Natural England Commissioned Report NECR239

# Remedial Works for the Catch Dykes at Decoy Carr, Acle

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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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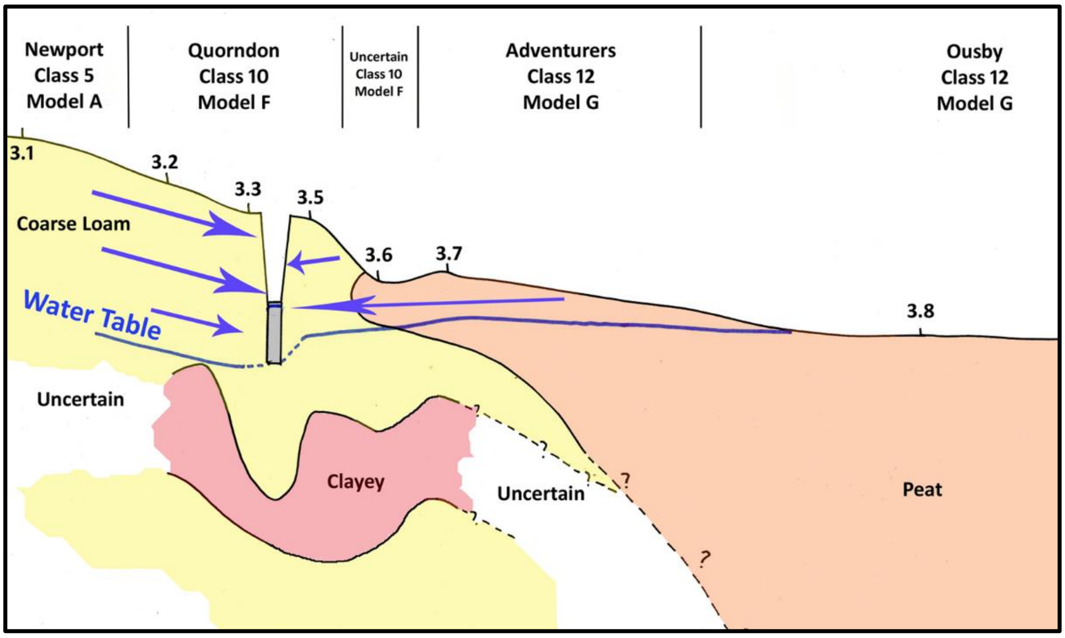

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# Remedial Works for the Catch Dykes at Decoy Carr, Acle

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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 Decoy Carr, Acle, to identify the site-specific impacts of the west-east and south-north catch dykes, 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 four transects plus coring in the Damgate Marshes and 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 peat flows toward the catch dyke, not down slope into the main peat body. The dyke may be depressing ground water level for up to 50m into the fen.

The study shows that both catch dykes are *Type 1: Groundwater Dykes With Significant Direct Drainage*, and are both rated as Severe Risk. The catch dykes are likely to cause the following:

- Change of ground water quality.
- Depletion of the water balance.
- Direct draw down of the water table.
- Generation of acid sulphate pollutants (mild impacts).
- 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 – either north to the Acle Pump along the Landspring corridor, or east to the lower level Damgate Marshes – is responsible, drawing water through the course loams which form the valley margin. There is some uncertainty over the relative importance of the two pathways, with both probably operating to an undefined degree. The south-north catch dyke is most strongly affected, being close to both outflow points and being unprotected by sluices.

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.

   In-fill of the south-north catch dyke would require re-opening of the southern connection of the dyke to the wider SSSI network and higher water levels in the south-east part of the fen. Other ancillary measures include adjustments to fence

lines and new gates, improving a gateway, improving access tracks, and post-project follow-up management to restore habitats.

2. **Raise Water Level**. The far western stretch of west-east catch dyke, which may not be in-filled, should have the water level raised to marsh level.

3. **Perforate perimeter to increase permeability.** The retained portion of the west-east catch dyke should have the margins perforated to promote down-slope movement of groundwater into the fen.

4. **Change upland land use to restore the wetland to dryland transition at the valley margin.** The principal action is to remove the accumulated scrub, subject to landowner approval.

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 in having land owners who are broadly supportive and without infrastructure or property that will be affected by remedial work. Scoping of stakeholders and consents suggested a number of issues, all of which can be resolved through refining the proposed works and submission of consents.

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

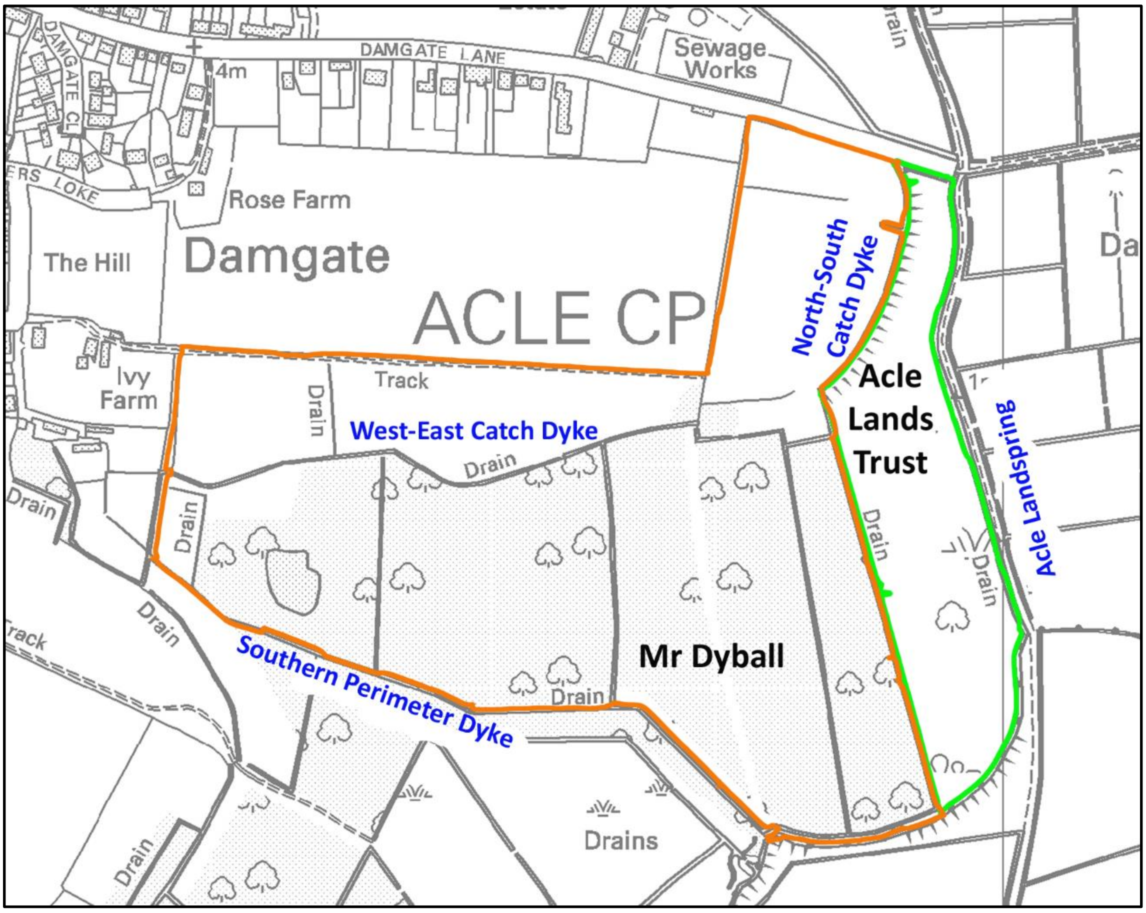
Hydrological and ecological monitoring is proposed. This consists of two belt transects perpendicular to the catch dyke corridor, stretching from up slope to down slope. Each transect includes up to 12 fixed vegetation monitoring plots paired with dipwells recording water table level. These have been 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 Decoy Carr, Acle SSSI (Figure 1).

**Figure 1: Location, Land Ownership and Principle Dykes.** Project area is the combined land area of Mr Dyball and the Acle Lands Trust



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 land owners, regulators and main stakeholders also need to be 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 damaged 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 and Decoy Carr, Acle. They became the study sites for this phase. Reports were split for practical reasons – see OHES (2016) for Ebb and Flow.

# 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 for topographic levels under scrub and trees, and 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 as representative surface level as possible. However, individual levels on the peat are extremely variable over short distances and specific levels should be viewed with caution.

### *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) or on a few occasions, by impacted and deep layers of dense stone. 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 cores in Damgate Marshes (not part of the transects) being taken in February 2016.

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. Line surveys of the long barriers were recorded to Ordnance Datum as specification of the barriers needs to be tied to a specific target depth below ground.

# 3. STAGE 1 : DESK AND FIELD RESEARCH

## 3.1 Ownership

Nearly all of the land is owned by Mr. Mark Dyball. The Acle Lands Trust own the fen compartment along the east margin of the site, adjacent to the Acle Landspring (see Figure 1).

## 3.2 Geology and Hydrogeology

Arthurton et al (1994) have mapped the area's geology. The Drift deposits of the upland are sands, gravels and silts/clays of the Happisburgh Formation (formerly the Corton Formation). They map the top of the slope as Happisburgh Till, the sandy clay member, a non-calcareous till (what is referred to in older accounts as the Norwich Brickearth). The Kesgrave Formation, a river deposit of sands and gravels, underlies the Till and outcrops on the valley sides and toe slope. This correlates with the densely stony subsoils recorded here in some cores. There may be wind-blown Loess deposits (cover silt) of variable thickness over both Formations. In the field, the boundary between the two Formations is not clear and is complicated by surficial mixing and downslope solifluction/colluvial processes.

This is not a calcareous Drift. The chalky boulder clay (Lowestoft Till Formation) ceases along the minor south-north road from Acle which borders the valley.

Arthurton et al (1994) map the valley bottom as peats of the Breydon Formation. The general confirmation of the Formation – the interleaving layers of peat and silty clay derived from marine transgressions. Coring at Decoy Marsh proved the Upper and Middle Peat and the Upper Clay (marine alluvium) components. There is no deeper Breydon Formation stratigraphy for the site.

The Drift is underlain by Crag. Arthurton et al (1994) do not map the separate Formations of the Crag Group, but it is likely here to be Norwich Crag, a more calcareous, shelly unit than the Wroxham Crag.

The main aquifer is the Upper Chalk Formation. It does not outcrop in the area, with both the chalk base and upper surface dipping from west to east, providing a groundwater gradient from the highland to the Damgate Marshes. However, the Upper Chalk is separated from the Crag by a significant thickness of clay (IGS 1981), the Harwich Formation (previously called the London Clay). This prevents immediate hydrogeological continuity between Chalk and Crag.

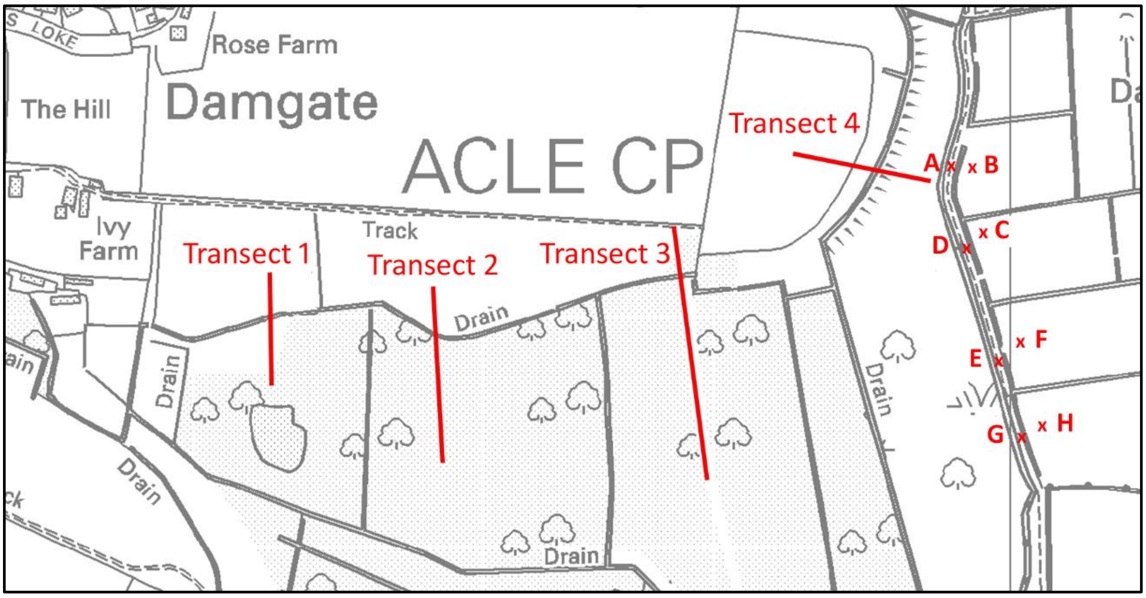
The Environment Agency (EA) piezometers located on the eastern margin suggest the Crag and Drift are the main contributors to the water table. Wheeler and Shaw (2006) acknowledge the undetermined role of rain and surface run-off, but the current work suggests it is very modest. They further suggest that lateral flow could be via preferential flow paths in loose peats (which are significant in the fen areas) and that there may also be upward flow into the peat within the fen – some ponds on the site are thought to be spring fed and presumably, then, also some dykes. The lateral extent and depth of the Upper and Lower Clay (marine alluvium) interleaved with the peat is not certain.

## 3.3 Soils

The upland soils are developed in Drift of the Happisburgh Formation with a variable surface deposit of wind-blown silty loess. All of the soils in coarse loam have high storage and leaching capacity, with little-to-moderate ability to attenuate non-adsorbed pesticides and other diffuse pollutants (NSRI 2014). Underlying groundwater is vulnerable to contamination. Risk of run-off is low, but where clay is significant in the upper profile, it may be higher. Natural fertility is low. With modern methods, the soils can provide very productive arable land. Under semi-natural conditions, they would sustain acid to neutral grassland and woodland.

The site falls within Hazelden's (1990) soil survey area. He maps most of the upland as Wick Series. The toe slope along the west and north margins are mapped as a complex of Arrow and Quorndon Series. The floodplain is mapped as Adventurers Series, a humified peat. The eastern half of the open fen area is mapped as a complex of Adventurers and Prickwillow Series, the latter being a peat soil with inter-bedded marine alluvium. Prickwillow soils can be very acid when drained. Just to the east of the site, adjacent to the Acle Landspring, the Damgate Marshes are mapped as a complex of Wallasea (calcareous and acidic phases) and Downholland Series. They are gley soils developed in clayey alluvium. The main characteristics of the complex is described as slowly permeable, grey mottled stoneless non-calcareous clay. Some soils with dark waterlogged sub-soils, becoming extremely acid when drained.

**Figure 2 : Core Transect Locations.** © Crown copyright and database rights 2016. Ordnance Survey 100022021.



Coring suggests Hazelden is only partially applicable within the SSSI, although the margins of Damgate Marshes were consistent with his description. Four transects of soil cores were recorded in the SSSI straddling the catch dyke (see Figure 2 for locations, Appendix 1 for logs of soil cores). Figures 3a –3d plot the stratigraphy for each transect, with a scaled cross-section for each in 4a-4d. All of the cores were levelled from benchmarks laid down in the

**Figure 3a. Soil Type and Shallow Stratigraphy, Transect 1.**

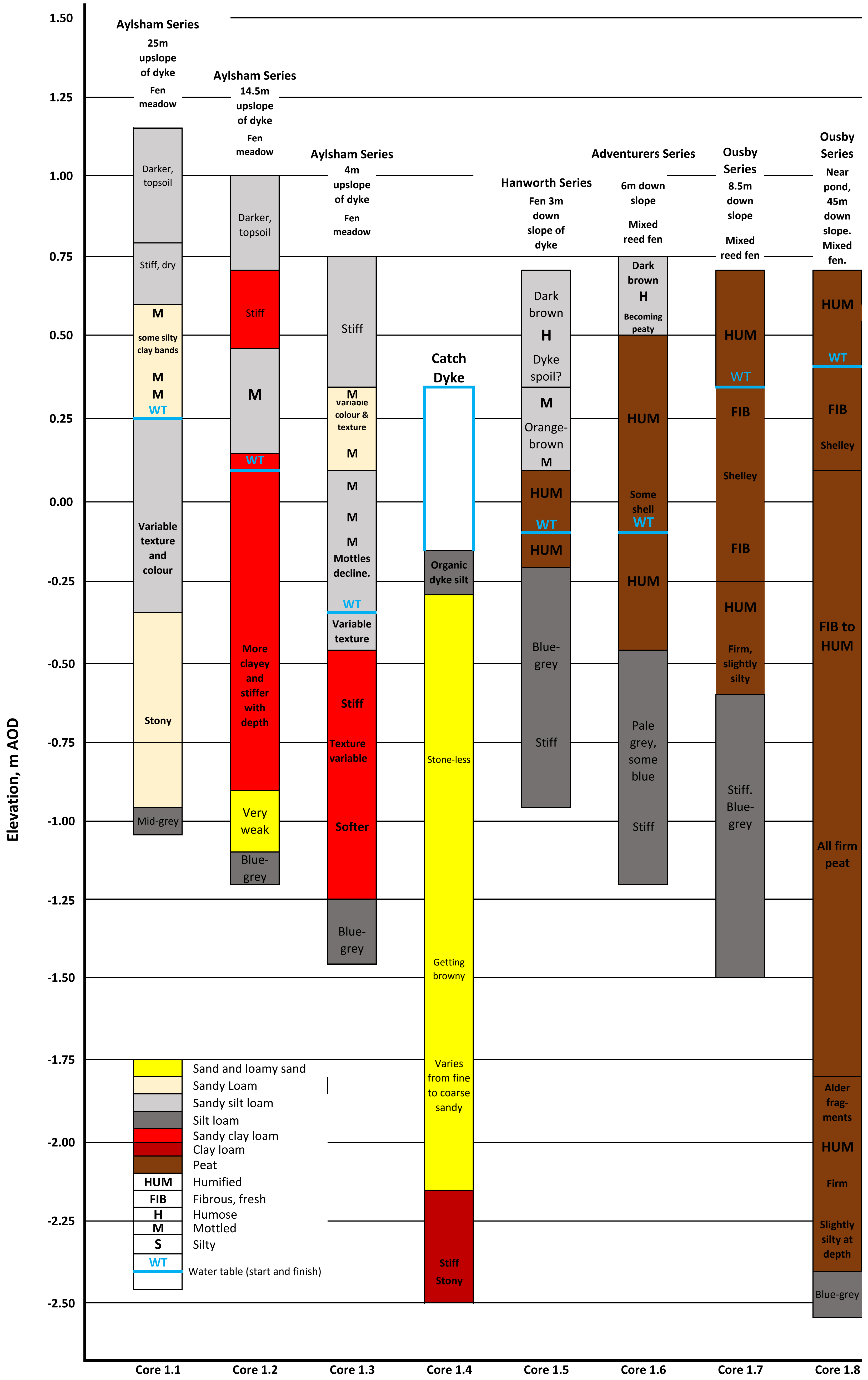


Figure 3b. Soil Type and Shallow Stratigraphy, Transect 2.

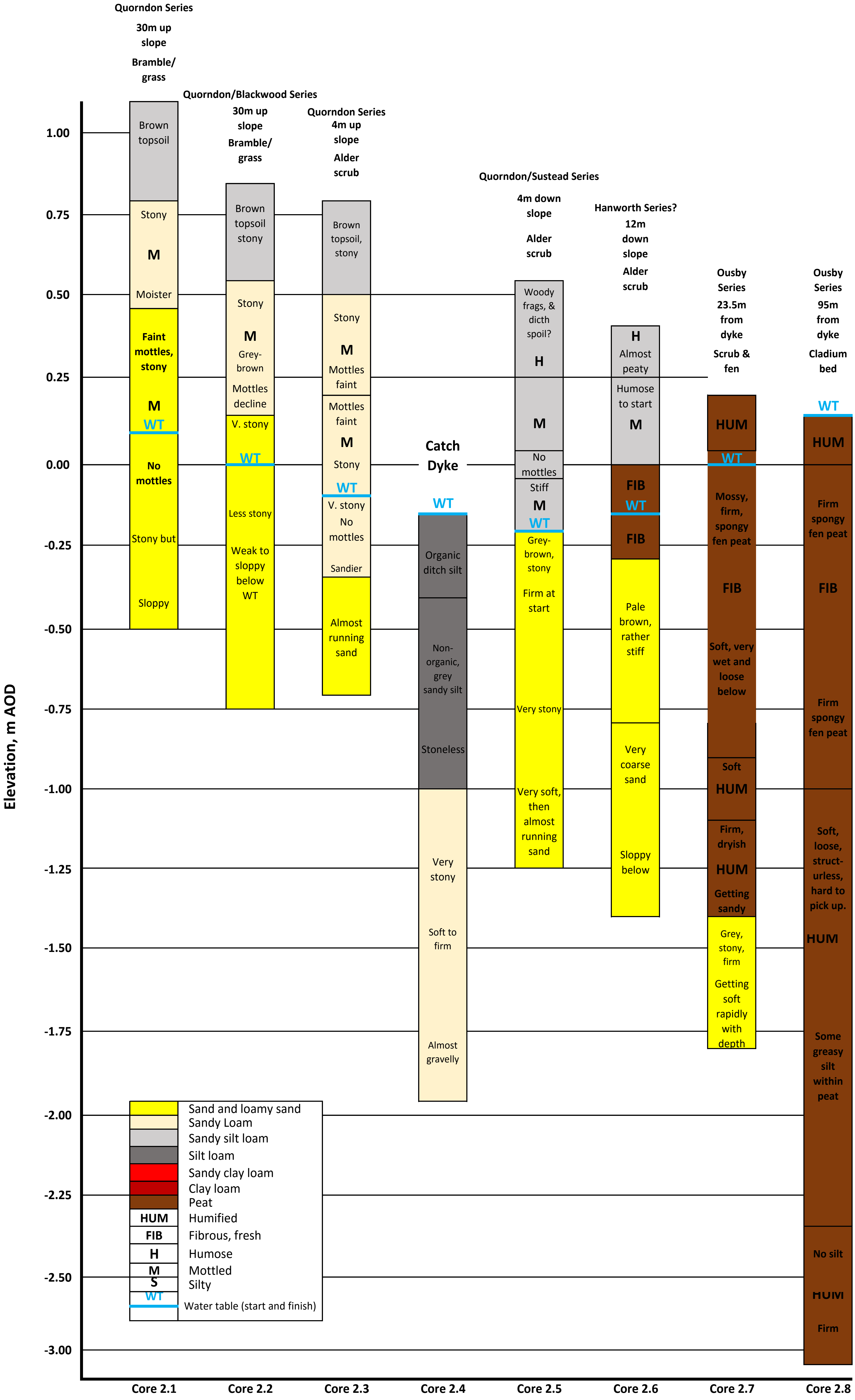


Figure 3c. Soil Type and Shallow Stratigraphy, Transect 3.

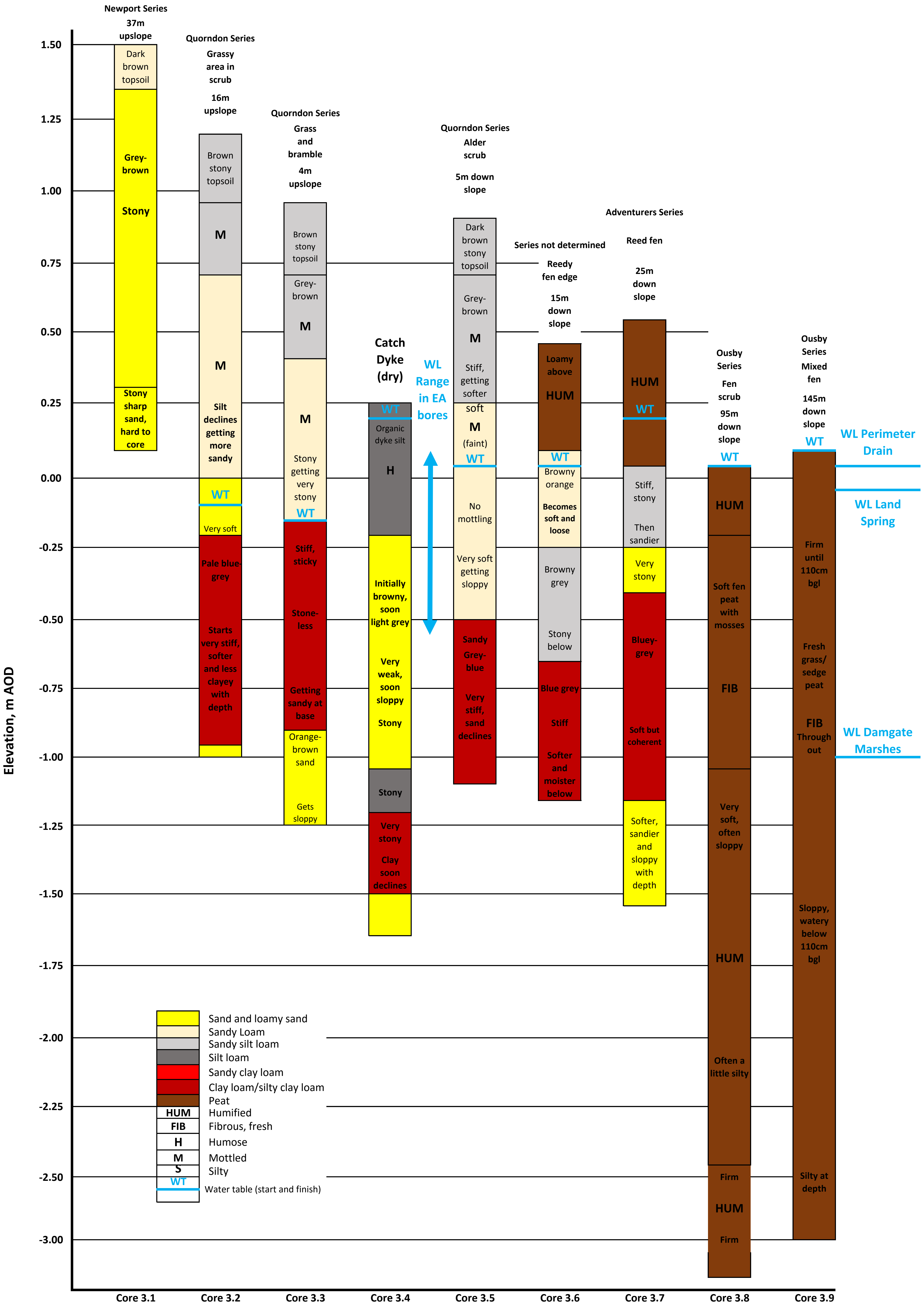


Figure 3d. Soil Type and Shallow Stratigraphy, Transect 4.

