy soils in stoneless drift**.**
	0-24	Dark brown topsoil, fine sandy silt loam, 30% macropores, stiff, stoneless.
	24-54	Mid-light brown, sandier than above, fine sandy silt loam, stiff. Mottled with fine brown mottles, 20% of soil, distinct, <5mm, speckled effect. Stoneless.
	54-74	Pale grey-brown fine sandy silt loam, stiff. Mottled with larger 20mm distinct browny-rust coloured mottles, 20% of soil. Stoneless.
	74-120	Pale grey very fine sandy silt, (overall sandy silt loam). Stiff. Mottled with diffuse large brown mottles, 30% of soil. Stoneless. Progressive increase in moisture. Mottles fade at 100cm then stop at 110cm. **WT 102cm**.
	120-170	Grey, coarse sand, saturated. Little if any silt, granular structure, weak.
	170-	Orangey-brown, very coarse sand. Running sand after 185cm. Coring stopped at 200.
3.4		0.35m AOD, Catch Dyke. 12cm water over. TG 36389 16338. Overgrown with reed and pond sedge, in scrub.
	0-10	Black silty leaf mould.
	10-105	Dark brown organic silt with leaf and root inclusions. Dyke silt.
	105-135	Pale grey, very fine sandy silt loam. Stoneless.
	135-	Mid-grey, very coarse sand. Very difficult to return. Stoneless. Running sand at 150cm. Coring stopped 160cm.
3.5		0.47m AOD. 5m downslope from catch dyke. Reed, sedge and scrub. TG 36388 16332. Very atypical because gleying is below silt loam, but closest to 8.7.1 Typical humic groundwater gley soils**. Hanworth Series.**
	0-33	Dark brown semi-humified peat. Von Post 6. Still much fibre around 20% when rubbed. Very little silt, Fresh and old root material. **WT 5cm.**
	33-85	Dark brown, soft to stiff, clayey silt (overall silty clay loam). Humic, greasy, stoneless. Overall silt loam. **Alluvium?**
	85-125	Pale grey very fine sandy silt (overall silt loam), stiff. Fine brown mottles in the first 15cm, <3mm, 10% of oil. Mottles decline to none rapidly. Stoneless. Transition to next.
	125-	Mid-grey very coarse sand, very little silt and declining. Becoming softer, difficult to return at 150cm, running sand at 170cm, coring stopped 180cm.

3.6		0.46m AOD 14.5m downslope of catch dyke. Reed and pond sedge fen. TG 36389 16325. **WT 0cm. Adventurers Series.**
	0-10	Loose brown peat with fresh fibrous peat of leaf and root.
	10-64	Dark black-brown rather humified peat, Von Post 7-8, rubbed fibre 10%. Much living root including reed rhizome.
	64-120	Dark brown (but soon becoming mid-grey) very soft buttery clayey silt (overall silty clay loam). Soft and stoneless. **Alluvium?**
	120-180	Pale grey, very fine sandy silt, stoneless, stiff. Overall silt loam. No mottles.
	180-	Mid-grey, very coarse sand. Becoming difficult to raise at 190cm, running at 200cm, coring stopped 205cm.
3.7		0.40m AOD. 25m downslope of catch dyke. Mixed reed fen. **WT +5cm**. TG 36390 16317. **Adventurers Series**
	0-80	Dark to blackish-brown humified peat, Von Post 7-8, very variable from relatively fresh for the surface 15cm to very humified, and sometimes with a little incorporated silt. Overall rubbed fibre <15%.
	80-160	Grey-brown, becoming mid-grey by 100cm, clayey silt, without sand – overall silty clay loam. Stoneless, relatively soft and buttery. **Alluvium?**
	160-220	Mid- to pale-grey very fine sandy silt (overall silt loam), very stiff, dry, stoneless.
	220-	Mid-grey, very coarse sand. Running sand immediately. Coring stopped 230cm.
3.8		0.45m AOD. TG 36393 16265. 75m from catchdyke. Reed and Calamagrostis fen. **WT +5cm.** 10.1.2 Raw eu-fibrous peat. **Ousby Series**
	0-10	Mid-brown fresh peat, much fresh plant material, Von Post 2.
	10--120	Fibrous peat brown and dark brown, variable between very fresh Von Post 2-3 and semi-fibrous Von Post 5-6. Occasionally slightly silty, especially near the base.
	120-225	Mid-grey, very soft and buttery, clayey silt, stoneless, sandless. Overall silty clay loam. **Alluvium?**
	225-	Mid-brown, rather dry, part humified peat. Layers of brushwood and some well humified peat. Coring stopped 330cm.