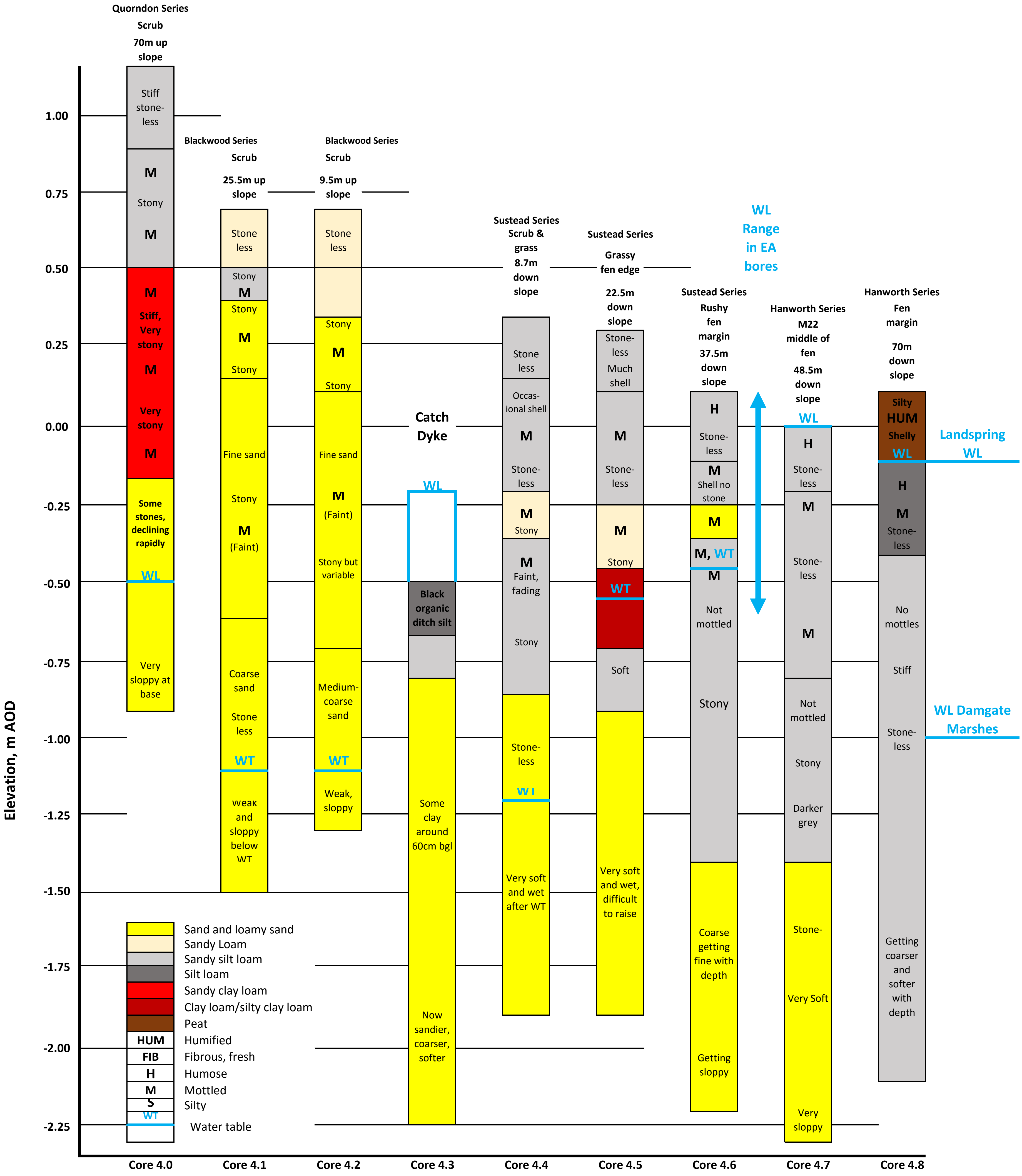
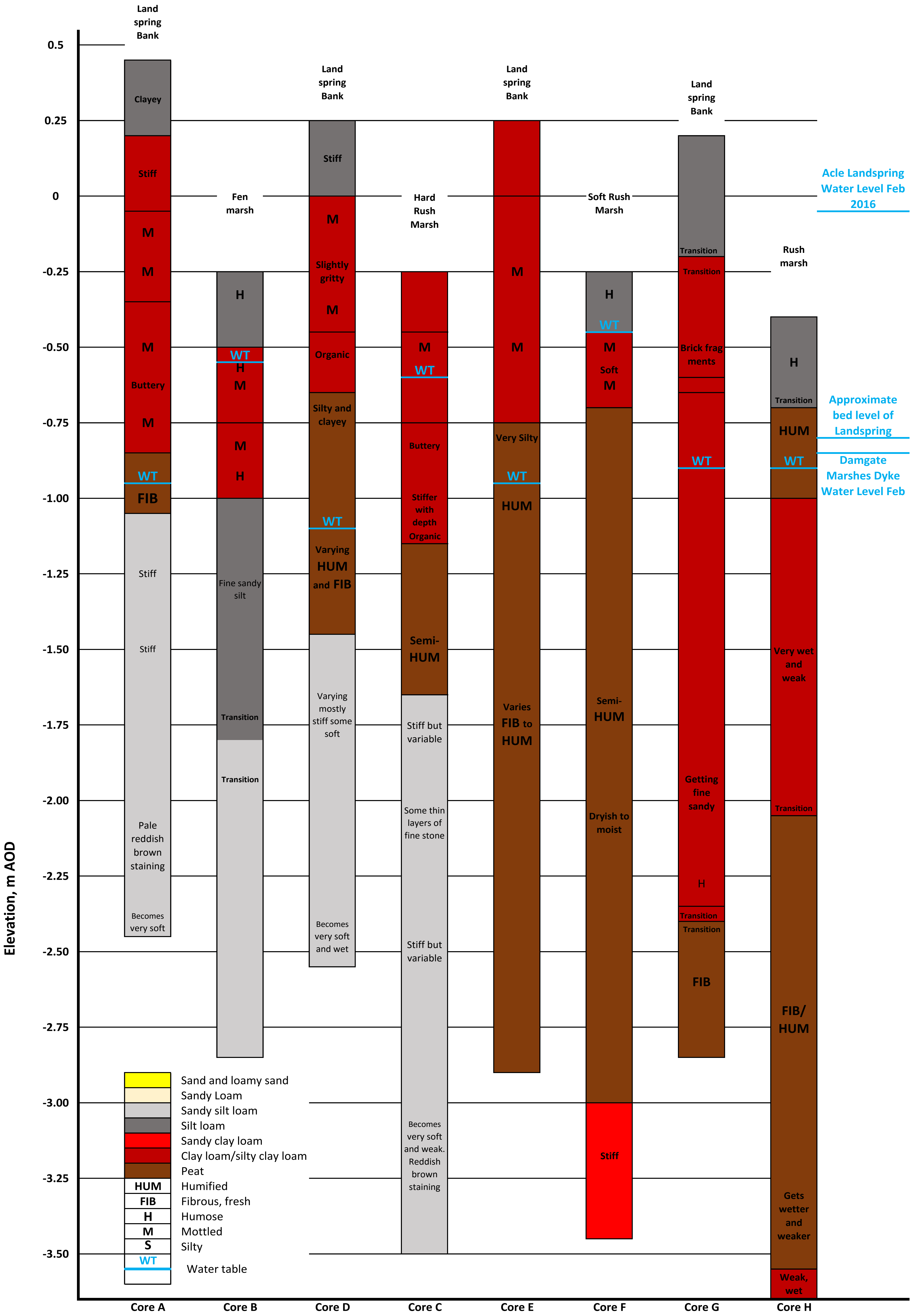


**Figure 3e. Soil Type and Shallow Stratigraphy, Damgate Marshes.**



topographical survey. Where possible each profile was assigned to a Soil Series so that HOST classification and conceptual eco-hydrological modelling could be undertaken (see later sections). A few cores did not key out clearly to Series but nearest approximations could be made and Host Class and Models were usually clear. The standard texts of Avery (1980) and Clayden and Hollis (1984) were used to define Series, supplemented by text and profiles in Hodge et al (1984), Hazelden (1980) and profiles in CU (2014).

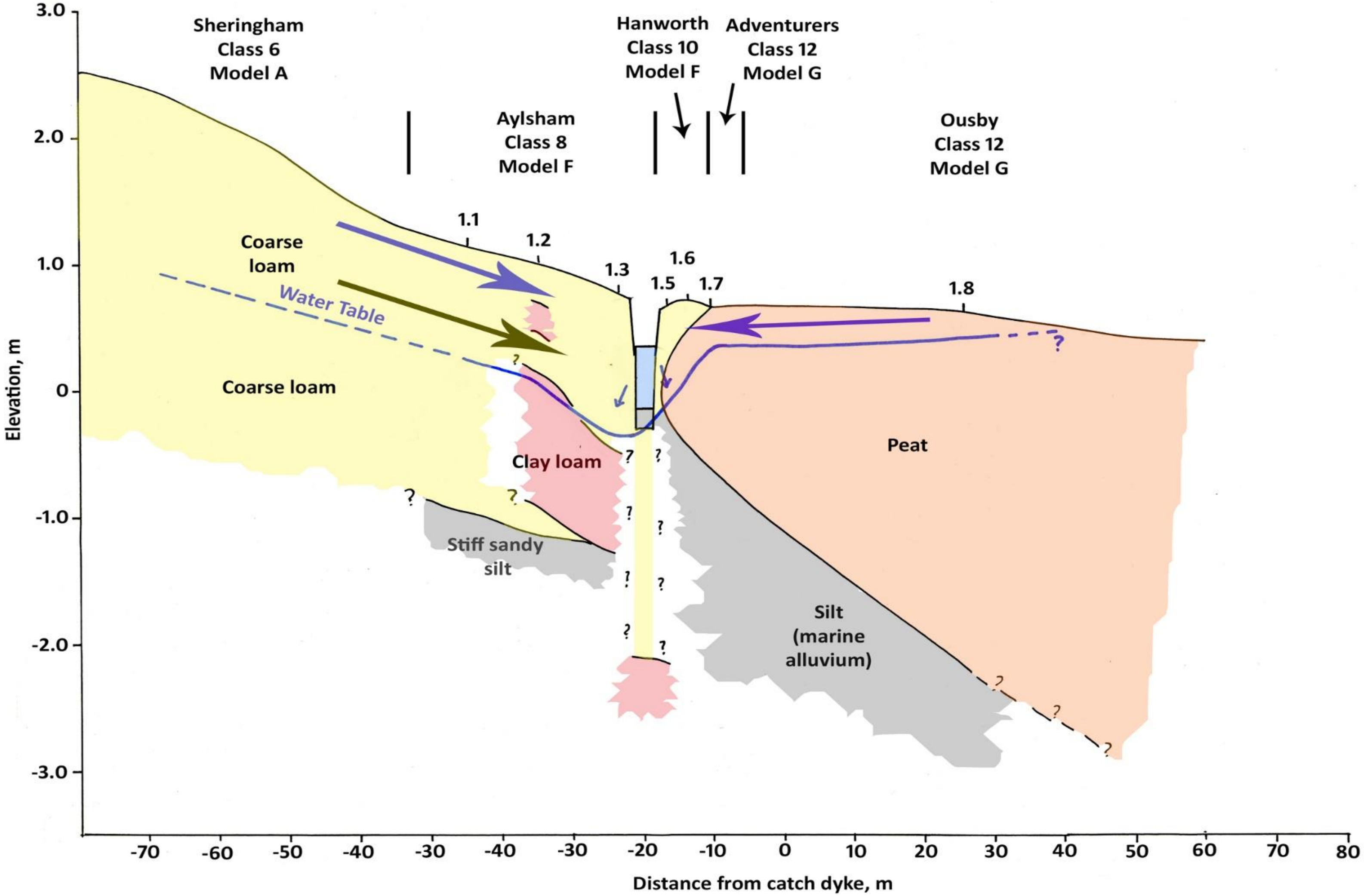
Coring of the high land which sits above all of the transects during the Pilot Phase (OHES 2014) showed the soils to be either Wick Series or Sheringham Series, the former being a stony profile on the hill crest, the latter being a stoneless soil in Loess on the slope toward the catch dyke. Both are permeable coarse loams, Host Class 5 and 6 respectively. They facilitate recharge of drift groundwater and the down slope movement of water to the wetland margin. The four transects show some significant differences along the catch dyke

**Transect 1** lies in the far west of the site, at the “head” of the valley system, terminating close to the recently excavated flight pond. Core logs are shown on Figure 3a, with a scaled cross section at 4a. On the upland side of the catch dyke, all cores are Aylsham Series, brown earths in coarse loamy, permeable profiles with gleyic features at depth. The water table was consistently 0.9-1.1m below ground level (bgl). Closer to the catch dyke, a curious body of clayey subsoil was contacted in cores 1.2 and 1.3, but was not found immediately adjacent. The lateral boundaries of this unit are uncertain but it must be discrete and suggests a clayey infill of a hollow or pit in the coarse loam. The clayey material appears to moderate the decline of the water table toward the catch dyke. The intensity and range of mottling (which indicates the range of groundwater fluctuation) in the coarse loams increases towards the catch dyke.

The water level in the catch dyke is perched on ditch silt above the groundwater either side. The dyke itself appears to sit over a narrow but deep column of silty coarse sand, which itself sits above clay loam. The corridor of the dyke has a peculiar stratigraphy, which seems to change laterally over very short distances. Strata with very different characteristics appear to terminate at the column of sand under the dyke. It is possible that the clay loam upslope and the silt downslope of the dyke have common origins and are closer in texture than the diagram suggests – both are stiff but sandy deposits. Even so, the narrow but deep trench of sand under the dyke is difficult to explain. It appears to be artificial, associated with the dyke, but there is no obvious reason for the creation of such a feature.

On the fen side of the catch dyke, the surface layers of the first two cores are rather humic sandy silt loam with a buried layer of peat which suggests possible deposition of ditch material when the catch dyke was first dug. There is mottling in the deeper section of the mineral soil. The surface sandy silt loam thins rapidly and is absent by 8m from the centre of the catch dyke, when peat becomes the surface layer, rapidly thickening to around 3m near to the pond. Below the peat is a stiff, grey or blue-grey silt loam, sometimes clayey or fine sandy, which is assumed to be the upper surface of the marine alluvium (Hazelden 1980). The peat profile near to the catch dyke and at the surface is humified, but deep peat away from the catch dyke is fresh and fibrous. The base of the peat has a steep slope, but less so than in transects

## Figure 4a. Scaled Cross-section of Soils and Hydrology for Transect 1.



further east, and the peat is generally shallower, both consistent with Transect 1 being at the "valley head".

There is a clear trough in the groundwater table associated with the catch dyke. Figure 4a indicates the drawdown affects surface peat for at least 40m into the fen. This long-standing depletion of surface water levels, which may have been stronger historically when the dykes were well maintained, may be responsible for the humified peat layer which here extends across the surface of the peat.

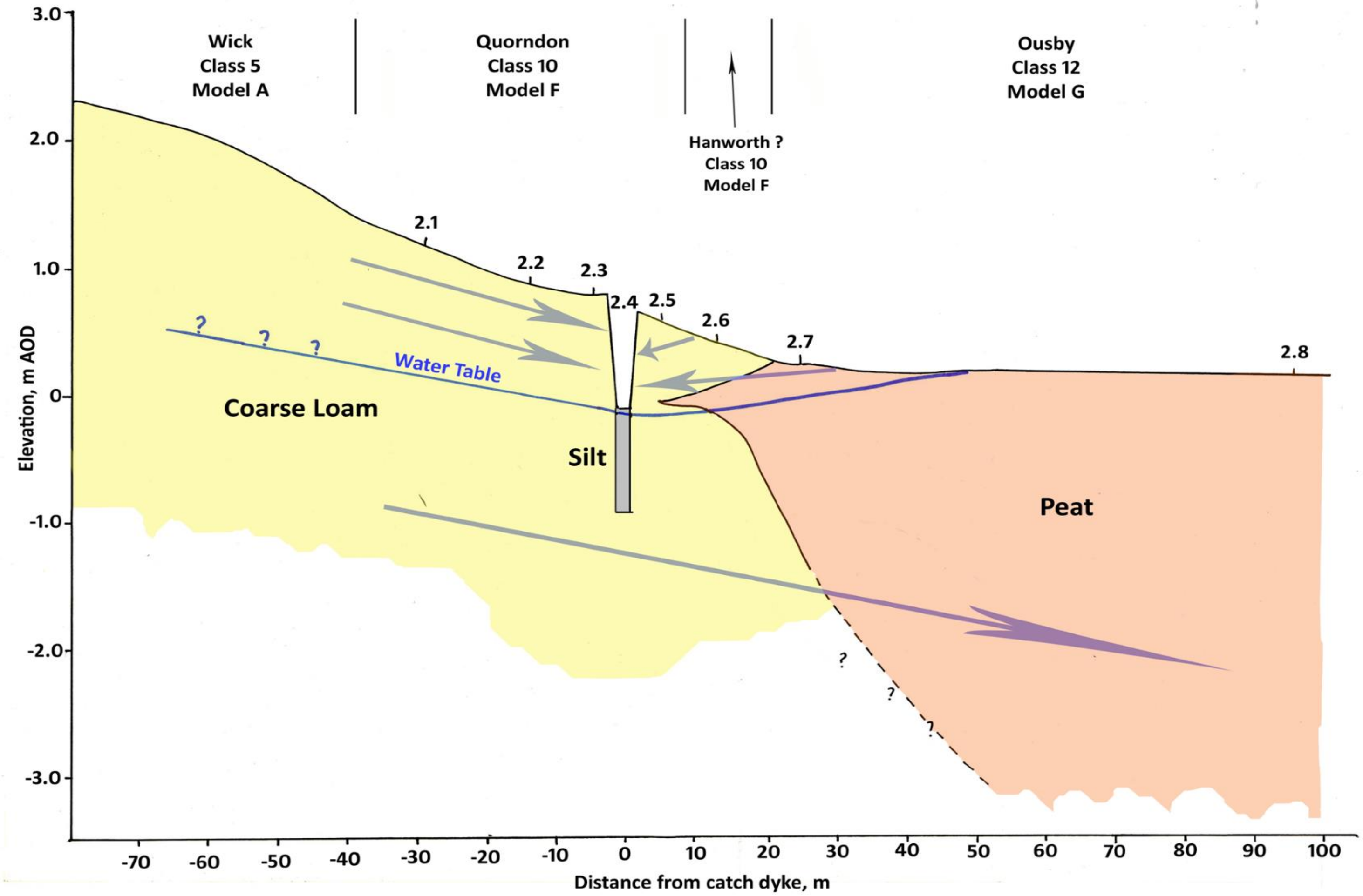
There is some uncertainty about the behaviour of the water table around the catch dyke itself. The water table appears to dip beneath the dyke, not intersect with the water level, suggesting the ditch is perched. If so, the groundwater must be moving eastwards along the axis of the catch dyke underneath the line of the dyke, being supported by the clay loam and stiff silt flanking the dyke.

In terms of soil hydrology, the upper slopes (Wick/Sheringham series) are freely drained permeable soils with the water table below 2m. Rain infiltrates vertically to the deep groundwater which then flows downslope towards the floodplain (Model A). On the toeslope, gleyic brown earths (Aylsham Series) have a shallower and more strongly fluctuating water table. Rain percolates down profile to the water table, but downslope lateral flow is significant and prolonged in the upper soil layers (Model F). On the downslope side of the dyke, immediate soils are also Model F, but because of the catch dyke, flows are reversed and move against topographic slope. The water table is higher with lateral flow closer to the soil surface. The soils are true ground water gleys, with humic surface layers, Hanworth Series. The mineral margin of the dyke quickly passes to true peat soils with persistently high and near surface water tables, but still providing lateral flow where the peat is sufficiently open-textured. This is Model G hydrology. Such lateral flow is again against the topographic gradient because of the draw of the catch dyke.

**Transect 2** (Figures 3b and 4b) shows a classic sag in groundwater tables associated with the catch dyke. The soils upslope of the ditch are very light-textured, mostly sand or loamy sand and very free draining, allowing groundwater to move rapidly to the fen margin. The water table is close to the surface near the dyke, all three cores being groundwater gleys of the Quorndon Series.

Downslope of the catch dyke, the first two profiles are very similar to the upslope profiles, with mottling suggesting groundwater fluctuation close to the surface. The fen side however shows a clear transition to wetland soils. The groundwater gleys have a mineral surface horizon, but both are humic to peaty. Core 2.6 has a thin layer of peat buried beneath the surface sandy silt loam. After 15-20m, peat reaches the surface of the profiles, initially with shallow humified peat, but then a significant depth of fresh fibrous peat over more humified peat below. The fresh peat was mostly very loose and watery. Unlike Transect 1, the marine alluvium was not contacted under what was much deeper peat. The base of the peat is marked by a steep decline at the highland margin.

## Figure 4b: Scaled Cross-Section of Soils and Hydrology for Transect 2



The catch dyke in Transect 2 did not have perched water, the water table being just below the dyke bed. Below the organic dyke silt is a deeper profile of non-organic sandy silt. If this is also in-fill silt, the original dyke seems unnecessarily deep. Otherwise, the catch dyke sits within deep coarse loam. With deep permeable profiles both sides of the catch dyke, and no low permeability clay or even stiff silt, the water table profile adopts an unusually regular and shallow sloped profile, dipping towards the catch dyke in both directions. Consequently, impacts of the dyke extend for some distance in both directions, around 50m into the fen. Soil water in the fen moves against the topographic gradient into the catch dyke.

Soil hydrology follows a classic hill slope sequence. High up the slope, freely draining Wick soils provide downward percolation to a deeply subsurface water table (Model A). All three upslope profiles and the first two downslope soils are groundwater gleys in coarse loamy drift. Rain moves down profile to a shallow, fluctuating water table with predominantly lateral movement of groundwater (Model F) to the catch dyke. Soil series vary according to stoniness and humic nature of the topsoil. Peat profiles (Ousby Series) on the flat marsh have the highest water tables on the Transect (Model G), but within 50m of the catch dyke, the water table is drawn down and moves towards the dyke against the topographic slope. After 50m, decline in elevation of the fen surface brings the water table close to ground level. If the unmanaged catch dyke is dredged to original depth, the impact on water tables could be severe.

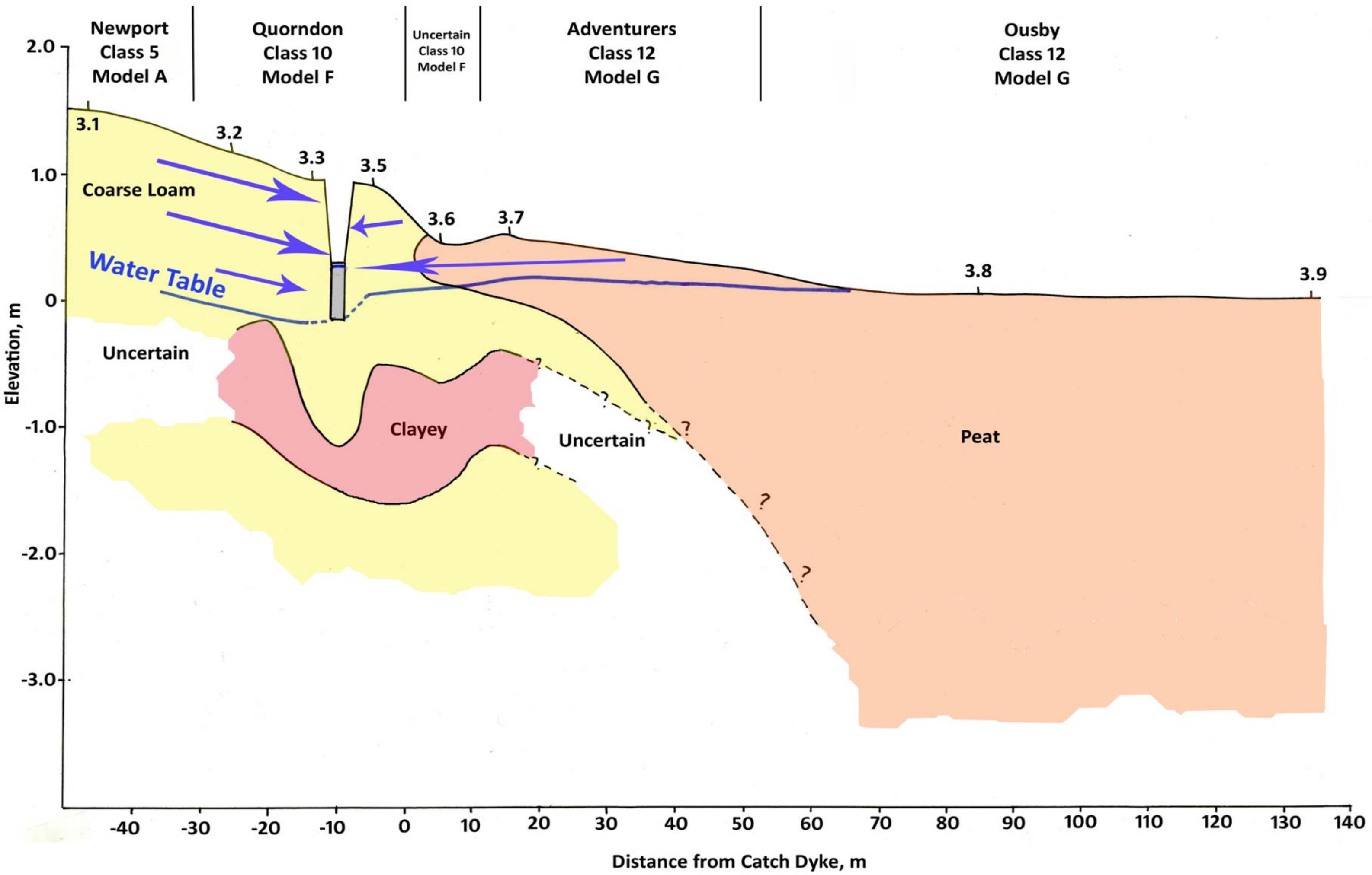
The water table range as indicated by recorded mottling is 0.5-0.75m above the saturated rest level. Without the catch dyke, the typical water table could be expected to rise to around 30cm bgl, possibly higher during sustained wet periods. Because of the decline of the fen surface below, intersection with the water table would lead to expression of groundwater in a seepage zone.

**Transect 3** is shown on Figures 3c and 4c. The first core, highest up the slope, was dry, sandy soil of the Newport Series. Coring did not contact the water table. Further down slope were sandy loam groundwater gleys of the Quorndon Series, with a deep water table which may be supported by a slowly permeable clayey sub-soil. This clayey material is not laterally defined. Down-slope of the dyke, the clay becomes very saturated and comparatively soft, and either discontinues or declines steeply beneath the peat – it was not contacted again after Core 3.6. As with Transect 1, it is possible that this has some relationship to the marine alluvium.

The catch dyke, which was more or less dry at the time of coring, has an infill of organic dyke silt over stony, sandy sub-soil. The silt seems to be maintaining a localised perched water table. The main water table seems to pass just under the dyke.

Downslope of the dyke, the Quorndon profiles continue but a peat profile is rapidly established, initially humified Adventurers Series, and then as with Transect 2, fresh fibrous peats of the Ousby Series. The peat can again be very watery and loose. Parts of the fibrous profile have fen moss peat. Again, the highland boundary of the peat shows a steep decline, such that the base was not recorded in the main fen. The marine alluvium was not contacted.

## Figure 4c: Scaled Cross-Section of Soils and Hydrology for Transect 3



Core 3.6 is recorded in a shallow depression that runs parallel to the main catch dyke. It has the feel of a terrestrialised dyke. The water table profile from up- and down-slope dips sharply toward the catch dyke, resting in freely draining coarse loams and peats of variable hydraulic conductivity. Only core 3.2 is influenced by the clay subsoil. The consequent impact on the shallow fen water table seems to extend to 50-60m from the dyke. The fen surface declines in elevation, eventually intersecting with the groundwater table controlled by the dyke. Again, the catch dyke reverses groundwater flow on the down-slope side.

The sequence of soil types is much the same as for previous transects – freely draining soils of Model A on the upper-most slope, groundwater gleys of Model F around the catch dyke, with high water table peats (Model G) in the fen. Mottling in upper toeslope profiles suggests a saturated water table that would rest at around 20cm bgl if the catch dyke were not a factor, with surface expression of groundwater when the toe slope surface declines below this level. A significant seepage slope may develop in such an area.

**Transect 4** crosses the south-north catch dyke, which at this location lies close to the Acle Landspring. It has a very different character to the other transects (see Figures 3d and 4d). The preponderance of coarse loamy soils (most of the Transect) is striking. The water table was very low upslope and below the catch dyke, rising to the surface only in the centre of the fen.

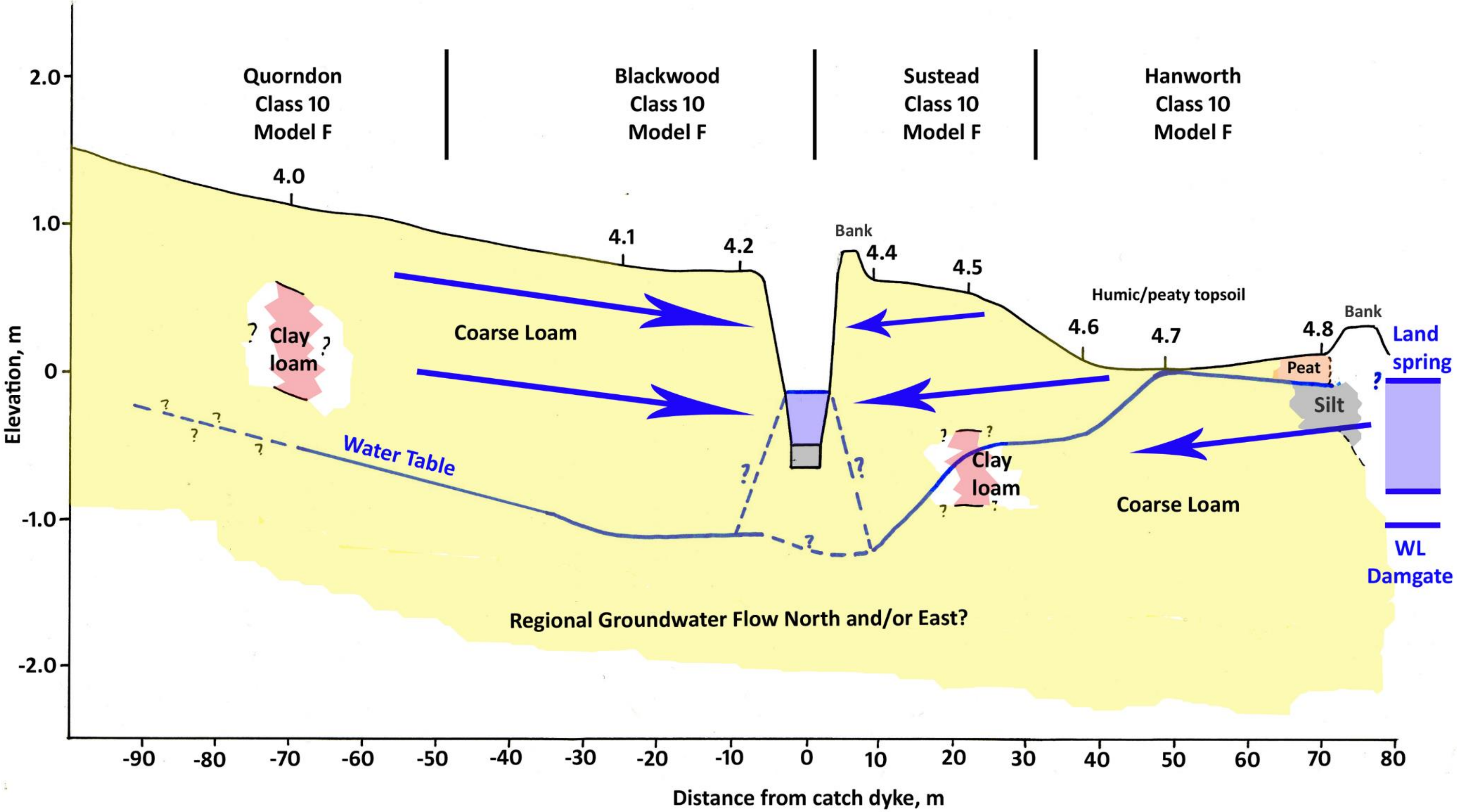
Only two areas of significant clayey strata were recorded, one a very stony layer some distance from the catch dyke, and one downslope under Core 4.5. The latter appears to provide local support of the groundwater. The boundaries of both clay bodies were not defined, being contacted in only these cores.

Silty material was recorded on the bed of the catch dyke, although it was relatively shallow and underlain by firm coarse sandy loams. There was also a localised and relatively thin bed of silty material near to the Acle Landspring. A small bed of surface, humified peat was located above this silt bed. The peat grades into peaty/humose topsoils across the low-lying fen. Otherwise, true peat was absent from this part of the site.

The upland has a typical slope profile at a similar elevation to Transect 3, but the downslope topography is rather different, due to the engineering of the catch dyke and the Acle Landspring. Both dykes have marked banks on the fen side. Overall, the fen surface has a distinctly dished profile. The catch dyke seems to have been dug a little above the break of slope. The dyke water level is perched by the silt bed. Hence the catch dyke is likely to be contributing to groundwater levels flanking the ditch. Were the ditch to be dredged, significant dewatering of the permeable up- and down-slope soils could be expected.

In terms of soil type and hydrological functioning, the higher upland edge again has free draining coarse soils, with a very low water table. Rainfall moves down the profile to a deeply sub-surface water table. The remainder of the downslope soil profiles are all ground water gleys, where the water table is high and fluctuates near to ground surface, characterised by persistent lateral flow in the upper horizons (Model F). There is no transition to peat soils and other hydrological models. Soil series are differentiated by stoniness in the profile, and by the presence and nature of humic and peaty topsoils.

## Figure 4d: Scaled Cross-Section of Soils and Hydrology for Transect 4



The groundwater sag beneath the catch dyke appears to be very marked. The water table on the upland slope, under the catch dyke and in the proximal areas of the fen were the lowest groundwater levels recorded anywhere on the site. There are two possible drainage routes for the groundwater under the catch dyke:

- Northwards, underneath and along the axis of the catch dyke, exiting the site to the low-level pumped drainage systems in the Halvergate/Acle Marshes. The symmetrical trough shown in the cross section certainly implies flow to the north. However, the level in the pumped Acle Landspring is only minus 0.20m AOD just north of the site. The groundwater level below the catch dyke is minus 1.0m AOD. The groundwater beneath the catch dyke must therefore be responding to the pumped level much further north, with the intriguing possibility that the trough continues under the Landspring some distance northward.
- Eastwards, to the low level Damgate Marshes, passing under the fen and under the Acle Landspring, entering marsh dykes east of the track. The ditch levels in the Damgate level were recorded by Lidar at approximately minus 1.0m AOD (see Figure 5c), although the season of the LIDAR is not known, nor how representative this level is. The level in the marsh dykes near to the Landspring was laser levelled at minus 0.86m AOD in February 2016. Although the level is consistent with the groundwater trough and provides a groundwater gradient to the east, this is not expressed in the water table profile which in fact rises eastwards from the low point. One possibility is that deep groundwater is moving out of the fen, east to Damgate. The resulting low groundwater table level is then being recharged back into the fen from the Acle Landspring. The level in the Landspring, held constant by the sluice about 1m above the groundwater level in the trough, provides a hydraulic gradient into the fen. This theory assumes (a) the perimeter of the Landspring is sufficiently permeable to leak into the fen and (b) the east margin of the Landspring and the marshes in Damgate are underlain by permeable loams allowing leakage eastwards.

### *Soil Cores in The Landspring Bank and Damgate Marshes*

These assumptions were investigated with 8 paired cores in the Landspring bank (Damgate Marshes side) and the Damgate Marshes – see Figure 2 for Locations and Figure 3e for the cores.

The main bank of the Landspring appears to be silty clay, probably “made” (some brick fragments were raised in Core G), laid on top of the local material. The base of the made bank is around minus 0.75m AOD in the first three cores, around 15-20cm above the level of the groundwater trough and the Damgate dyke water level. It is also *approximately* the level of firm bed of the Landspring. Probings of the dyke bed showed there was around 0.25m of soft and mobile dyke silt over the firm bed of peat in the north or silty sand to the south. The peat bed in the north is likely to be relatively thin and underlain by the silty sand, consistent with the bank and fen cores in that area. The bed of the Landspring is *relatively* permeable, depending on the ability of the bed silt to reduce leakage. In the fourth core in the bank, furthest south, the made bank rests on what is probably natural silty clay and is relatively impermeable to groundwater. Investigations suggest that water can move into the fen to the west, and east to Damgate, for the northern length of the Landspring (for most of the length of the south-north catch dyke), although leakage rates are uncertain. The water table in the Landspring bank is about 15-20cm below dyke bed level, and about the same as the water level in the Damgate Marsh ditches.

Regarding the Damgate Marsh soils, clay was located on the surface, ceasing between minus 0.75m to minus 1.0m AOD. This is at or just higher than the groundwater trough. In the northern-most marsh core, the clay was underlain by silt loam and then by the sandy silt loam. In the next marsh core (C), the silt loam is replaced by humified peat which has similar, more restricted hydraulic conductivity. The upper surface of the relatively permeable sandy silt loam is around minus 1.70m AOD in these marshes, but is not contacted at all further south. It is replaced by a deep bed of peat around 2.5m thick, and then by silty clay. There is a layer of silty clay within the peat in the southern-most Core H. The peat is very variable in nature, from humified to fibrous. Its transmissivity is therefore uncertain, as is its ability to provide a pathway for groundwater leaking from the SSSI.

The critical cores in terms of the south-north catch dyke are the northern pairs, A/B and C/D, as they are directly opposite. The more permeable loams at around minus 1.70m AOD are significantly below the groundwater trough recorded at minus 1.0m AOD. There is a lower permeability layer between the coarser loams and the clay at minus 1.0m AOD. Leakage of fen groundwater into Damgate Marshes under the Landspring dyke is possible but is likely to be modest. In addition, the hydraulic gradients very flat – the trough in groundwater and the marsh dykes both being minus 1.0m AOD in the autumn.

**Conclusion:** The coring has established that there are pathways from the deep coarse loams of the toe slope and fen through to the lower level Damgate Marshes, and that there is potential leakage through the bed of the Acle Landspring. However, permeabilities are moderate and the hydraulic gradients from the fen groundwater table moderate to low - there is no hydraulic gradient from the groundwater “trough” to the Damgate Marsh water table. Consequently, while there may be leakage eastwards, compensated by inflow from the Landspring, it can only be partially responsible for the water table profile observed in Transect 4. Most likely is a combined northern groundwater flow and eastwards leakage, but there is great uncertainty regarding proportion.

## 3.4 Topography

The site was levelled (Figures 5a and b) using satellite DGPS, with laser levelling in the scrub areas where satellite signals were blocked. Levels outside of Mr Dyball’s and the Acle Lands Trust land (including Damgate Marshes (Figure 5c) are derived from LIDAR data.

The site is tucked into a western embayment of the Halvergate Marshes complex. The current project area occupies a landscape context similar to a valley fen[1]. The sheep field to the north lies between 2.50-5.50m AOD. It falls from west to east, and also southwards to the fen. The slope declines to the catch dyke whose banks are at around 0.75-1.0m AOD along the whole of its west-east trending length. It sits significantly above the flat peat marsh, which is

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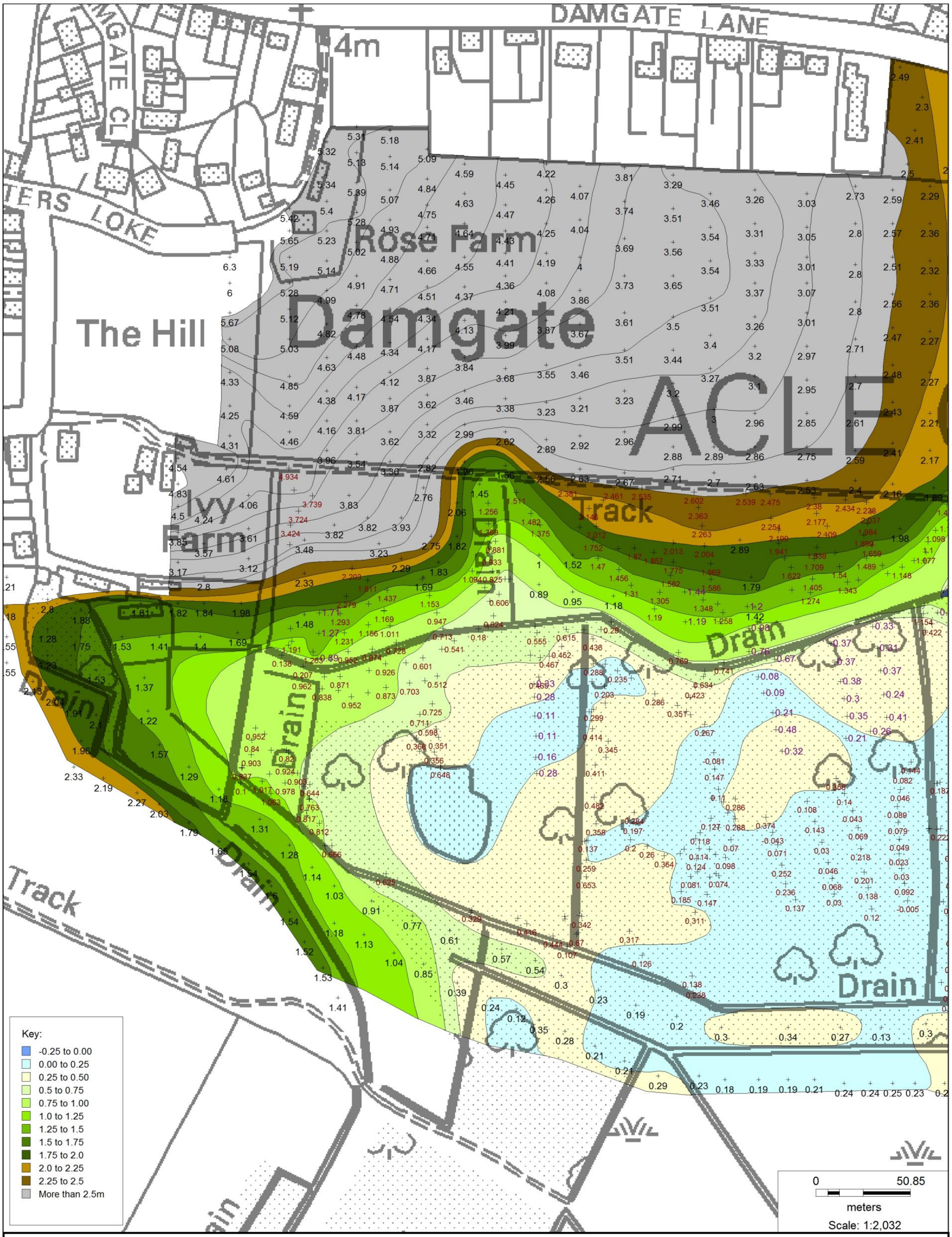
[1] Francis Rose referred to the site as a valley fen when he first visited in the 1950s (NE file notes).

Figure 5a. Topography, West of Site



\+ 0.24 = Land elevation (from DGPS)

\+ 0.24 = Land elevation (from Lidar data)

\+ 0.24 = Land elevation (from Laser groundtruthing)

Note: All levels in metres (AOD)

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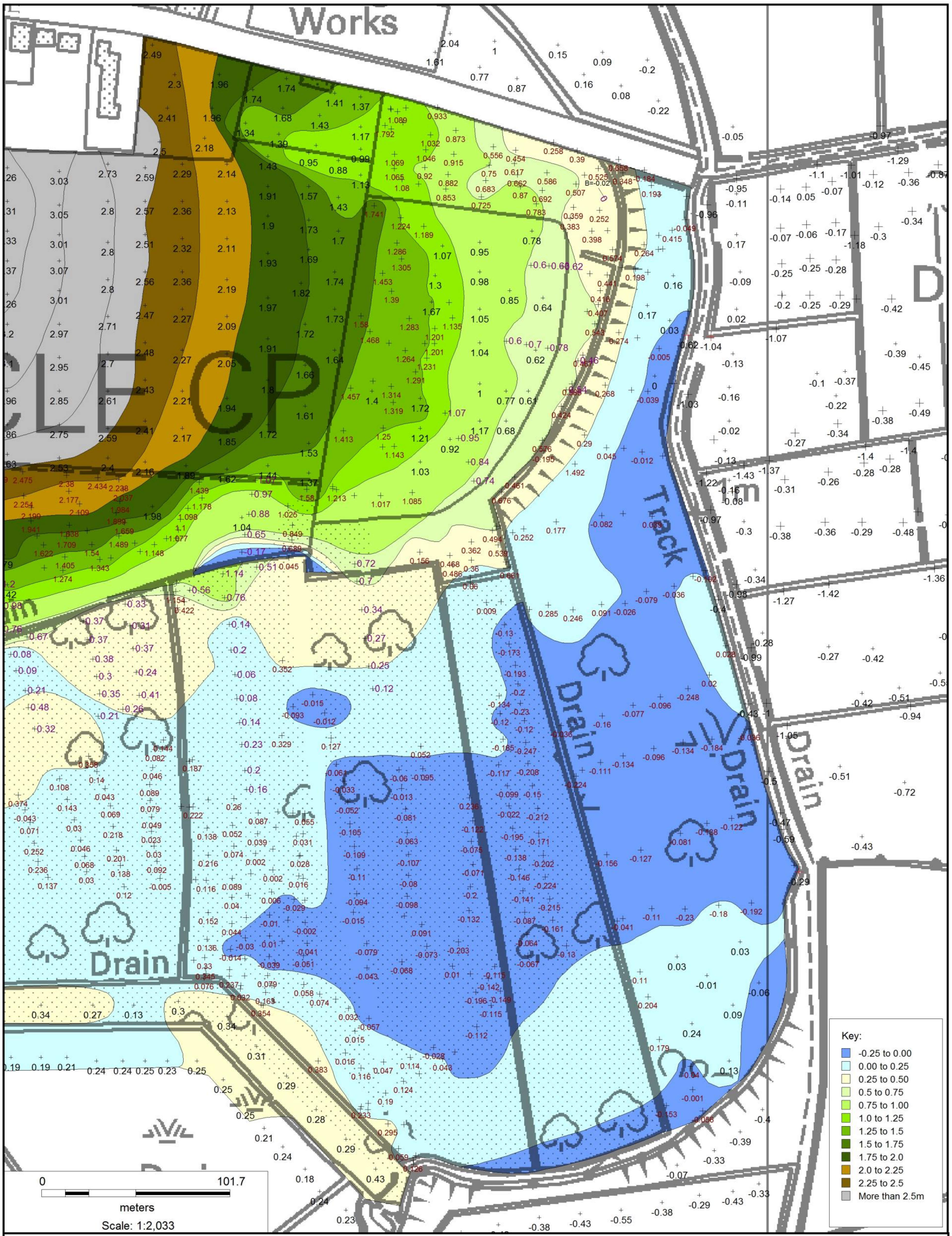
**Figure 5b. Topography, East of Site**



\+ 0.24 = Land elevation (from DGPS)

\+ 0.24 = Land elevation (from Lidar data)

\+ 0.24 = Land elevation (from Laser groundtruthing)

Note: All levels in metres (AOD)

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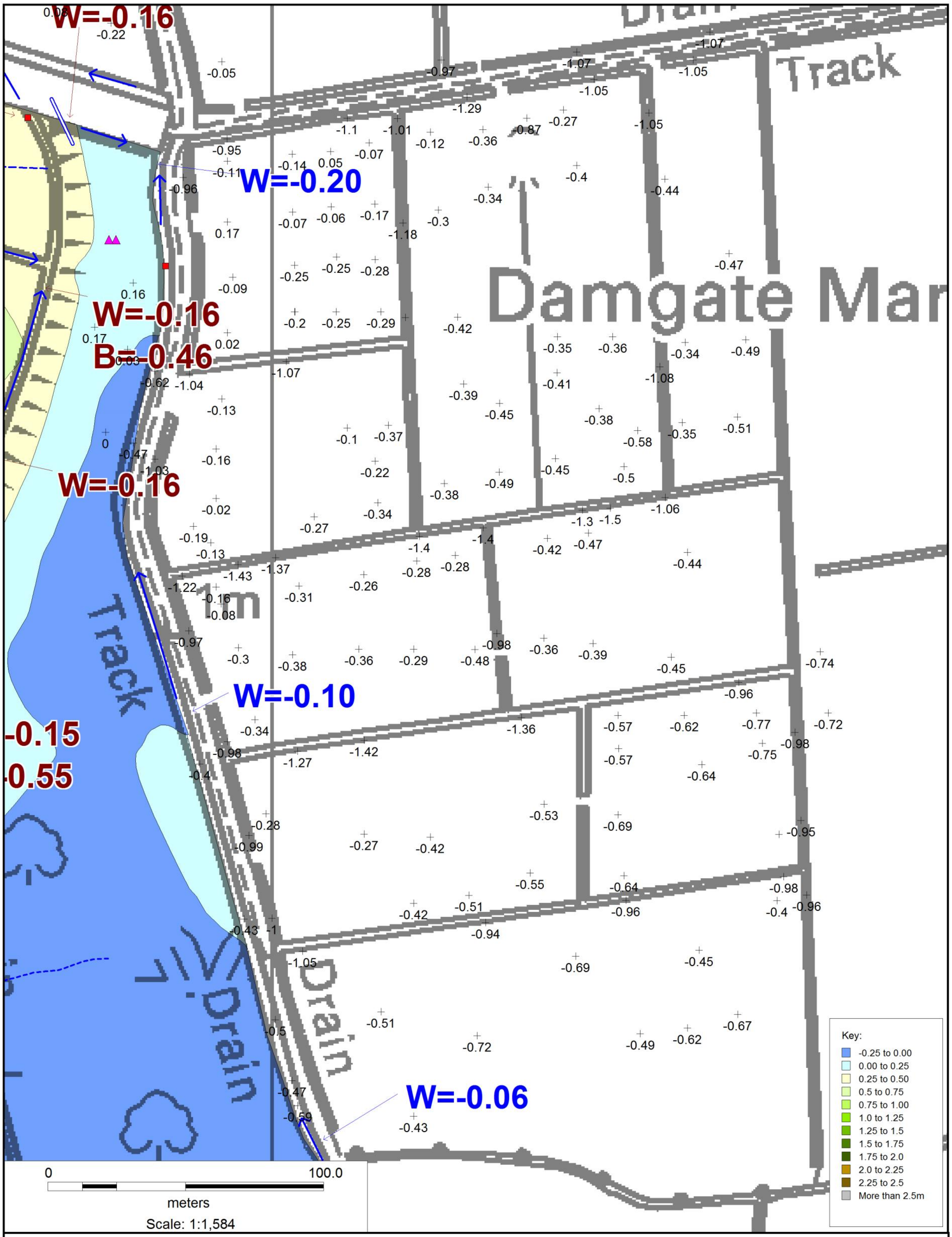
**Figure 5c. Topography in the Damgate (Halvergate) Marshes, from LIDAR surveys.**



+ 0.24 = Land elevation (from DGPS)

+ 0.24 = Land elevation (from Lidar data)

+ 0.24 = Land elevation (from Laser groundtruthing)

Note: All levels in metres (AOD)

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between 0.05 and 0.25m AOD. The south margin of the site is bounded by the southern perimeter dyke whose level is held at around 0.06m

There is also a topographical fall on the peat surface from west to east. The westernmost compartment is at the upper margin of the valley edge. The peat fen surface here and in the western margin of the next compartment is around 0.5m higher than the flat fen to the east. The peat marsh surface continues to decline eastwards reaching 0m AOD around the line of Transect 3 and the power lines, and then declining to around minus -0.20m AOD in the lows.

The Acle Landspring around the eastern perimeter was maintained at minus 0.06m AOD in autumn 2015. It thus appears to be a raised carrier. The marshes of the Damgate Level are variable, with those nearest the Landspring around minus 0.3-0.4m AOD, a little lower to the south. Figure 5c suggests ditch water levels in Damgate are around minus 1.0m AOD, measured at minus 0.86m AOD in February 2016.

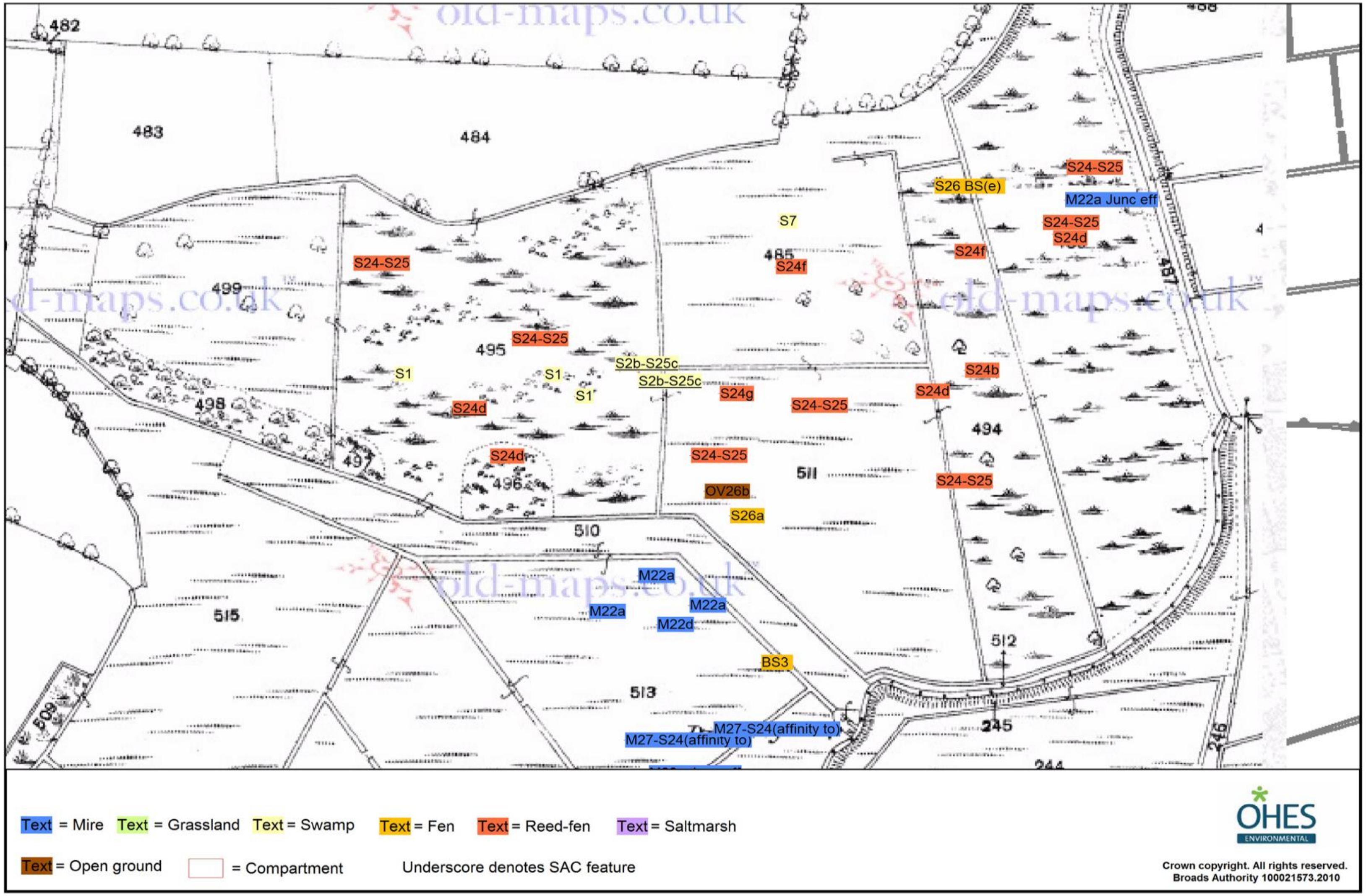
## 3.5 Vegetation

Vegetation recorded in 2007 (ELP 2010) is shown on Figure 6, overlaid on the OS 1886 map. The main communities recorded are given in Table 1.

**Table 1: Principle Plant Communities At Decoy Marsh.**

| **NVC community** | **Number of samples** |
|---|---|
| SAC Feature – *Cladium*-rich fen (also assigned to one of the below NVC types, mostly S24d and intermediate S24-S25). | 3 |
| SAC Feature – Calcareous pools (also assigned to the below NVC type | 2 |
| S24d *Phragmites-Peucedanum* tall-herb fen, Typical sub-community | 4 |
| S24f *Phragmites-Peucedanum* tall-herb fen, *Schoenus nigricans* sub-community | 2 |
| S1 *Carex elata* swamp | 3 |
| Intermediate:<br>S2b *Cladium* swamp and<br>S25c *Phragmites-Eupatorium* tall-herb fen, of the *Cladium mariscus* sub-community | 2 |
| Intermediate:<br>S24 Phragmites-Peucedanum tall-herb fen and<br>S25 Phragmites-Eupatorium tall-herb fen. | 7 |
| S24b *Phragmites australis-Peucedanum palustre* tall-herb fen, *Glyceria maxima* sub-community | 1 |
| S26a *Phragmites australis-Urtica dioica* tall-herb fen, *Filipendula ulmaria* sub-community | 1 |
| S26 *Phragmites australis-Urtica dioica* tall-herb fen, BS(e) *Calamagrostis canescens* sub-community | 1 |
| M22a *Juncus subnodulosus-Cirsium palustre* fen-meadow | 1 |
| S24g *Phragmites australis-Peucedanum palustre* tall-herb fen, *Myrica gale* sub-community | 1 |

**Figure 6: Vegetation Communities Recorded During the Fen Resource Survey (ELP 2010), overlaid on the 1886 OS 1st Edition Six Inch Map.**



As Figure 6 shows, there is considerable variation in fen type across the site, reflecting combinations of differing water table heights and scrub management history (OHES 2013). In 2007, the wettest communities of highest conservation value were generally found in the central compartments. They coincide with those areas marked out as fen in the 1886 OS map. The higher value communities are S1 *Carex elata* swamp (now in the Broads a community of dyke edges and low-nutrient fen pools) and an intermediate between S2 *Cladium* swamp and the *Cladium* sub-community of S25 *Phragmites-Eupatorium* tall-herb fen (typically restricted to former turbaries or swampy hollows in calcareous and base rich marshes). Examination of historical maps showed no evidence of turbaries on this site, though the possibility cannot be ruled out.

In dryer areas within the central fen, a *Thelypteris-Calamagrostis* dominated stand occurs, classified as a type of S24 *Phragmites-Peucedanum* fen. There are also small stands of species-poor and eutrophic reed fen, with *Phalaris arundinacea* and *Urtica* occurring along the margins of the main dykes.

The 2007 NVC survey does not record the pools[2] which occur within the carr along parts of the northern site boundary (just south of the catch dyke). These pools lie within an area of very soft peat and are often occupied by *C. elata* and sometimes *C. acuitiformis* swamp.

Eco-hydrological guidelines for some of these communities are published by Wheeler *et. al.* (2004). They suggest that optimum water levels associated with S2 *Cladium* swamp are generally well above the surface for most of the year. They state that "*Cladium* grows best when the water table remains between c. 15 cm below ground and 40 cm above, and standing water in winter may help to protect the growing point from frost damage". The report goes on to state that "Subsurface winter water tables and strongly subsurface summer water tables will lead to a loss of *Cladium* ". It is therefore no surprise that this community was not recorded in close proximity to the catch dyke, but only occurred within the central fen.

Wheeler *et. al*. state that optimum summer water tables within S24 fen will vary depending on the sub-community. At Decoy Carr, the main community type currently found is S24d (mean summer water table of 14.3cm below ground level) and S24f (mean summer water table of 14.5cm below ground level). Winter inundation is a natural feature of S24 and therefore would only be limiting if deep and persistent spring or summer inundation occurred.

The far east of the site contains transitional communities of grassland (MG10) and fen meadow (M22).

Further fen vegetation monitoring has been conducted by the Broads Authority on Decoy Carr in 2013 and 2015. The samples taken are roughly within the same area as used in the 2007 NVC survey (ELP, 2010). They show higher proportions of *Carex paniculata* and lower abundance/occurrence of *Cladium, Juncus subnodulosus* and *Carex elata* than was recorded in 2007. However, this is most likely due to subtle differences in quadrat placement rather than a floristic change in response to a change in site conditions. Because of scrub clearance, there is much more fen now than in 2007. Much of the site is now grazed, which is a significant management change. Mowing has become more regular and extensive in the *Cladium* beds to the west. The site would benefit from full re-survey and permanent monitoring plots.

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[2] This would not have been recorded in 2007 because the survey was restricted to open fen only.

## 3.6 Hydrological Data

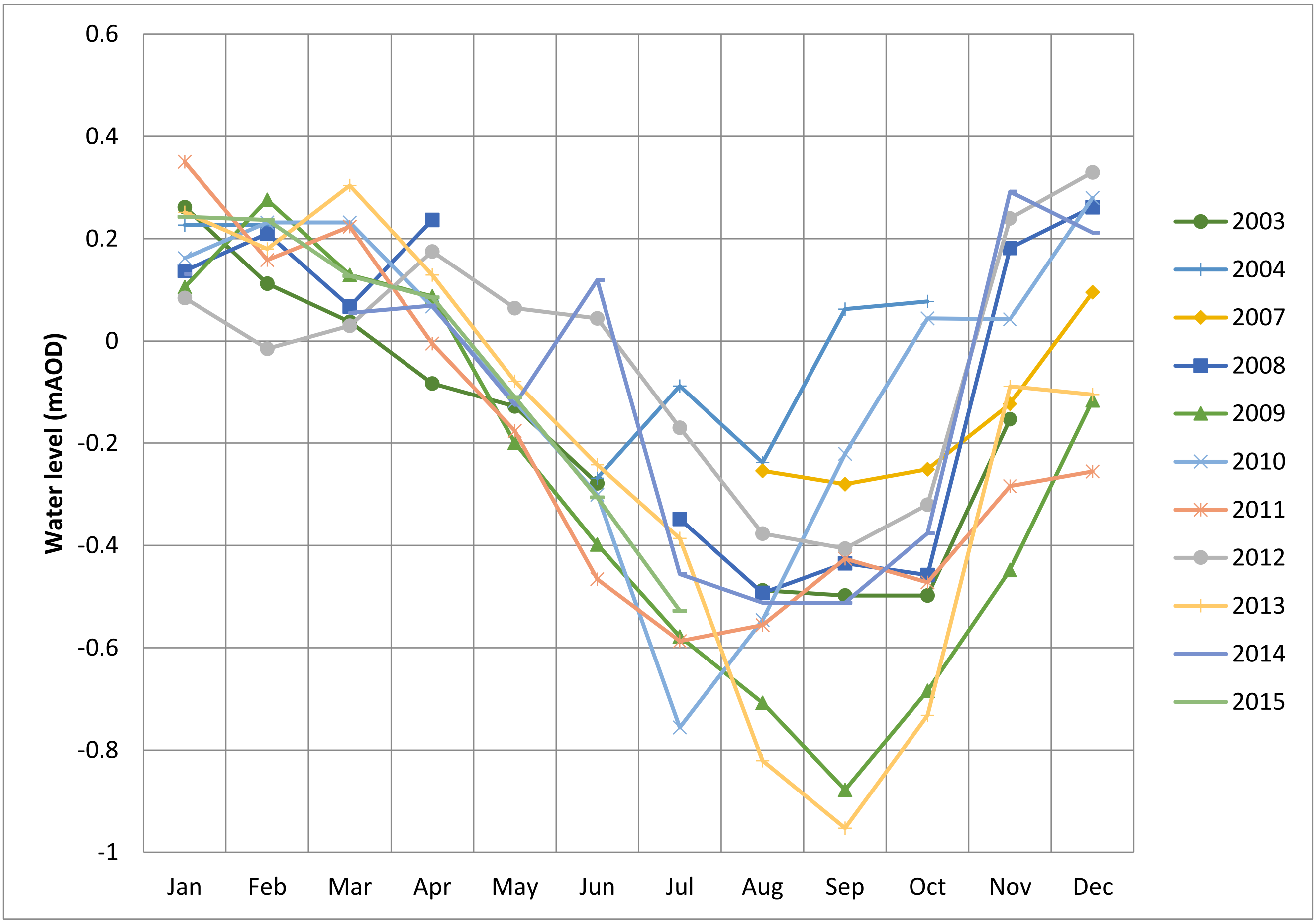
### 3.6.1 Water Level Data

EA has installed three piezometers between the south-north catch dyke and the Acle Landspring. Data for P2 and P3 in the period 2003 to 2015 were used for the analysis below. The piezometers are remote from the main fen areas but are helpful in interpreting water levels in Transect 4. Table 2 provides the mean water levels recorded for the two boreholes, with more detailed monthly water levels provided in Figures 7a and 7b.

**Table 2: Mean Water Levels Recorded For The Two Boreholes.** P2 at TG 640943 309701, P3 at TG 640896 309586[3]

| **Recorder:** | **Distance from Catch dyke, m** | **Water level, mAOD** | | |
|---|---|---|---|---|
| | | **Mean Summer** | **Mean Winter** | **Mean Annual** |
| Borehole P2 | 17 | -0.39 | 0.16 | -0.13 |
| Borehole P3 | 20 | -0.36 | 0.08 | -0.13 |

**Figure 7a. Water Level Data For P2, 2003-2015.** See Figure 10 for locations. Courtesy of EA



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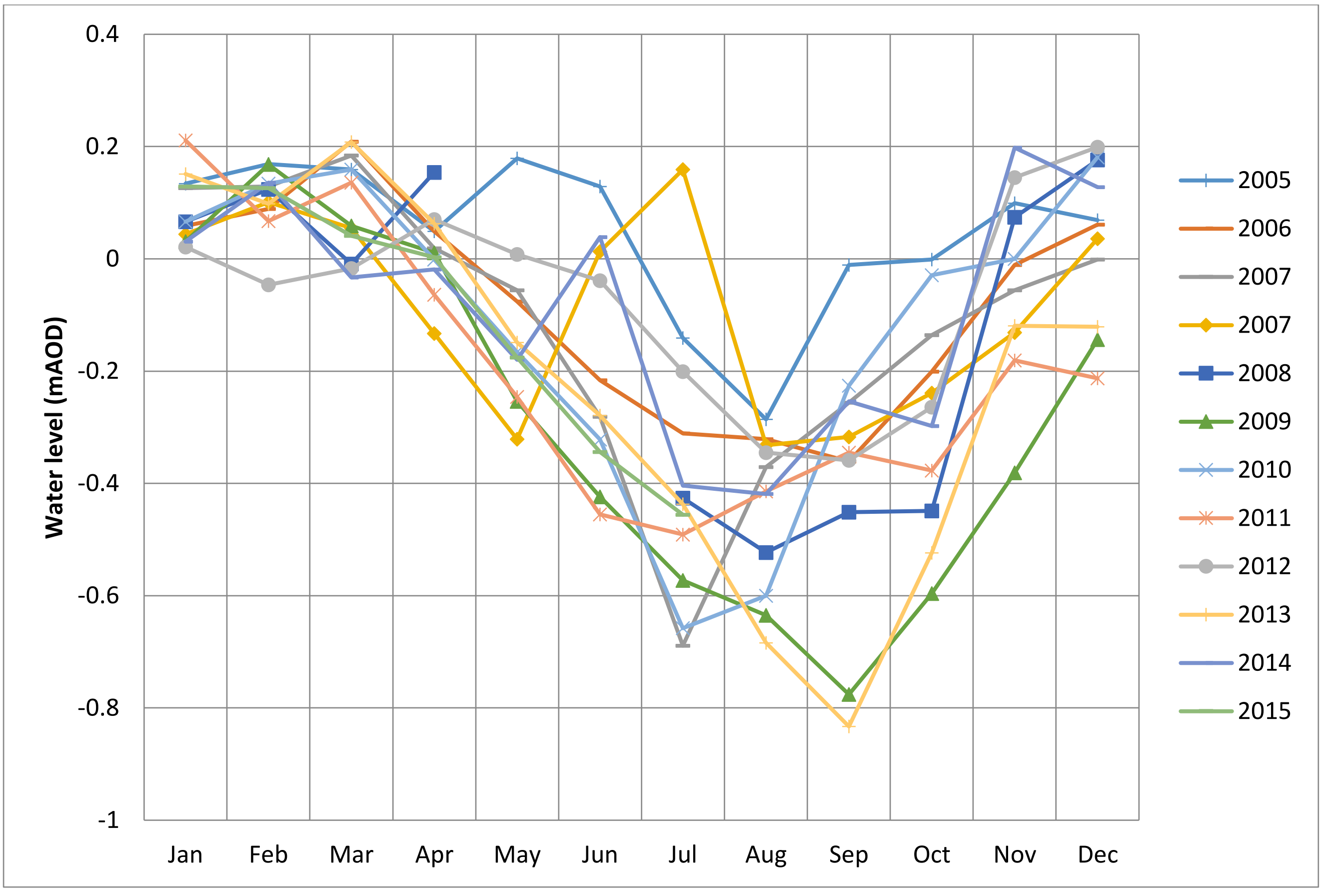
[3] The EA coordinates provided within the datasets for these boreholes are inaccurate.

**Figure 7b. Water Level Data For P3 (2003 to 2015).** See Figure 10 for locations. Data courtesy of EA



These data suggest:

- Water levels in summer are typically 0.5 to 0.9m below the fen surface in the north-east of the site. This would be outside of the optimal summer water level range for fen and fen-meadow communities (see section 3.5), and correlates with the "dry margin" nature of the vegetation around the boreholes.
- Water levels show a summer decline of approximately 0.5m to 0.6m, with slightly less variation shown in the tube nearest to the Landspring.
- Groundwater recorded in transects are within the upper limits of observed borehole water levels, suggesting conditions were wetter than normal for this time of year. This corroborates landowner suggestions the fen has been very wet this year.
- Winter water levels typically range from the surface to 0.2m below ground level. This level is a suitable winter level for a range of wetland plant communities and is not seen as a limiting factor at this site.
- Mean summer borehole water levels are 15-20cm below the water level recorded in autumn 2015 in the south-north catch dyke. Mean water levels are also similarly below the water level in the Acle Landspring. There is a modest hydraulic gradient into the fen from both water courses.
- Piezometer levels are well above the groundwater "trough" below the bed of the south-north catch dyke. There is therefore a hydraulic gradient from the fen and watercourses toward the "trough".

- Mean summer levels in the piezometers are also above the water levels in the dykes in Damgate Marshes, although minimum water levels are around Damgate dyke water level.
- Typical October water levels in the piezometers lie between 0.1m to minus 0.6m AOD. The water table and mottled zone[4] observed in the eastern soil cores also lie between 0.1m to minus 0.6mAOD.
- Ground water levels in the boreholes are comparable with groundwater levels along the west-east catch dyke corridor.

### 3.6.2 Water Quality

#### Ochre

Ochre has been observed in the west-east and south-north catch dykes as a bed deposit (see Figure 8). It has not been observed in suspension, nor in the fen dykes. Some deposits have also been noticed in shallow depressions or terrestrialised dykes on the site margins. There is significant ochre in some (but not all) the dykes in the Damgate Marshes.

**Figure 8: Ochre On The Bed Of The West-East Catch Dyke.**

#### Acle Landspring

Water quality was monitored by EA between October 2002 and July 2013, approximately monthly. Mean levels of relevant determinands were:

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[4] The mottled zone representing those areas where the water table periodically occurs.

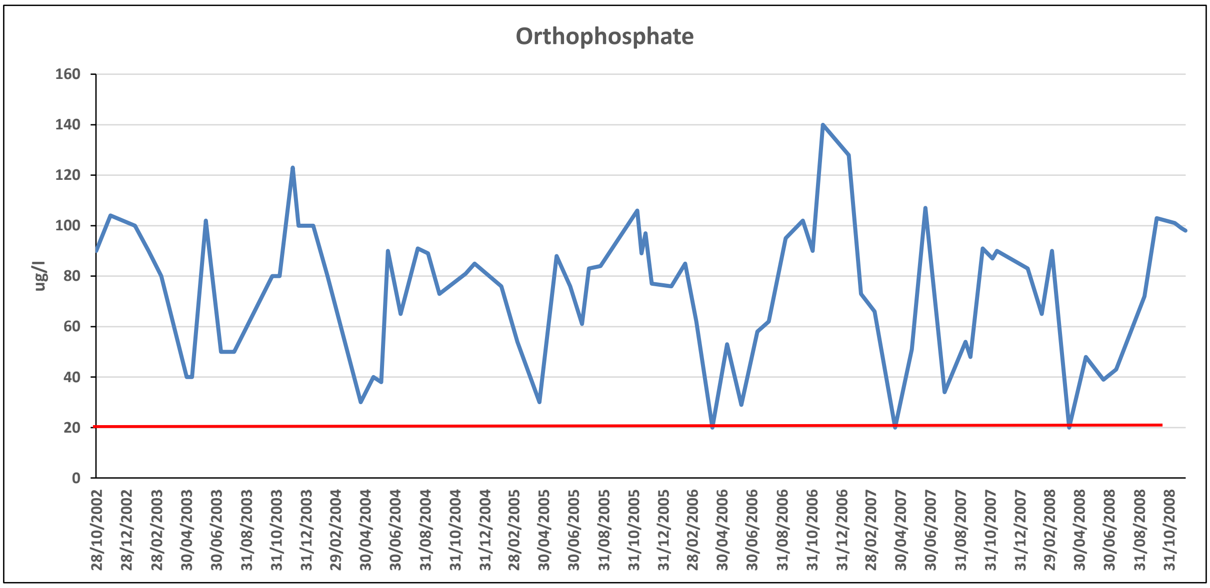
| | |
|---|---|
| pH (79 readings) | 7.64 |
| Conductivity (59 readings) | 853 µS/cm$^{-1}$ |
| Total Oxidised Nitrogen (80 readings) | 3.37mg/l |
| Orthophosphate (80 readings) | 73 µg/l |

Both pH and conductivity are suitable for the fens and dykes of the SSSI, although Geoff Philips indicates the pH of the fen dyke leading to the south-north catch dyke has a pH below 7. Landspring readings had low variability. Total Nitrogen and Total Phosphorous were not measured, so the available data for nutrients is more difficult to assess. Targets quoted here are for SSSI/SAC Common Standards Monitoring Guidance (JNCC 2015) which broadly adopts Water Framework Directive standards for P and provides best estimates for N (which WFD does not define).

The target for oligotrophic waters (suitable for maintaining *Chara*-dominated aquatic communities) is 10 µg/l Total P, with 20 µg/l Total P for mesotrophic aquatic communities. Although charaphytes have been recorded in the dykes, mesotrophic communities are more characteristic of those observed at Decoy Carr. Orthophosphate alone, only a component of Total P, exceeds the mesotrophic target by nearly four times.

Nitrogen is more difficult to assess as it is generally considered to be less critical in determining trophic status unless it is the limiting nutrient. JNCC have determined a base level of 1.5mg/l total nitrogen as the standard for shallow waters (if a site-specific target has not been developed), above which a site may be deemed in unfavourable condition. Mean total oxidised nitrogen is more than twice the recommended target.

**Figure 9: Orthophosphate and Total Oxidised Nitrogen for the Acle Landspring, October 2002 to December 2008.** Data Courtesy of EA. The red lines indicate the target for Total P and Total N respectively (JNCC 2015).



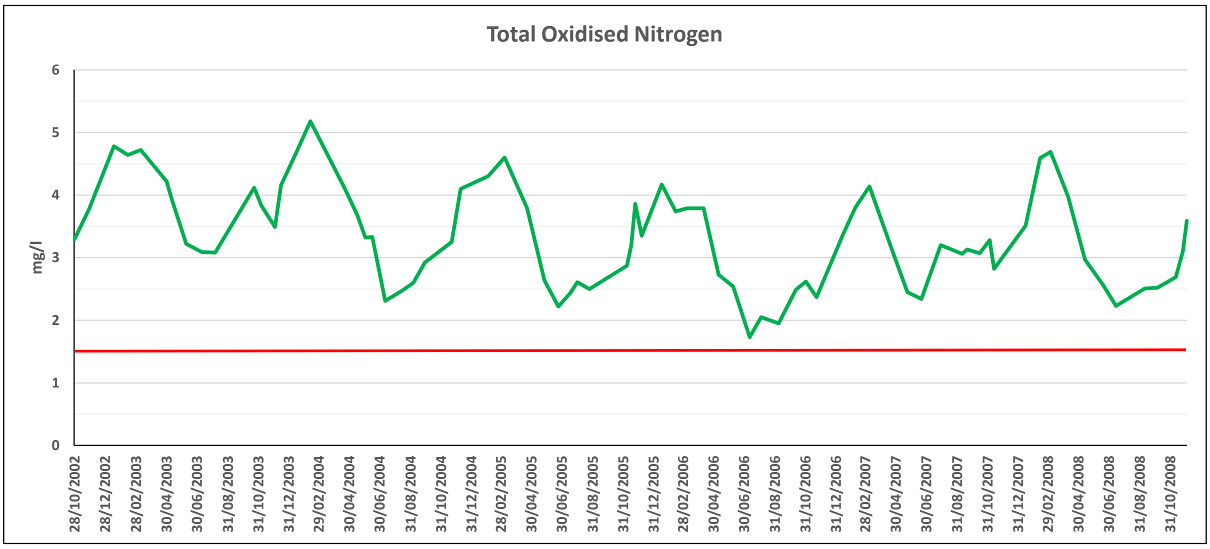


Figure 9 shows graphs for the period October 2002 to December 2008, and includes 75 evenly spaced recordings[5]. They show determinands to be permanently above the target levels for Total N and P. There is strong seasonality for both, with the lows being in summer when these available forms of nutrient are removed from the water column by macrophyte growth. Peak concentrations are in winter, despite effects of dilution, perhaps reflecting flushing from agricultural soils in the upper catchment as well as lack of utilisation by plants. The pattern is more disrupted for orthophosphate, with some atypical spikes in summer, and the growing season sag in values is more confined to spring and early summer.

Overall, the data suggest water in the Acle Landspring is too eutrophic for at least aquatic communities. This may raise concerns regarding use of this water to support dykes in the Damgate Marshes SSSI, where the principle feature is mesotrophic dyke communities. Although relating stream sampling of mineral nutrient determinands to peat fertility and fen condition is extremely difficult, it is probable that these waters are too enriched to sustain low fertility fens were the Landspring to regularly inundate the peatland.

### 3.6.3 Surface Water Flows

Surface water flow is summarised on Figure 10. Although it is within the Broads IDB area and falls within the Halvergate catchment, the relevant Water Level Management Plan (Tolhurst et al 2000) did not consider the project site and is now rather out of date.

The main west-east catch dyke connects with the central marsh dyke, which flows to the southern perimeter dyke. All of the other marsh dykes are blocked off from this drain. The southern boundary dyke (and therefore the main marsh dyke) is maintained at around 0.06m AOD by a sluice at the eastern end at the junction with the Acle Landspring. This sluice is not currently managed by the landowner. The southern boundary dyke collects water from the head of the valley just south of Ivy Farm, but is not connected to the catch dyke at this

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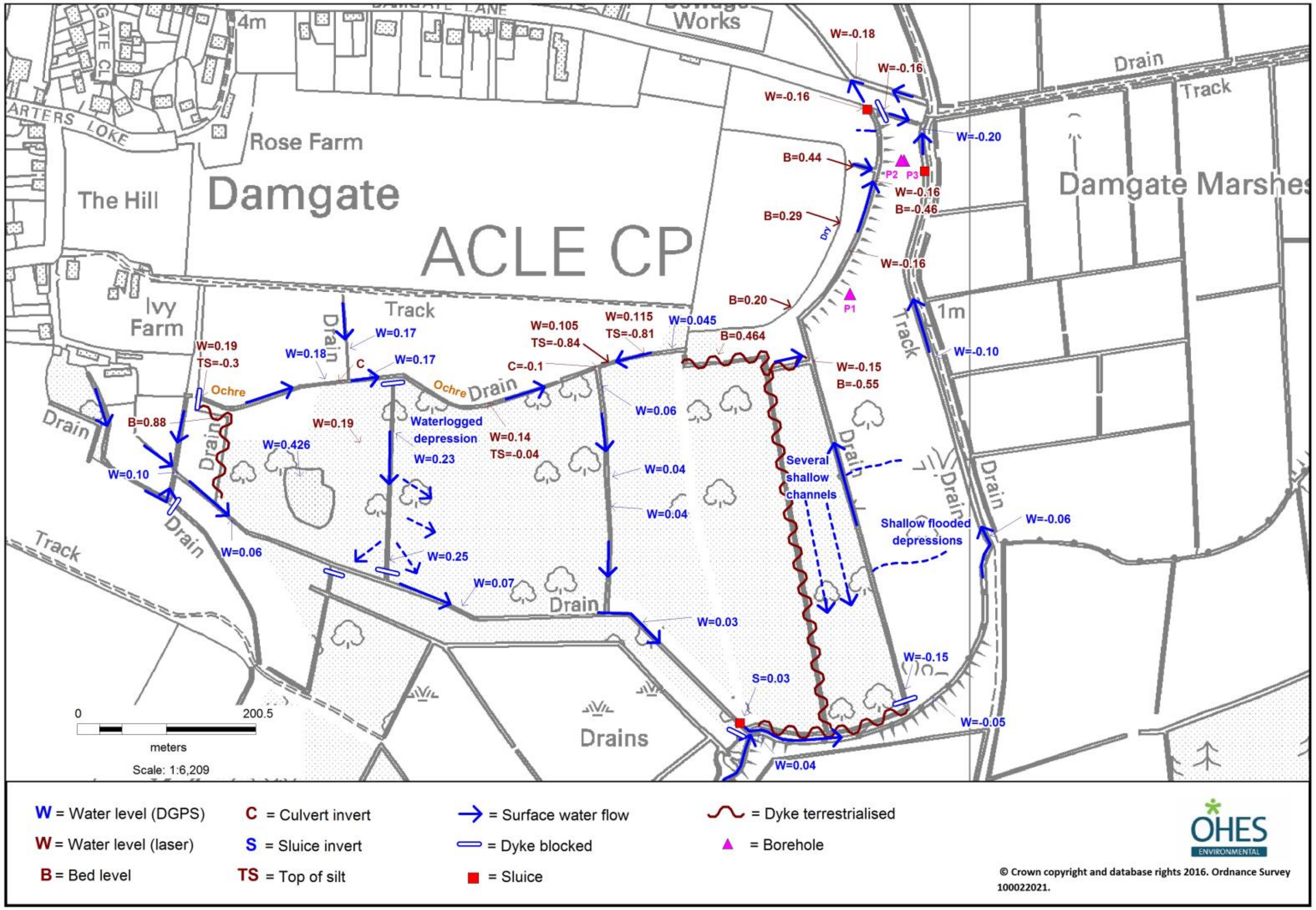
[5] Readings became disrupted and irregular after 2008 and were excluded from the graphs.

**Figure 10: Surface Water Flows.**



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western end. Hence the main marsh dyke and the west-east catch dyke are all maintained by the sluice at 0.06m AOD.

The west-east catch dyke is mostly derelict and filled with silt and vegetation. In summer, there is not therefore a regular water level, with the very shallow patches of water often being perched in dyke silt. Many sections are dry. In winter the level rises, and there is water throughout. However, levels are still low even in winter, because water is drained by the main fen ditch. Water levels in the catch dyke cannot drop below 0.06m AOD, but this provides a very low freeboard.

The south-north fen ditch to the west (adjacent to the pond) is closed at both ends. The water level, at around 0.30m AOD, is well above the level of the dykes controlled by the pipe sluice. This level reflects the elevated nature of the peat surface around this dyke. Water may move through the peat laterally following the topographical gradients, south to the boundary drain and eastwards to the lower peat surface.

At the eastern end of the catch dyke, there is a terrestrialised dyke, now little more than a shallow grip. In summer this is dry, but in winter surface water is carried east to the dyke which becomes the south-north catch dyke, between Mr Dyball's land and the Acle Lands Trust.

The Acle Landspring, managed as Main River by EA, forms the eastern perimeter of the site, dividing the elevated peat marsh from the low-level grass marsh of the Damgate Level. The Landspring, was re-engineered in 1963. Wider drainage improvements (the Acle-Tunstall Drainage Scheme) may have led to reductions in groundwater levels in the Damgate and Halvergate Marshes. It is elevated above both, being embanked and engineered. The elevation creates a modest water level gradient into the fen, with leakage probably mostly through the semi-permeable peat/silty sand bed. It is possible that the Landspring leaks water directly into the south-north catch dyke at the southern blocked end, where the gap is narrowest.

The Landspring is retained by a sluice at the northern end, installed by the Broads IDB in c.2011 (Figure 11). The sluice has an off-take to abstract water which supports the dykes in the Damgate Level SSSI. The sluice does not have a written down water level management protocol but is managed by judgement by the Broads IDB personnel. Water in the Damgate Marshes Level drains eastwards to the IDB's Tunstall Pump. LIDAR data suggest water levels in the Damgate Marshes is around minus 1.0m AOD (the date of recording is not known) with the level in February 2016 recorded as minus 0.86m AOD.

There is a significant gradient on the Landspring. At the outlet of the southern perimeter dyke sluice the level in October 2015 was around 0.04m AOD (fractionally below the southern perimeter dyke), dropping to minus 0.10m AOD around the eastern edge of the fen. The winter level at the sluice had risen to 0.04m AOD on 25/1/16. The level just downstream of the sluice is around minus 0.20m AOD.

**Figure 11: The Broads IDB Sluice At The North End Of The Landspring Dyke.**

The Landspring can drop to almost dry during droughts and can be flashy during catchment storms (WLMA *pers comm*). It usually carries around 0.75m water with c. 0.25m dyke silt over a firm bed. The firm bed level at the sluice was measured at around -1.0m AOD. The Landspring drains a significant area of arable land to the south and west.

The south-north catch dyke has a separate water level management regime to the rest of the SSSI. In autumn 2015, the water level was significantly lower than the west-east catch dyke, at around minus 0.15m AOD. This was also 5cm lower than the Landspring upstream of the sluice. By January 2016 this had risen only to minus 0.10m AOD. The catch dyke flows to the north. There is a sluice on the culvert under Damgate Lane, but it is derelict with water flowing through/under it without significant retention of the surface water. The catch dyke joins the Acle Landspring immediately downstream of Damgate Lane. Hence, the south-north catch dyke by-passes the Landspring sluice, explaining its lower level. The south-north catch dyke is effectively part of the pumped Acle Landspring Level without effective water control structures.

The level in the south-north catch dyke is consistent with the significant drop in the marsh surface either side of the fen dyke which becomes the south-north catch dyke. Here the marsh is around -0.10m to -0.20m AOD.

## 3.7 Site History and Management

Inspection of available maps shows the arrangement of ditches has changed very little since the OS 1st Edition 1886 map (Figure 6 above) was published. The map shows a small pump just south of the project site (near to the sluice in the southern perimeter dyke) which presumably lifted water from the marshes to the Acle Landspring. It also shows the embankment on the fen side of the south-north catch dyke, and the current line of the Landspring. The pump is still shown on the 1908 OS 6-inch map and the 1950 OS 1:10,560 County Series, but not the 1957 1:10,560 Plan. The 1908 map shows the west-east catch dyke has been extended east to join to the minor west-east dyke, and then connects to the south-north catch dyke. This connection has now terrestrialised. One small fen dykes which split the main grazing compartment has terrestrialised, as has a fen dyke which runs parallel to the south-north catch dyke. None of the maps indicate old turbaries, surprising considering the body of loose watery peat encountered during coring.

Natural England's site files provide the following site history:

| | |
|---|---|
| 1957 | Francis Rose describes the site as "…an excellent piece of calcareous valley fen". |
| 1958 | File note BFT Tucker. *Eriophorum gracile, Camptothecium nitens* and *Cinclidium stygium* recorded along with many indicators of high quality, low-nutrient calcareous fen. [6] Probably refers mostly to old Decoy area in Mr Wright's land to the south. Area then mostly open, but already scrubbing over. It is an indication of the quality of the site. Described as "…complimentary to other valley fen areas such as those along the Little Ouse River valley….". |
| 1963 | Acle Landspring is enlarged under a capital improvement scheme. No further details of scheme. |
| 1977 | *E. gracile* declared extinct (G. Compton and PW Lambley). |
| Early 1980s | Mr Dyball's pond dug. Stocked with trout, golden tench and carp. |
| 1981 | Friends of the Earth note: "Due to lowering of water levels associated with the recently completed Acle-Tunstall Drainage Scheme, the dykes nearest to the Acle Landspring are already laden with ochre derived from the acid sulphate soils". Presumably these are dykes on the Damgate Marsh side of the IDB drain, not the fen side, but suggests water tables may have been lowered in the fen, too. |
| 1982 | File Note (PA Wright) Proposals to reinstate the Acle Landspring, unmanaged since the 1963 scheme, to the original design specification. He is concerned this will affect the fen. He reports the site has become almost impenetrable with scrub. The note states there is active springflow to the site from the highland margin. Aerial photos show the project site heavily scrubbed up. |
| 1985 | Species list for the open fen includes: *Carex appropinquata, C. lepidocarpa, Cirsium dissectum, Epipactis palustris, Schoenus, Menyanthes. Listera ovata.* |

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[6] *Parnassia palustris, Eriophorum angustifolium, E. latifolium, Epipactis palustris, Salix repens, Menyanthes trifoliate, Schoenus nigricans, Riccardia pinguis, Climacium dendroides.*

| | |
|---|---|
| | The Dyball's land is used for pheasant shooting with a release pen on the northern margin. Wet rides cut 3-4 times/year. *Cladium* areas mown on 3-4 yr rotation. |
| 1991 | July: Fen scrubbed up and dry. *Carex dioica* and *Danthonia decumbens* recorded around the pond. Area in the north (not defined) burnt and eutrophic. |
| 1992 | January - Dam installed at the end of the southern perimeter dyke. Scrub removed along the dyke. Dykes dredged for first time in 60 years. Mostly peat brought up, but some marine clay. Planting of exotic tree species recorded along flanks of catch dyke.<br>Summer/autumn - Southern perimeter dyke – large beds of *Chara* recorded. Freeboard <10cm, wet conditions in the open fen. Sluice working well.<br>Note from J Parmenter – rare plants listed in 1985 still recorded – plus *C. pulicaris.* |
| 1995 | Scrub clearance along dykes and around the pond. *Tollypella nidifica* var *glomerata* (a rare stonewort) recorded in cleared dyke. |
| 1996 | Site Condition Assessment: woodland optimal, dykes sub-optimal, swamp and fen sub-optimal declining, needing cutting and/or grazing.<br>C Doarks, English Nature, writes to EA to express concern at the lack of management strategy for the Acle Landspring. Requests EA provide a Water Level Management Plan. One of the issues cited is the backflow of nutrient-rich water into the SSSI dykes. |
| 2003 | Acle Lands Trust introduce grazing. |
| 2005 | English Nature express dissatisfaction about the management of the Acle Landspring. The IDB want to take on management from EA. |

## 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 (2007).

### 3.8.2 Designated Features

Natural England have assessed the SSSI and Natura 2000 features present on Decoy Carr, Acle (Table 3). Some of the designated features are recorded on other parts of the SSSI, not on Mr Dyball's and the Acle Lands Trust areas. Wet woodland is extensive on the project site, but it is of recent origin, barely passing closed-canopy scrub stage.

## Table 3. SSSI and Natura 2000 site features at Decoy Carr, Acle. 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**<br>Lowland Ditch Systems<br>**SAC**<br>Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation | Freshwater ditch systems | * | * | | | | * | | | |
| | *Anas clypeata* | Shoveler | | | | * | * | | | * | |
| | Aggregation of non-breeding birds | Wintering waterfowl assemblage | | | | * | * | | | * | |
| | Vascular Plant Assemblage:<br>*Potamogeton coloratus*<br>*Stratiotes aloides* | Plant assemblage:<br>Fen pondweed<br>Water soldier | *<br>* | | | | | | | | |
| Broadleaved, Mixed and Yew Woodland | **SSSI**<br>W5 *Alnus glutinosa-Urtica dioica* woodland<br>**SAC**<br>Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* | Alder Woodland | * | * | | | | * | | | |
| | **SSSI** | Alder woodland | * | | | | | | | | |

|  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | W6 *Alnus glutinosa-Carex paniculata* woodland<br>**SAC**<br>Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* |  |  | * |  |  |  | * |  |  |  |
|  | W2 *Salix cinerea-Betula pubescen-Phragmites australis* woodland | Wet woodland | * |  |  |  |  |  |  |  |  |
| Fen, Marsh and Swamp | **SSSI**<br>M24 *Molinia caerula-Cirsium dissectum* fen meadow<br>**SAC**<br>*Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*). | Marshy grassland | * | * |  |  |  |  |  |  |  |
|  | **SSSI**<br>S24 *Phragmites australis- Peucedanum palustris*<br>**SAC**<br>Calcareous fens with *Cladium mariscus* and species of the *Carex davallianae* | Tall-herb fen | * | * |  |  |  | * |  |  |  |
|  | *Lutra* | Otter |  | * |  |  |  |  | * |  |  |
|  | *Vertigo moulinsiana* | Desmoulin’s Whorl Snail |  | * |  |  |  |  | * |  |  |
|  | *Circus aeruginosus* | Marsh Harrier |  |  | * |  |  |  |  |  |  |
|  | *Anas clypeata* | Shoveler |  |  |  | * | * |  |  | * |  |
|  | Aggregation of non-breeding birds | Wintering waterfowl |  |  |  | * | * |  |  | * |  |
|  | Vascular Plant Assemblage: | Plant assemblage: |  |  |  |  |  |  |  |  |  |
|  | *Carex appropinquata* | Fibrous tussock-sedge | * |  |  |  |  |  |  |  |  |
|  | *Sonchus palustris* | Marsh sow thistle | * |  |  |  |  |  |  |  |  |
|  | *Peucedanum palustre* | Milk parsley | * |  |  |  |  |  |  |  |  |
|  | *Thelypteris thelypteroides* | Marsh fern | * |  |  |  |  |  |  |  |  |
|  | *Sium latifolium* | Great water parsnip | * |  |  |  |  |  |  |  |  |

Some of the features could be affected by potential restoration works. These are principally the dyke and aquatic flora where established and species-rich dykes could be infilled (this applies to only very short parts of the west-east catch dyke), and areas of wet scrub to be removed. The benefits of restoring seepage and transition mire will outweigh such impacts.

NE (2007) provides further 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.

## 3.9 Existing Vegetation and Hydrological Monitoring

There is no formal vegetation fixed –plot monitoring undertaken on site. EA's deep monitoring have been discussed above. Two transects of dipwells were inserted as part of this project.

## 3.10 Conceptual Eco-hydrological Model of Current Functioning

Figure 12 summarises in plan the likely eco-hydrology of the site. Boundaries between WetMec types are diffuse and are tentative. There are the following components:

1. The sandy upland is freely draining, carrying dry grassland and scrub. This **Dryland** does not therefore have a WetMec type. The boundary of this unit along the catch dyke margins is difficult to define and variable, as the derelict catch dyke has in places allowed some wetland plants to creep back up the slope. Essentially, however, areas up slope, and the immediate few metres down slope, are currently non-fen habitats that fall outwith WetMecs.

   The non-fen element passes along the margin of the south-north catch dyke, including the marked embankment on the fen side, to a point where the sluice on the IDB Main Drain retains a high water level.

2. The core of the wetland is **WetMec 9, Groundwater Fed Bottoms**. This unit recognises the critical influence of groundwater in maintaining the site, even with catch dykes in place. Groundwater fed bottoms are topogenous sites that have water tables controlled by topography and the level of surface water ditches, but where the main supply to the water balance is groundwater. The water table can be at or below ground surface for some or all of the year. The marine alluvium, assumed to underlie all of the peatland at depth[7], is slowly permeable and would restrict upward water movement into the peat from below, as perhaps would some of the thicker deposits of well humified peat in the Middle and Lower Peat. In some situations, the marine alluvium would suggest WetMec 8 Groundwater Fed Bottoms with Aquitard. However, the ground water feed at Decoy Carr is lateral, from the permeable highland margin, passing into the margin of the peat which has a very steep slope of descent at the upland margin, with substantial contact

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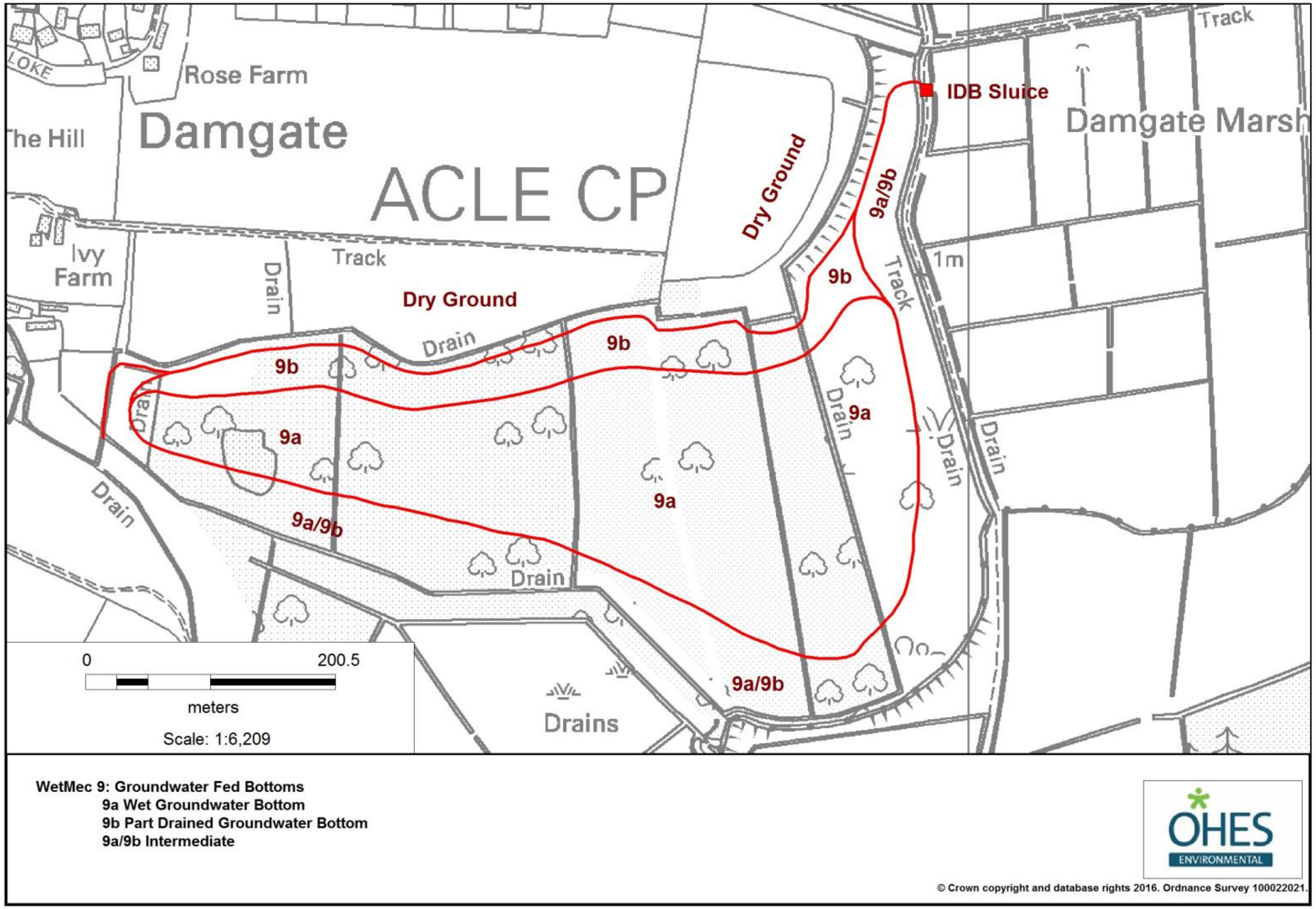
[7] Marine alluvium was only proven in coring in Transect 1 at the west end of the site.

Figure 12. WetMec Zones At Decoy Car Acle, Existing Condition



areas with the transmissive coarse loam. Groundwater moving laterally from the margin is therefore able to supply the full body of the wetland. Hence the peat mass has been placed in WetMec 9

While this site has no true hover or “quag-fen”, the watery peat mass may offer some buffering against low water levels, and may possibly exhibit some rise and fall when groundwater levels alter. The surface of the wetland may receive significant input from rainfall, feeding shallower rooted plants and be especially important in summer when evapotranspiration pulls down the water table. However, groundwater will always provide the bulk of the wetland water balance. Very high quality fen may grow in WetMec 9 systems including M13, M24 and a range of base-rich communities (Wheeler et al 2009).

Two variants of WetMec 9 have been identified:

a. **WetMec 9a Wet Groundwater Bottom**. These are summer-wet sites. They are usually close to the valley margin (Wheeler et al 2009), but at Decoy Carr, this is not the case because of the drainage effect of the catch dyke. WetMec 9a occurs once the effect of the catch dyke has been cancelled out by (1) topographical declination of the fen surface bringing ground level to the groundwater table, and (2) high retention levels in the southern perimeter dyke preventing excessive leakage from the fen compartments. The net result is a wet fen surface supported by groundwater. The landowner remarked that water levels in 2015 were exceptionally high and were stable all through the year, being at or near the surface. However, in a typical year, water levels are likely to be drawn down beneath the surface by evapotranspiration, the typical condition for this WetMec type.

b. **WetMec 9b Part-drained Groundwater Bottom**. This WetMec sub-type occurs where drainage ditches lower the groundwater table with consequential impacts upon the fen. This is clearly the case in a zone along the main catch dykes, but not along the N-S fen ditches which are controlled by sluices or bunds. WetMec 9b is undoubtedly derived from WetMec 9a, and forms a transition to non-fen dryland habitats delimited by the catch dyke. The water table profiling contained in the cross-sections (Figures 3a-d) suggests WetMec 9b may extend 40-50m down slope of the catch dyke.

3. The area along the southern and eastern margin, abutting the perimeter dykes, is arguably intermediate between **WetMecs 9a and 9b.** While sluices are raised, the adjacent fen remains wet (WetMec 9a). However, this WetMec is not characterised by surface water level retentions. In addition, if and when the sluices are lowered, the adjacent fen will drain. The situation then suggests WetMec 9b. Hence it has been mapped as intermediate between the two types.

# 4. STAGE 2: DEFINING THE PROBLEM

## 4.1 Catch Dyke Characteristics

### 4.1.1 West-East Catch Dyke

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 a little atypical as the dyke is essentially derelict (Type 7 Redundant or Derelict Dykes), and also connects to floodplain dykes whose level is controlled by sluices and is not directly pumped (suggesting Type 2 Groundwater Dykes With Minimal Direct Drainage). However, the West-East Catch Dyke is raised well above the marsh dykes. It is not adequately controlled by perimeter dyke sluices. Although it is derelict (re-dredging would open free connection with the lower level marsh dykes), coring and water table profile shows it still has a marked effect on the shallow groundwater table. When considering the broad grouping of characteristics associated with the seven types described in Table 3 of OHES (2014), it is clear that the dyke falls into Type 1.

### 4.1.2 South-north Catch Dyke

This catch dyke has a more straightforward diagnosis in Table 4 of OHES (2014), being a **Type 1**: **Groundwater Dykes With Significant Direct Drainage.** It has a significant flow and water depth and is not managed effectively by sluices. It discharges to the low-level Landspring which is pumped at Acle.

## 4.2 Catch Dyke Risk Assessment

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

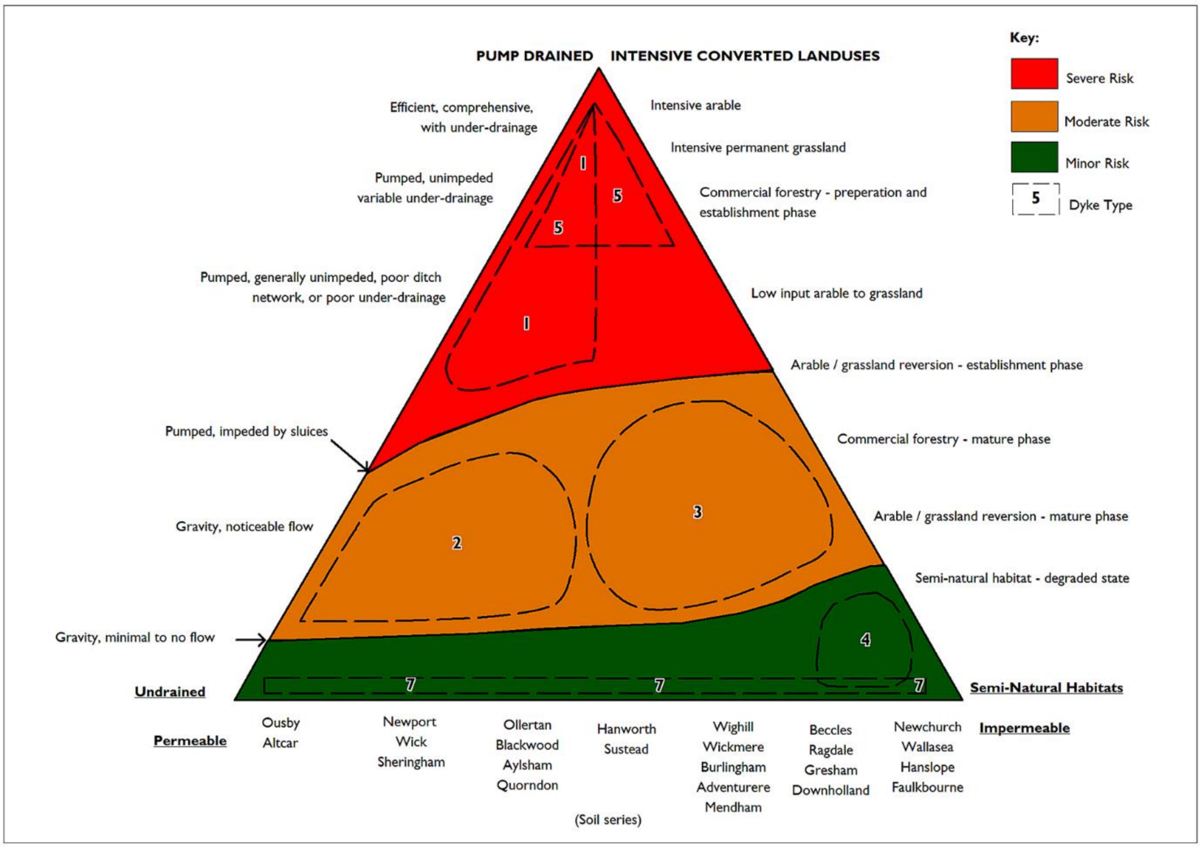
> Because of the context, they are likely to be in locations where groundwater plays a significant role in water budgets and water quality in the floodplain. The adjacent floodplain may also be the locus of wetland types most closely associated with low nutrient water tables, with characteristic natural chemistries vulnerable to disruption. Because of their direct drainage, they are likely to most 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 research collated in the current report suggests that this characterisation is accurate for both catch dykes at Decoy Carr.

In terms of the Risk Triangle presented in OHES (2014, Figure 13), the area occupied by Type 1 is located in the red **Severe Risk** zone. Under normal circumstances, control sluices and moderation of pumped systems and the low intensity land use would place this dyke in the middle, brown areas of Moderate Risk. Because the catch dykes are elevated, the sluices do not provide sufficient water level control on these catch dykes.

The risk to water quality from intensive up slope land uses does not pertain here. Instead, there appears to be ochre contamination of the dykes which would be worsened if the dyke were dredged.

**Figure 13: Risk Triangle.** Type 1 Dykes are in the Severe Risk Zone but risk of agricultural pollution/eutrophication at Decoy Carr is low.



## 4.3 Likely Impacts of Catch Dykes

### 4.3.1 Mechanisms

The following impact assessment uses information in Table 5 of OHES (2014):

**Change of ground water quality**. Groundwater affected by the catch dykes arises from Drift deposits. NSRI (2014) indicates Drift water would be low nutrient under natural conditions, supporting acid to neutral grassland and woodland. The wetland plant communities are however clearly rich-fen. There are no marl layers in the peat. More calcareous elements are likely to be derived from Crag which is in continuity with the Drift. The peat is known to contain shell fragments especially along the margins. Historically, irrigation by base-rich surface waters (the Acle Landspring for instance) is possible, and there is contemporary evidence of water level gradients from the Landspring into at least the eastern margin of the fen. The peat itself could retain a reservoir of bases and alkalinity from historic irrigation by base-rich waters. Although exact chemistry is uncertain, loss of Drift and Crag groundwater certainly depletes an important source of low nutrient water, and will alter the balance of natural groundwater chemistry.

**Depletion of Water Balance**. The drainage of groundwater depletes the water balance. The wetland already experiences lower water tables at the highland margin. The main fen will in summer suffer increased soil water deficits (both intensity and duration) because of reduced groundwater delivery, and will be less buffered against drought stress.

**Direct Draw Down of the Water Table**. This effect has been demonstrated and quantified in the stratigraphy survey. The impacts extend 40-60m down slope of the catch dyke.

**Generation of Acid Sulphate Pollutants**: Ochre is the oxidised form of iron generated when reduced iron in the soil is exposed to air by drainage. Along with ochre, products of acid drainage include release of acid and toxic elements such as reduced iron and aluminium (ELP 2001). Ochre was observed in the sediment of the west-east catch dyke and the south-north catch dyke.

**Truncation of the** wetland to dryland transition at the valley margin. Decoy Carr has a truncated habitat sequence. Although land above the dyke is now reverting from arable to a mosaic of scrub and grassland, the natural transition from wetland to dryland is absent. Downslope, the valley margin transition has been disrupted by reversal of groundwater flow in the dyke margin zone. Only in the flat valley bottom do natural conditions reassert. Overgrowth by scrub which straddles the catch dyke has further disrupted the habitat sequence.

Taken together these are significant impacts, wholly altering the catch dyke corridor and with consequential impacts potentially on the whole of the site.

### 4.3.2 Impacts on WetMec Types

Compare WetMec types currently existing (Figure 12) with those that might exist without the catch dykes (Figure 14, Section 5.1) shows clearly the potential impact of the catch dykes. The catch dyke may have removed WetMec 10b Permanent Diffuse Seepage Slopes and the associated WetMec 17a/b Strongly/Weakly Groundwater Flushed Slopes. There are likely consequential impacts on valley bottom regions that would have received seepage/flush waters.

# 5. STAGE 3: DEVELOP SOLUTIONS

## 5.1 Eco-hydrological Model With a Remediated Catch Dyke

If the catch dyke were remediated, Section 3 above suggests that groundwater levels on the higher gleyed toe slope soils should recover to approximately 25cm bgl in typical conditions, perhaps higher in prolonged wet years. The possible implication for this on WetMec type is shown of Figures 14 and 15, although note that with current data the proposal remains speculative.

Because of declining topographic levels, combined with controlled levels on perimeter dykes, groundwater would be forced to express over significant areas of fen, as seepage. The seepage area would be **WetMec 10b Permanent Diffuse Seepage Slope.** Although variable in extent, the seepage slope would form a narrow zone parallel and downslope of the catch dyke, occupying transitional areas between the mineral profiles and the deep peat fen. Seepage would be strongest where the groundwater table intersected with the ground surface. The size of this seepage area is likely to vary between years, and seasonally, reflecting preceding winter rainfall and levels of summer evapotranspiration.

It is not expected that concentrated groundwater outflows such as springs would result. It is possible that the spring area identified by Mr Dyball just west of the flight pond would strengthen to a localised **WetMec 10a Permanent Localised Strong Seepage.** This would be limited in extent.

Down slope of the seepage zone would be a second parallel zone, 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 would drop below marsh surface in dry periods when evapotranspiration is high and groundwater levels are low, but the water table would rarely be far from the surface. Locally, and perhaps temporarily, there may be apparent seepage induced by rainfall sitting over a very shallow groundwater table. This zone would still be on the declining valley margin slope. The substrate is generally mineral or thin peat.

Above the restored catch dyke, and upslope from WetMec 10b Permanent Diffuse Seepage Slopes, would be a form of **WetMec 17b Weakly Groundwater Flushed Slopes.** Here, groundwater would flush upper soil profiles which currently show evidence of mottling. Because of topographic elevation, groundwater feed would be comparatively weak here and would be 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 fen communities could develop. At the elevated end of the zone, there would be a transition to true dryland soils marked perhaps by a rushy area of MG10 *Holcus lanatus-Juncus effusus* rush pasture.

**Figure 14: Potential WetMec Type Following Restoration of Catch Dyke.**

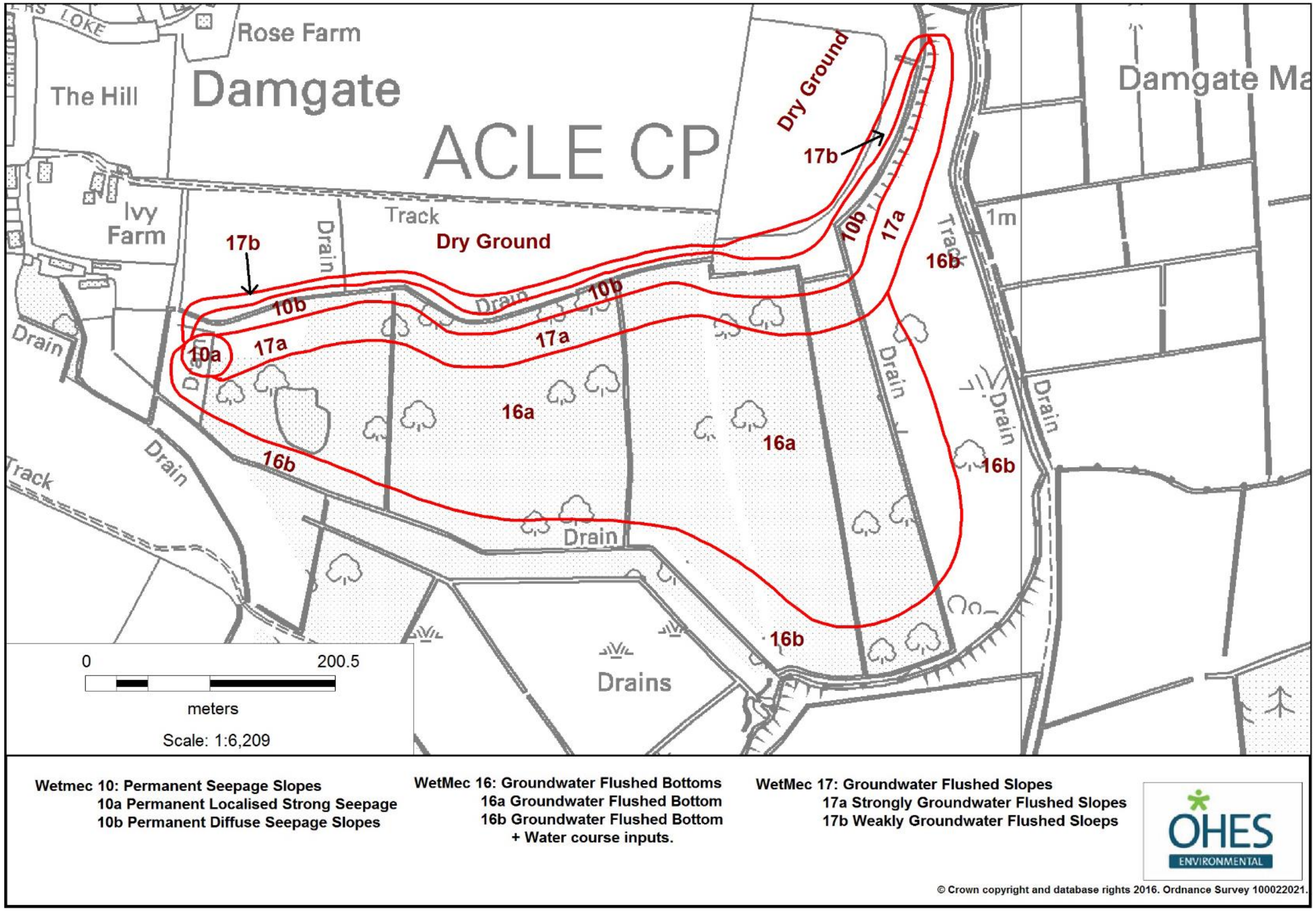
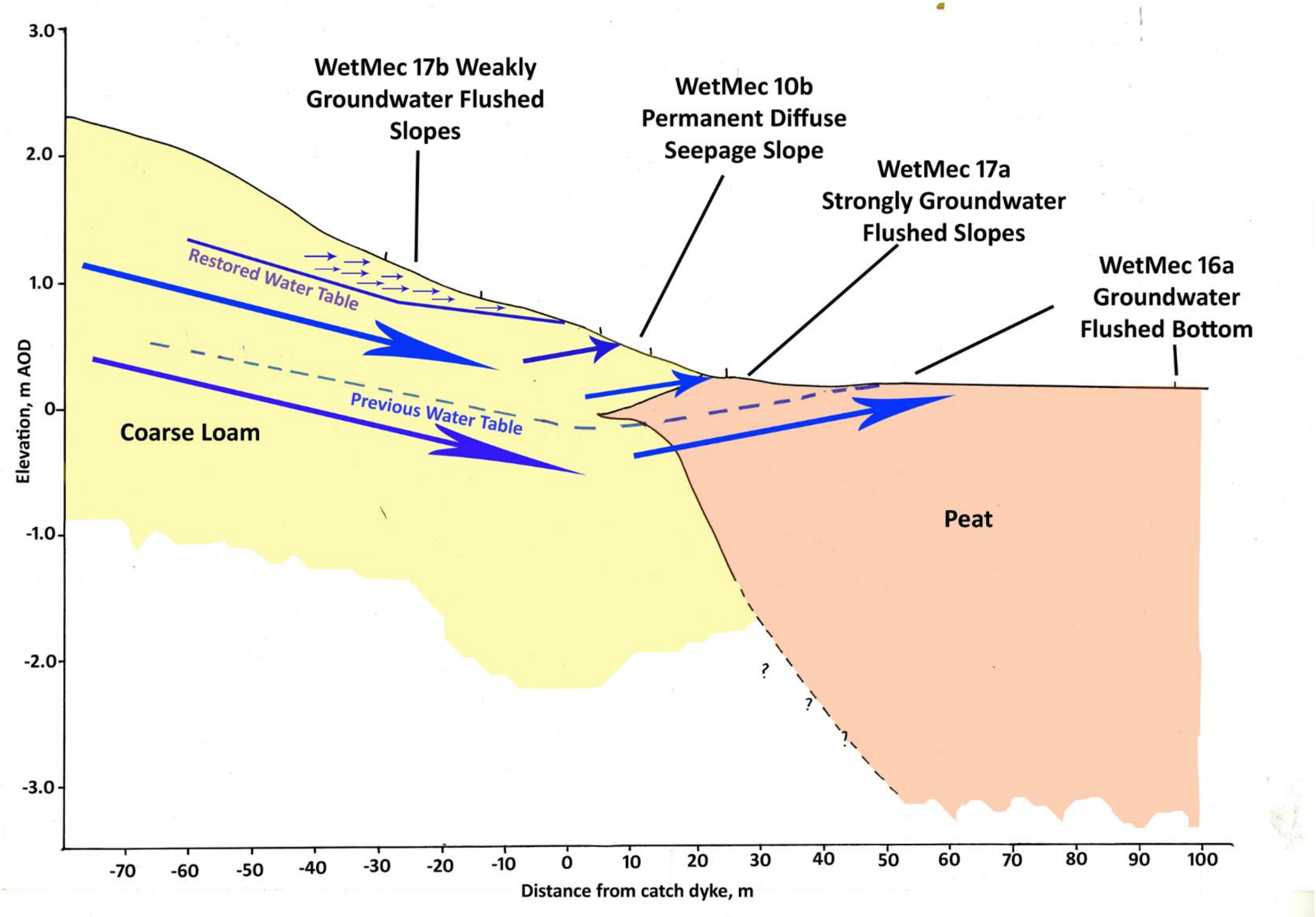


**Figure 15: Possible Water Table Adjustment and Arrangement of WetMec Types Following Catch Dyke Restoration.** Base Cross-section is taken from Soil Core Transect 2.



Where the ground surface flattens out and the peat thickens up, there is a transition to **WetMec 16a Groundwater Flushed Bottom**. This would encompass the greater part of the flattish ground supporting deeper peats, where the site is topogenous rather than soligenous. The water balance of the fen body would be dominated by ground water, to a greater degree than currently, and with a more stable water table regime that was buffered against evapotranspiration and periods of low rainfall. Maximum water tables would not increase over current levels because this is controlled by the levels on the perimeter ditches. In addition, the watery peat beneath the fen surface further dampens extremes of water level by providing a flexible area of groundwater storage. This is an unusual site for WetMec 16, being on deeper peat, but the presence of low permeability humified peat and marine alluvium, together with the strong lateral groundwater flow to the shallow peat, indicates the flat fen is best placed in WetMec 16a.

There is likely to be a zone of **WetMec 16b Groundwater Flushed Bottom + watercourse inputs** along the south and east perimeters. A distance decay is expected to operate for groundwater contributions to the fen from the highland margin, such that the outer fringe of wetland may benefit from inputs from high level watercourses. The contribution from the Acle Landspring along the east boundary, indicated by coring, is likely to persist as long as the sluice is maintained at current levels. The southern perimeter drain, which is mostly at adjacent marsh level, may make more modest contributions, when groundwater flows have weakened and evapotranspiration within the fens is especially strong,

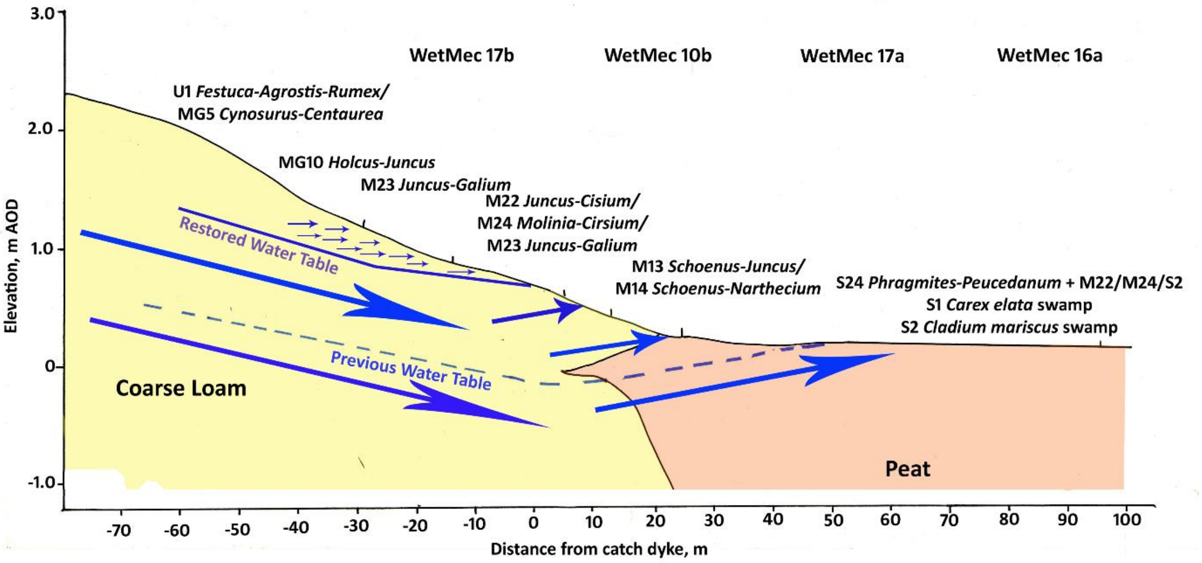
## 5.2 The Vision for Decoy Carr, Acle: Optimal Site Condition

If the eco-hydrological functioning outlined in Figure 15 can be restored, the full hydroseral sequence of habitats may be recovered.

The succession of plant communities is shown in Figure 16. 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 15 is simplified, and patterning is expected to vary laterally as well as down slope.

The dryland would be a mosaic of grassland, bramble and scrub, if the currently policy of developing the mosaic continues. The soils are too fine-textured, lacking coarse gravelly-sandy soils typical of natural heather heath, hence *Calluna* heath is not proposed. Instead, a sward 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 lower nutrient mesotrophic grassland – such as the *Danthonia decumbens* sub-community of MG5 – would be most likely develop, reflecting the intermediate nature of the soils.

## Figure 16: Potential Arrangement of Habitats Following Catch Dyke Restoration



There would be a narrow zone of rush pasture where soils are dry in summer but water logged in winter. At higher elevations, the MG10 *Holcus lanatus-Juncus effusus,* 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 of the toe slope, with groundwater derived from the decalcified drift.

The sequence thereafter is difficult to determine and may vary across the toe slope depending on local soil and groundwater conditions. Wet fen meadow could develop where groundwater flushing is strong, but elevation inhibits permanent seepages. 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 rather than Crag water. As a consequence, there could be considerable overlap with M23 *Juncus-Galium* mire, with mosaicking and intermediates common.

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 from the Crag, 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 substantial 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.

On the flat peat surface, in the WetMec 16a Groundwater Flushed Bottom, the plant communities will be largely as they currently are. 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, such as *Calamagrostis*, 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. In swampy hollows where fertility is low and conditions base-rich, *Cladium* communities could thicken up to dense stands of S2 *Cladium mariscus* swamp. With increased wetness and more hollows created by scrub removal, expansion of S1 *Carex elata* swamp is also expected.

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 have similar management dependencies and clear relationships with other fen communities. Sump type communities associated with fen pools and recent peat diggings could develop communities new to the site such as M9 *Carex rostrata-Calliergon cuspidatum/giganteum* mire, if the hydrochemistry were appropriate.

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

A review of constraints using Table 2 of OHES (2014) shows that the main catch dyke and working corridor is relatively unconstrained, having low intensity grass/scrub to the north and fen to the south and east. There are no known records for protected species around the dyke or immediate working corridor, although specific protected species surveys have not been undertaken. The dyke is in poor ecological condition and mostly does not support SSSI or Natura 2000 features. However, the most westerly length of the catch dyke is open and well vegetated with a calcareous aquatic community which is likely to be an SSSI and SAC feature.

Although the catch dykes feeds eventually into the controlled Acle Landspring, none of the watercourses subject to restoration are Main Drain or Main River. Remedial works are not likely to affect flooding or land drainage other than for the fen and land immediately upslope.

Infrastructure is relatively unconstrained although there is a set of powerlines running south-north which may affect the working corridor. 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. Potential constraints may be summarised as:

- Agreement to the works of the landowners. Both landowners have a positive interest in the nature conservation interest of the land and have been managing the fens appropriately for decades. Overall they are positive toward the scheme, but have some issues with detail and practicality, particularly in terms of scrub removal and the management of grazing.

- Funding: Currently there is no funding for implementation, although this is in process.

- Scrub removal. The scrub varies from very young to well established. There may be regulator or local resident concerns regarding the requirement to remove significant areas of scrub.

- The power lines. The power lines crossing the valley may constrain the working corridor especially in terms of sheet pile barriers. Tall or long-arm machinery cannot work near to the powerlines. Disturbance along the corridor of the powerlines may be a concern to Eastern Electricity.

- The western-most length of the west-east catch dyke is of high intrinsic nature conservation interest with aquatic communities that may qualify as SSSI/SAC feature habitat. The south-north catch dyke has a similar length of good quality habitat to the south of the area to be treated, extend the full length of the fen section of the dyke.

- Infill of the south-north catch dyke to ground level would cause issues for the drainage of the areas of fen which flank the dyke in the far south. Low areas in the fen are around minus 0.10m AOD, and minus 0.20m AOD in the lowest spots, broadly consistent with the current water level in the catch dyke. Raising the level in the catch dyke would cause water levels above ground in winter, although summer evapotranspiration would reduce surface water.

- If the south-north catch dyke were opened to the Acle Landspring at the south end, allowing drainage of the fen to minus 0.05mAOD, the catch dyke through the toe slope could be fully restored. However, this means connecting the dyke to Main River. Water quality of the Landspring is not ideal. The water level regime is unpredictable from low levels in droughts (which would drain the fen) to flashy overbank floods after heavy catchment rain. Introducing connections to the Landspring therefore seems high risk.

**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: Mark Dyball. | Positive and support overall, but would like to see the following incorporated into the final scheme:<br>• Fencing removals would need to be agreed by the family and replaced like for like. Hidden fencing in the *Cladium* compartment is not favoured (it has not be included in the final proposals).<br>• The existing grazing compartments should be maintained.<br>• They wish to keep the grazing entirely separate from that on the Acle Lands Trust which is grazed by different stock. They would ideally wish to prevent nose to nose contact between cattle.<br>• They would prefer that their fence along the south-north catch dyke is not disturbed and any in-fill work is conducted from the Trust side.<br>• They are not keen on opening up the connector dyke along the southern margin.<br>• They wish to agree all scrub clearance and indicate that some of the scrub marked for removal on plans in this report would not be acceptable to them. This relates to scrub on the upland side of the catch dyke.<br>It has been confirmed to Mr Dyball that he would need to be in full agreement with all of the plans before they can proceed and that there would be a further round of amendments in discussion with himself and other stakeholders before plans went to implementation. | Formal written agreement to proceed. | This report. |
| Acle Lands Trust. | Positive and supportive. Overall agree to scheme going forward, but have some concerns regarding loss of scrub on the catch dyke margin, particularly with regard to a pair each of Garden Warbler and Lesser Whitethroat. | Formal written agreement to proceed. | This Report. |

| | | | |
|---|---|---|---|
| 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 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<br>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.<br>To help give you an indication of the likely judgement I have looked at the 'Town and Country Planning General 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 | Most likely Planning Permission.<br>Initially a "Prior Notice". | Full specifications for proposals and description of purpose.<br>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.<br>There are some concerns with uncertainties regarding groundwater flows around the south-north catch dyke. | SSSI Consent.<br>At least initial scoping required under the Habitat Regulations. | This Report.<br>Full specifications for proposals |

|  |  |  |  |
|---|---|---|---|
| Forestry Commission, Santon Downham, Brandon, Suffolk<br>IP27 0TJ<br>eandem@forestry.gsi.gov.uk<br>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 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. | Uncertain, depends if the tree works form part of a planning application, and on FCs opinion on the initial inquiry. | Full specifications and proposals for the trees. |
| UK Power Networks (own and maintain the powerlines on Mr Dyball's Land). 0800 316 3105 (Option 9), asknetworks@ukpowernetworks.co.uk | No specific advice or regulations until plans are presented. They will then provide advice from a network engineer within 3 working weeks from notification. |  |  |
| Environment Agency, responsible for the Acle Landspring Main River. **Mike Davison,**<br>Environment Agency<br>Broadland Flood Alleviation Project,<br>Harrier House, 9 Whittlingham Lane<br>Thorpe St Andrew, Norwich, NR7 0QAS. 020302 55426<br>mike.davison@environment-agency.gov.uk | EA have no detailed information about the Acle Landspring in terms of flows, permeability of bed and banks, construction of the watercourse or operation of the sluice. There is no Water Level Management Plan. The Agency intend to upgrade the Acle Pump (although there is no firm timeframe) and are seeking stakeholder views on how the Landspring is managed. EA would like to see a scope of works for the catch dykes to give an opinion as to whether Flood Defence Consent is required. | Flood Defence Consent required for significant works within 9m of the Acle Landspring. The reconnection of the southern drain and the long barrier on the northern catch dyke may qualify. | Specifications and diagrams in this report. |

# 6 STAGE 4: PROPOSALS AND CONSENTS

## 6.1 Consideration of Management Solutions

The five issues/impacts of the catch dyke identified in Section 4.3.3 are:

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

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

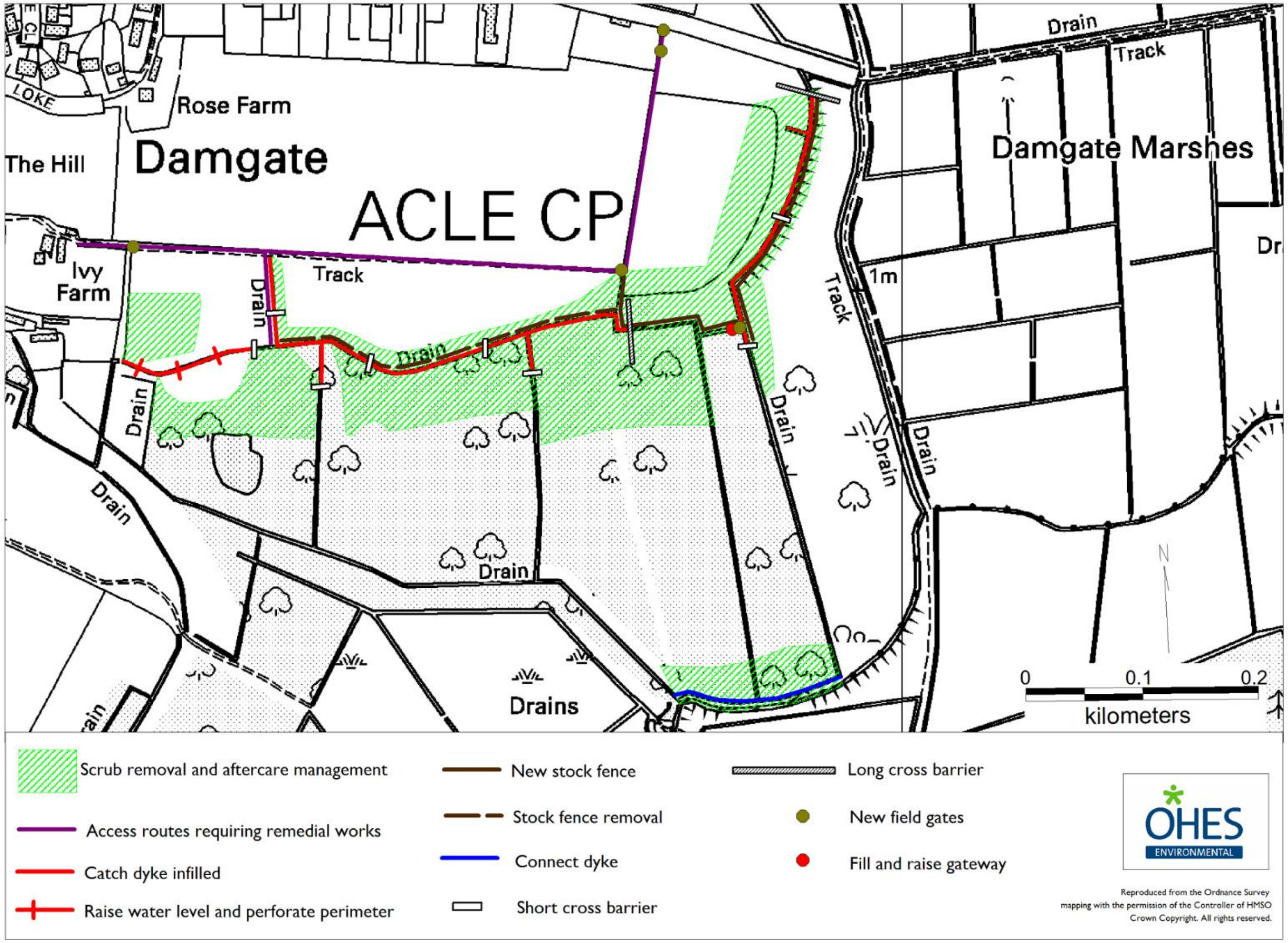
5. **Comprehensive infill of the catch dyke**. This single action is the core solution which addresses all of the five issues. Because groundwater is being depleted underneath the dyke and eastwards and northwards, cross-barriers at depth will be required in addition to infill.
6. **Raise Water Level**. The far western stretch of west-east catch dyke which will not be in-filled should have the water level raised to marsh level.
7. **Perforate perimeter to increase permeability.** The retained portion of the west-east catch dyke will have the margins perforated to promote down-slope movement of groundwater into the fen.
8. **Change upland land use to restore the wetland to dryland transition at the valley margin.** The toe slope is in sympathetic management, although is densely scrubbed up. The recent scrub along the catch dyke corridors needs to be removed to restore the full valley transition. In time, the large grass field upslope of Mr Dyball's land could be restored to species-rich grassland but this is a long term aspiration not included in this phase.

## 6.2 Remedial Measures Adopted

Because many of the constraints can be overcome, comprehensive and sustainable options (rather than the heavy engineering options described in OHES 2014) can be implemented. Hence Solutions 1-4 will be progressed, subject to landowner agreement and funding.

Remedial measures are summarised on Figure 17. Both catch dykes are treated.

Figure 17: Summary of Remedial Measures at Decoy Carr Acle



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### 6.2.1 Solution 1 : Comprehensive Infill of the West-East and South-North Catch Dyke

Scrub removal, some of which is essential for in-fill of the catch dykes, is described under Solution 4. There are three other components to this solution:

**In-fill of the dyke**: Both catch-dykes could be in-filled with permeable material, coarse loams typical of the toe slope. The embankment on the east margin of the South-North catch dyke would be used for dyke in-fill. Vegetation and dyke silt should be removed to hard bottom, where this exists, representing the original dyke bed. Where no firm bottom exists, slubbing should leave a mean dyke depth of 1.5m, measured from fen side bank. This represents an approximation of the probable original dyke profile. The south-north catch dyke has an embankment on the fen side – the 1.5m measurement should be from the top of the dyke perimeter, not the embankment. The slubbing should be set aside while the dyke is back filled from locally-won coarse loam from upslope, although the creation of an upslope dyke-like feature should be avoided. 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 a tined digger bucket or similar. The in-fill should not be compacted but laid loose, and should be left 15% over-filled to allow for settlement. Figure 18 shows a representative cross section.

**Figure 18: Cross-section of Ditch Infill and Cross-barrier (NOT TO SCALE).** Dyke silt and the ditch margins should be removed (hatched brown) and the dyke infilled with coarse loam to 15% above the finished (settled) level. The sheet pile barrier (blue) should be driven though the infill to Finished Level (piling in loam infill not shown below for clarity).

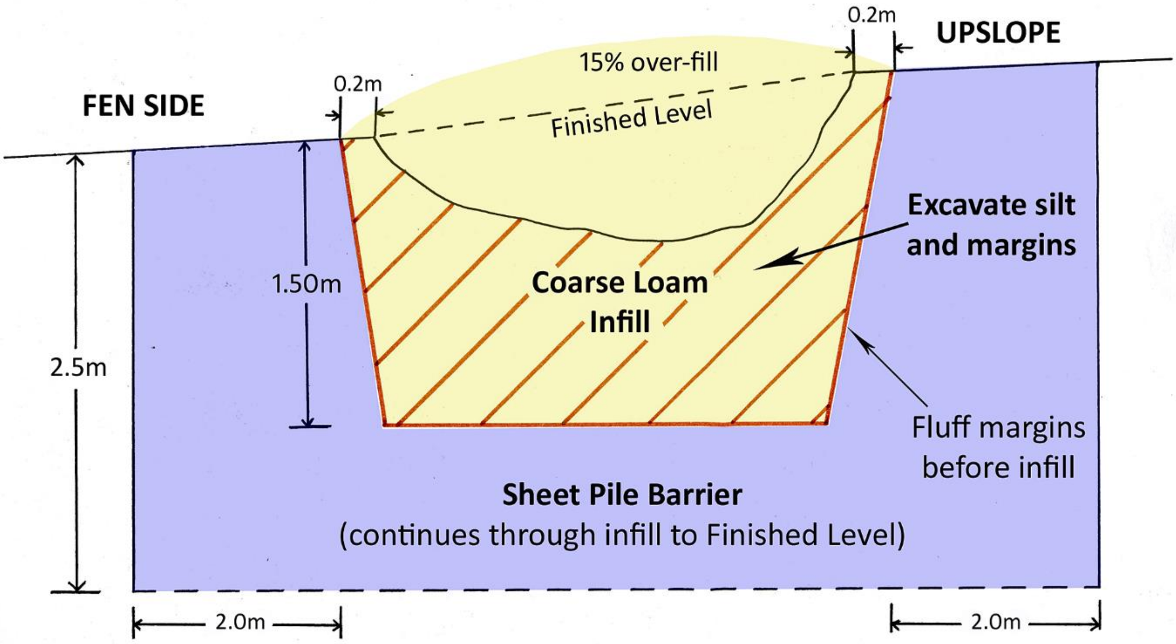


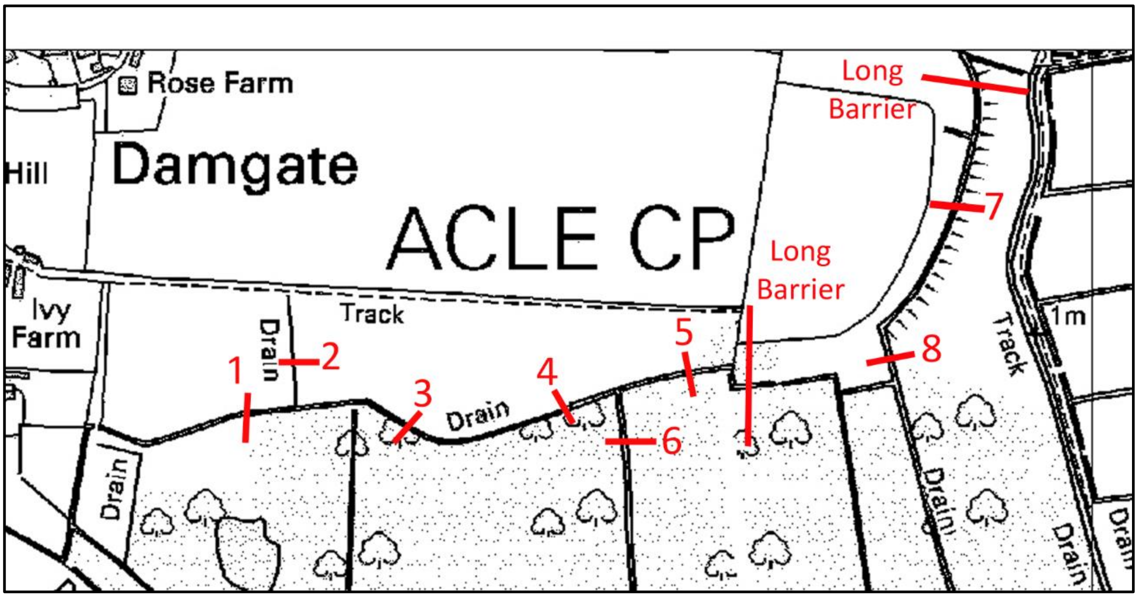
Figure 19 shows selected cross sections of the existing dykes, with a generalised red line indicating the approximate desired finished profile. The silt in the dykes is soft and lifts on flooding. The quantity of in-situ silt is therefore variable and difficult to estimate. It should be measured by contractors to satisfy themselves of quantities. The sections were constructed using levels taken every 1m and are diagrammatic, with the elevation not to Ordnance Datum.

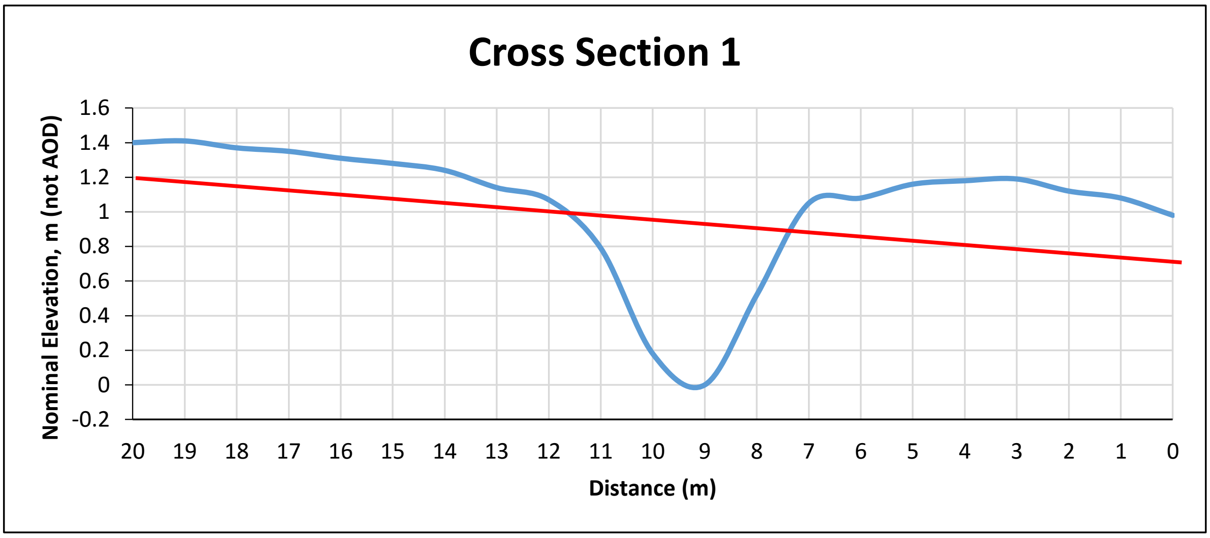
The silt and ditch slubbings should then be spread upslope on the surface and the whole slope graded to a smooth natural surface. Ideally the slubbing should be removed from site but the high cost and carbon footprint of doing so means a long term view of stripping the contained nutrients needs to be 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 three locations, the catch dyke is joined to existing or former dykes trending south-north which connect (or used to) to marsh dykes. These ditches could drain the toe slope area and hence should also be infilled as shown on Figure 17. To prevent through-flow in the loose fill, there should be a ditch barrier at the end of the infill.

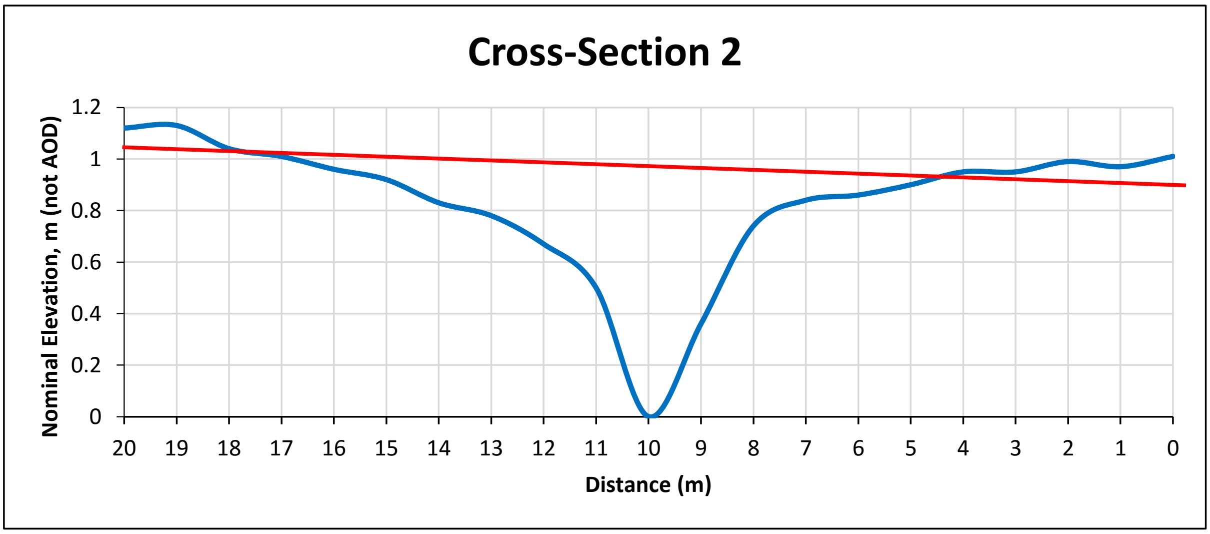
The short ditch draining a small depression upslope of the catch dyke will also need to be infilled with an associated cross-barrier.

**Figure 19: Representative Cross-sections of the Catch Dyke.** The map shows locations, including proposed long barriers**.** The blue line is the approximate top of firm silt. Semi-suspended silt which will settle out when the dyke dries is not shown. The red line is the approximate desired finished profile. A photo of the current condition of the catch dyke is shown following each cross-section.




Cross Section 1
Nominal Elevation, m (not AOD)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
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)
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0.6
0.4
0.2
0
20
19
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16
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13
12
11
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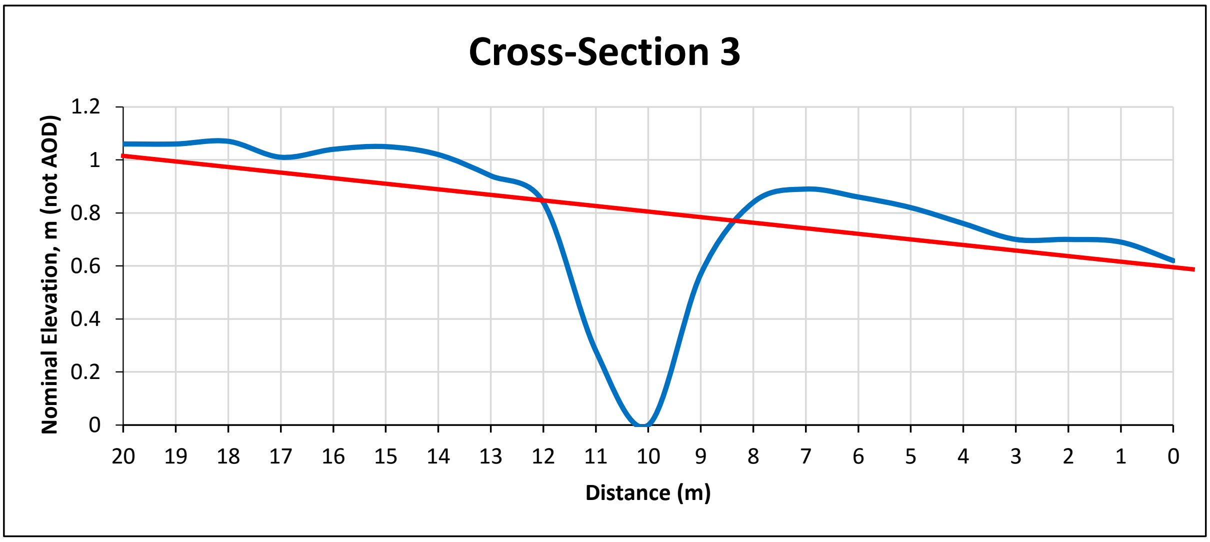
9
8
7
6
5
4
3
2
1
0
Distance (m)


Cross-
Section 2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0.6
0.4
0.2
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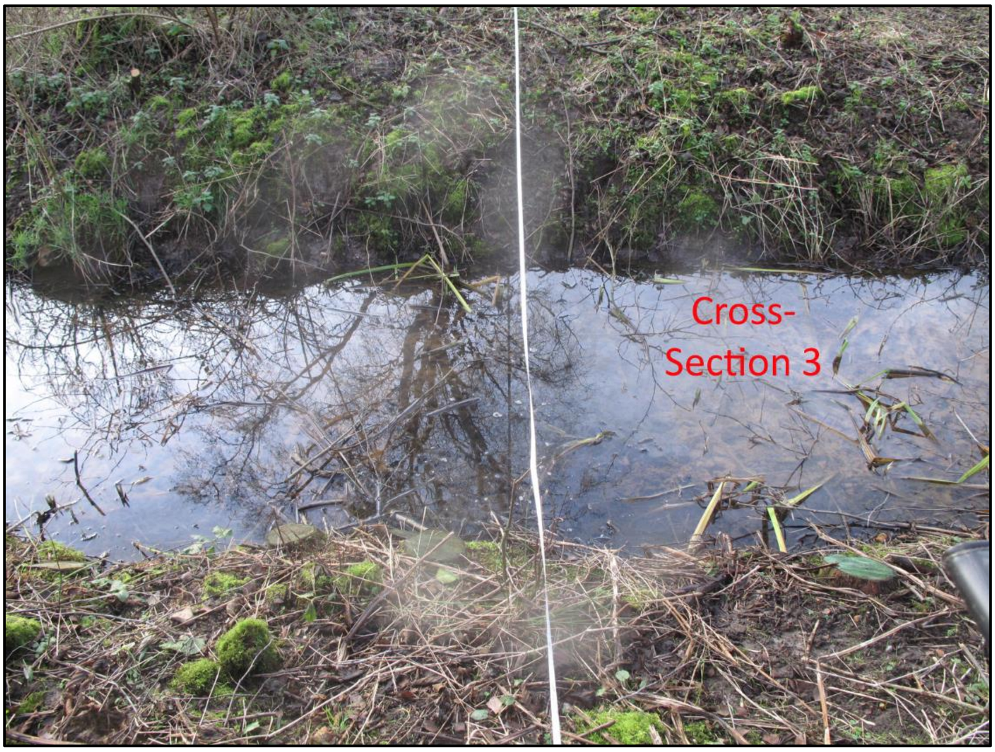
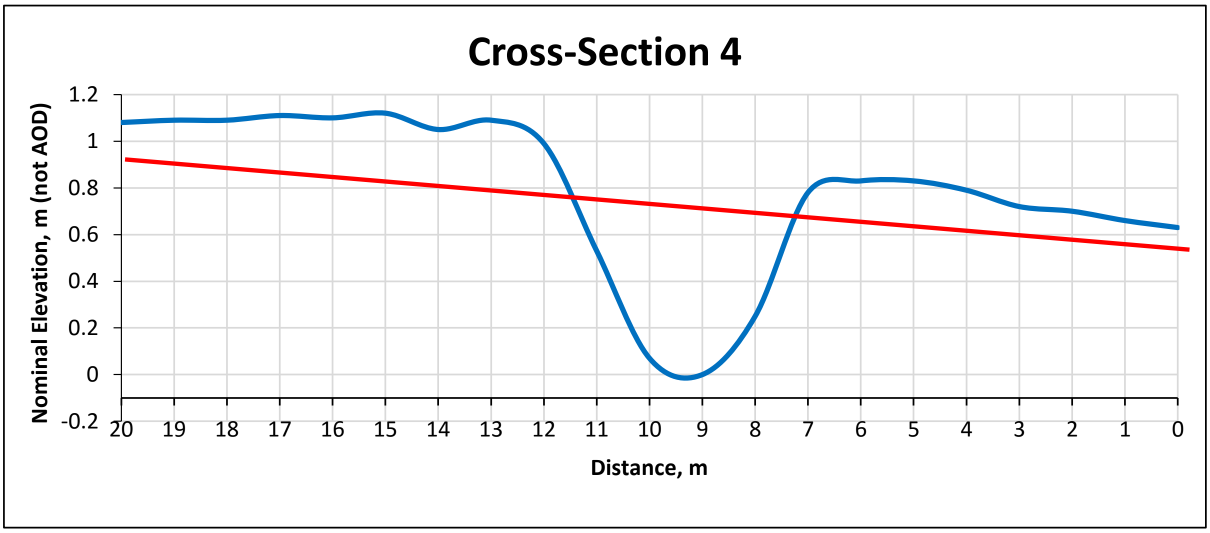
Distance (m)


Cross-
Section 3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0.4
0.2
0
-0.2
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19
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16
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12
11
10
9
8
7
6
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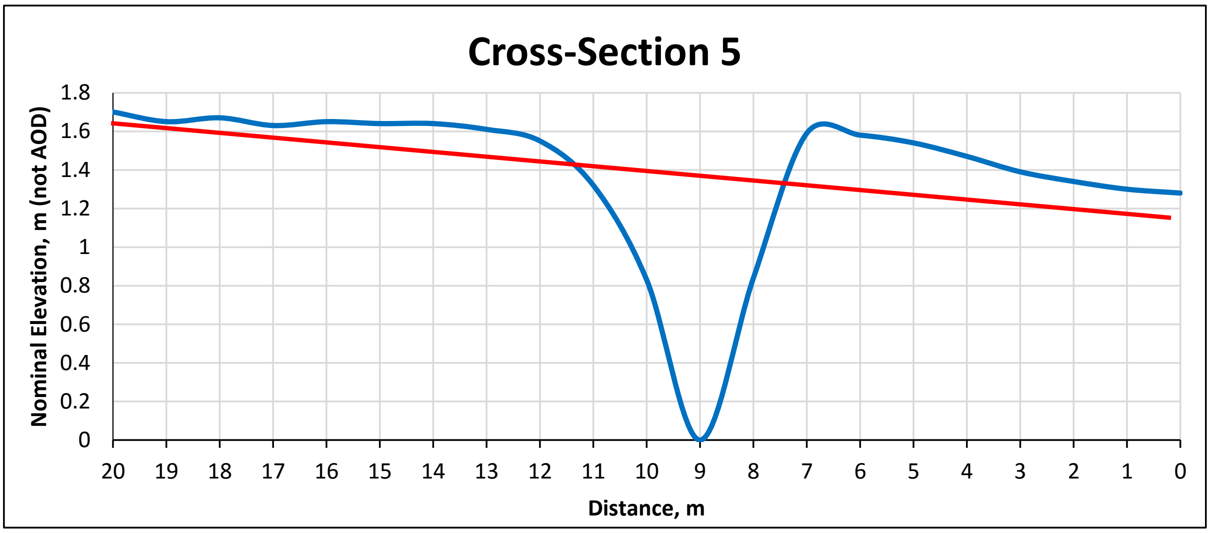
4
3
2
1
0
Distance, m


Cross-Section 4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20
19
18
17
16
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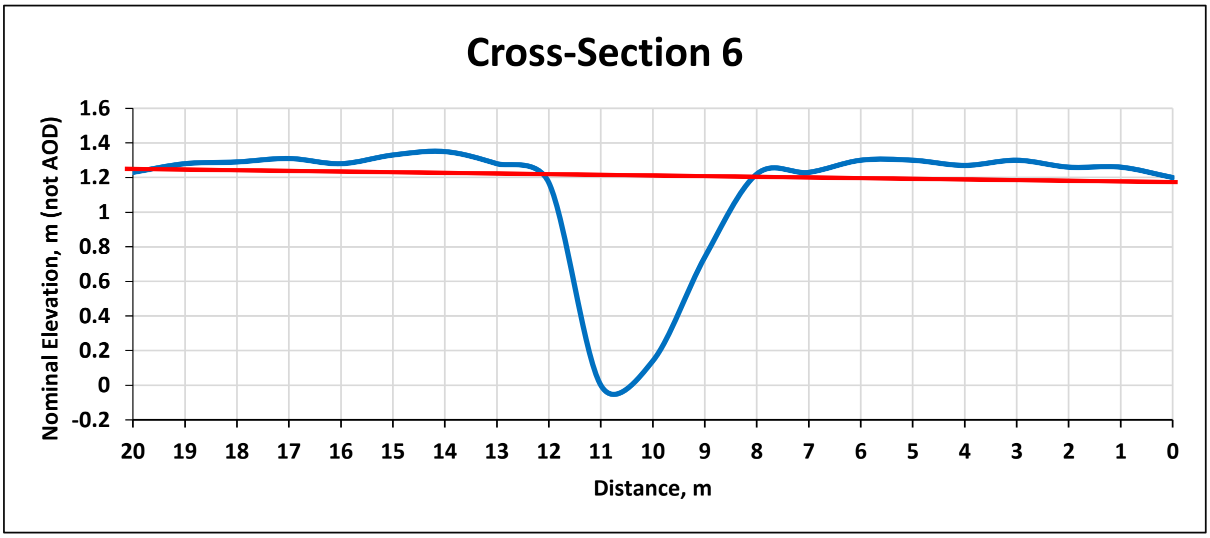
Distance, m


Cross-
Section 5


Cross-Section 6
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18
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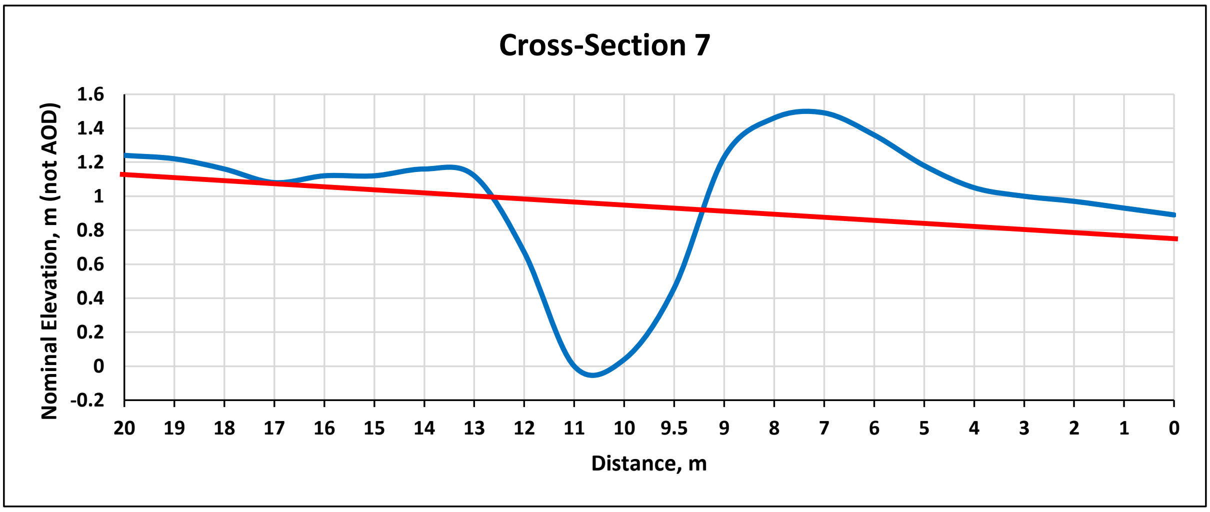
Distance, m


Cross-
Section 6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0.8
0.6
0.4
0.2
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-0.2
20
19
18
17
16
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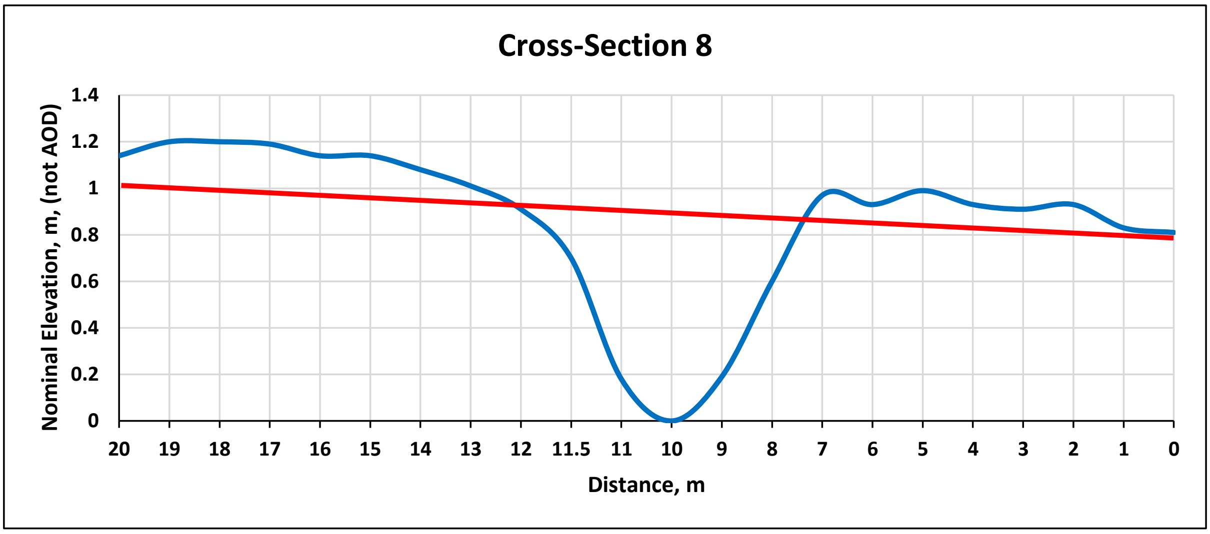
14
13
12
11
10
9.5
9
8
7
6
5
4
3
2
1
0
Distance, m


Cross-
Section 7


Cross-Section 8
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1.2
1
0.8
0.6
0.4
0.2
0
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18
17
16
15
14
13
12
11.5
11
10
9
8
7
6
5
4
3
2
1
0
Distance, m


Cross-
Section 8

**Prevention of groundwater flow.** Even the in-filled ditch, with loose coarse sediments, could form a preferential flow line. 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 18). Every 100m or so, a cross-barrier should be inserted into the former catch dyke, from finished level to 2.5m below fen side ground level, and keyed 2m into each bank. The final barrier width will vary by location, according to ditch channel width, with the cross sections in Figure 19 providing an indication of the range. Interlocking trench sheet should be used and should be finished flush to the ground level expected after settlement. Ideally, the trench sheeting should be driven through the fill material.

One major cross-barrier is needed in each catch dyke to prevent groundwater flow under or around the infilled catch dyke. This will need to penetrate down to base drainage level which is taken as the dyke water level in the Damgate Marshes[8]. This has been measured in the LIDAR survey as around minus 1.0m AOD. To allow for drought conditions and errors in LIDAR data, the design base level for the trench sheeting will be minus 2.0m AOD. Interlocking trench sheeting should be used. The barrier should extend up and downslope far enough to encompass the main width of the groundwater draw down. The form of the barriers is shown in Figures 20 and 21. Figure 22 shows photos of the line of the barriers.

Figures 20 and 21 also show a topographic survey of the line of the barrier with a level to mAOD recorded every 1m from 30m upslope to 30m downslope of the centre of the catch dyke in each location. For the south-north catch dyke, the line survey extended to the Landspring Dyke. The two barriers have different design parameters:

- West-East Catch Dyke: This is located c.20m east of the end of the catch dyke to avoid the powerlines. The arrow in Figure 20 indicates the centre of the track. To reach design depth of minus 2.0m AOD the piles will need to be longer upslope to account for the rise in land, around 3m long, with piles on the downslope side around 2.5m long. To seal the main width of the groundwater trough, the barrier should extend 25m up and down slope of the centre of the catch dyke, 50m in total. The ground surface should be left flush with the top of the barrier requiring some fill.

- South-North Catch Dyke: The barrier stretches from 25m upslope of the catch dyke to 30m downslope, 55m in total. It will more or less seal across the fen to the Landspring and is placed just upstream of the main IDB sluice. The piles upslope of the dyke need to be 2.5-3.0m long to reach design depth of 2.0m AOD, downslope 2.5m piles should be sufficient. Again, the ground surface should be left flush with the top of the barrier, requiring some fill.

---

[8] Ideally, the barriers should seal down to a substantive impermeable layer, but none was encountered under the south-north catch dyke, and only a thin and variable clayey sub-soil was found at the east end of the west-east catch dyke (see core transects 4 and 3 respectively). Base drainage level is the next best option.

**Figure 20: Cross-Dyke Sheet Piling Barrier (in blue) To Prevent Eastern Flow of Groundwater – West-East Catch Dyke.** The red line is the ground surface. The barrier should extend from ground surface to minus 2.0m AOD. It should extend 25m upslope and 25m downslope of the track, 50m total.

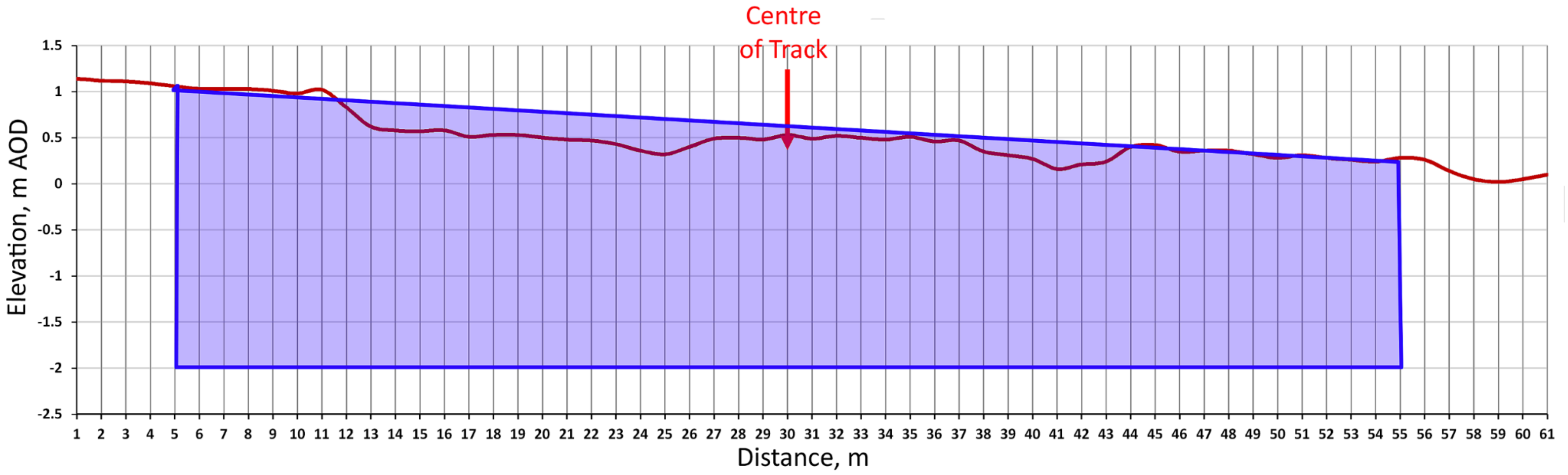


**Figure 21: Cross-Dyke Sheet Piling Barrier (in blue) To Prevent Northern Flow of Groundwater – South-North Catch Dyke.** The red line is the ground surface. The barrier should extend from ground surface to minus 2.0m AOD. It should extend 25m upslope and 30m downslope of the centre of the catch dyke, 55m total.

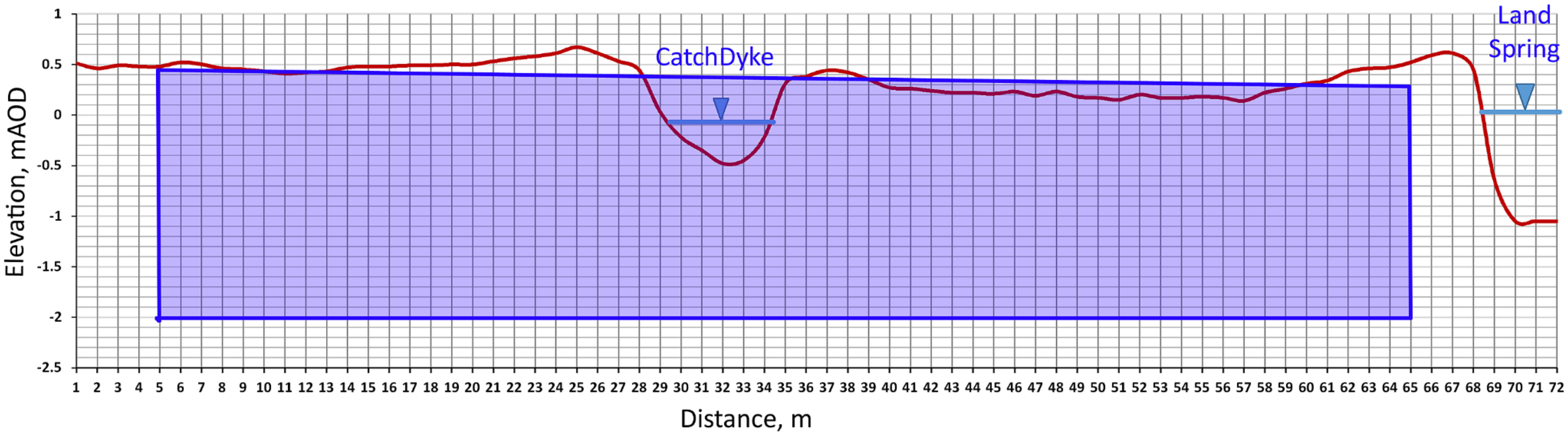


Figure 22: Photos Of The Line Of The Long Barriers.

Long Barrier
North-South catch dyke
Upslope

Long Barrier
North-South catch dyke
Downslope

**Leakage East to the Damgate Marshes**: Potential deep groundwater flow to the Damgate Marshes would undermine the effectiveness of infill of the south-north catch dyke. A long barrier down the length of the Acle Landspring would be prohibitively expensive. It was concluded above that there is likely to be both a south-north and eastern component to groundwater flow with uncertainty over proportion. It is therefore suggested that if project partners are not comfortable with this uncertainty, only the main cross-barrier be installed in the first instance. If this maintains catch dyke and ground water levels at ground surface, progression to in-fill could follow. Re-connection of the southern end of the dyke would still be required.

**Ancillary Works**: The gateway adjacent to the south-north catch dyke should also be raised to prevent water leaking eastwards along the terrestrialised dyke. It will also make the gate more useable. This was originally part of the dyke system and has turned back to quagmire. Figure 23 shows current condition.

**Figure 23: Current Condition of the Gateway.**

The gateway should be dug out to a depth of 1.50m or to hard bottom, for a width of 5m and a length of 10m. This should then be back-filled with mineral soil (which can be impermeable) won locally from the toe slope. The in-fill should be compressed as hard as possible. The final surface should grade to the slope to the north and be cambered to shed water. The middle of the gate should be 300mm above surrounding level.

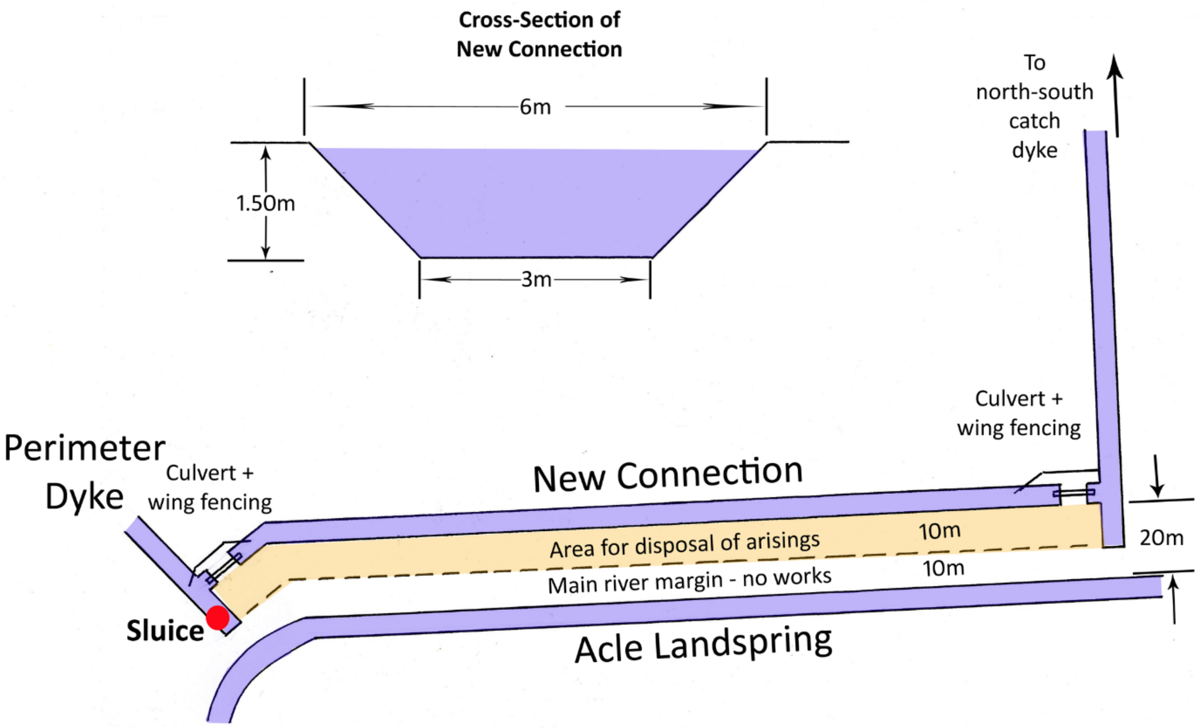
The existing stock fencing along the margins of the catch dykes will need to be removed. A new fence will be needed along the in-filled south-north catch dyke because it is an ownership boundary. This is an awkward location for a fence as it will be a seepage slope. It would be better to site the fence upslope on hard ground but this would require agreement between landowners. A fence is not needed along the west-east catch dyke. Fencing specification should be a like for like replacement with pressure treated softwood, box strainers and round intermediates with four strands of strained barbed wire.

New field gates will be needed as shown, five in total, allow 2m each side of 4-rail post and rail.

In order to provide some drainage to the low areas in the Acle Lands Trust and Mr Dyball's fen areas, an alternative drainage route is needed if the south-north catch dyke is infilled. The southern end of the south-north catch dyke should be reconnected to the southern perimeter drain. The level on this is maintained at 0.05m AOD. This level would create higher water levels than at present, with 15cm of standing water in the low lying areas, although this will draw down over the summer.

There is no trace of the old dyke on the ground, although the line is occluded by scrub. To avoid working within 9m of the bank of the Landspring, Main River (a regulatory issue), and to minimise leakage from the Landspring, the arrangement shown in Figure 24 is suggested. The two culverts shown should use a 6m length of 300mm twin walled pipe. The rail fencing should use four rails, reaching into the water, assume length of 15m of fence for each.

**Figure 24: Design for the Reconnection of Dykes Near the Landspring.**



Because the in-fill of the catch dykes and scrub clearance work will create substantial areas of un-vegetated 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. Initially, cutting of 30% of the area cleared of trees three times per year should be budgeted for.

The two main access tracks are likely to be affected by the works and will need remedial works on completion. Trafficking will cause rutting and compaction. On completion of the works, the track should be sub-soiled, rolled flat, a geotextile laid on the surface and the width treated with 150mm crushed concrete (no mixed rubble). The design width for the track is 3m. New field gates will be needed as shown on Figure 17.

### 6.2.2 Solution 2 : Raise Water Level

This solution applies to the western-most section of the west-east catch dyke which will not be infilled.

A trench sheeting cross-barrier, set at marsh level should be installed at east end of this dyke section, just upstream of the gate culvert. It should have the form of Figure 18, but without the channel infill.

### 6.2.3 Solution 3 : Perforate Perimeter to Improve Permeability

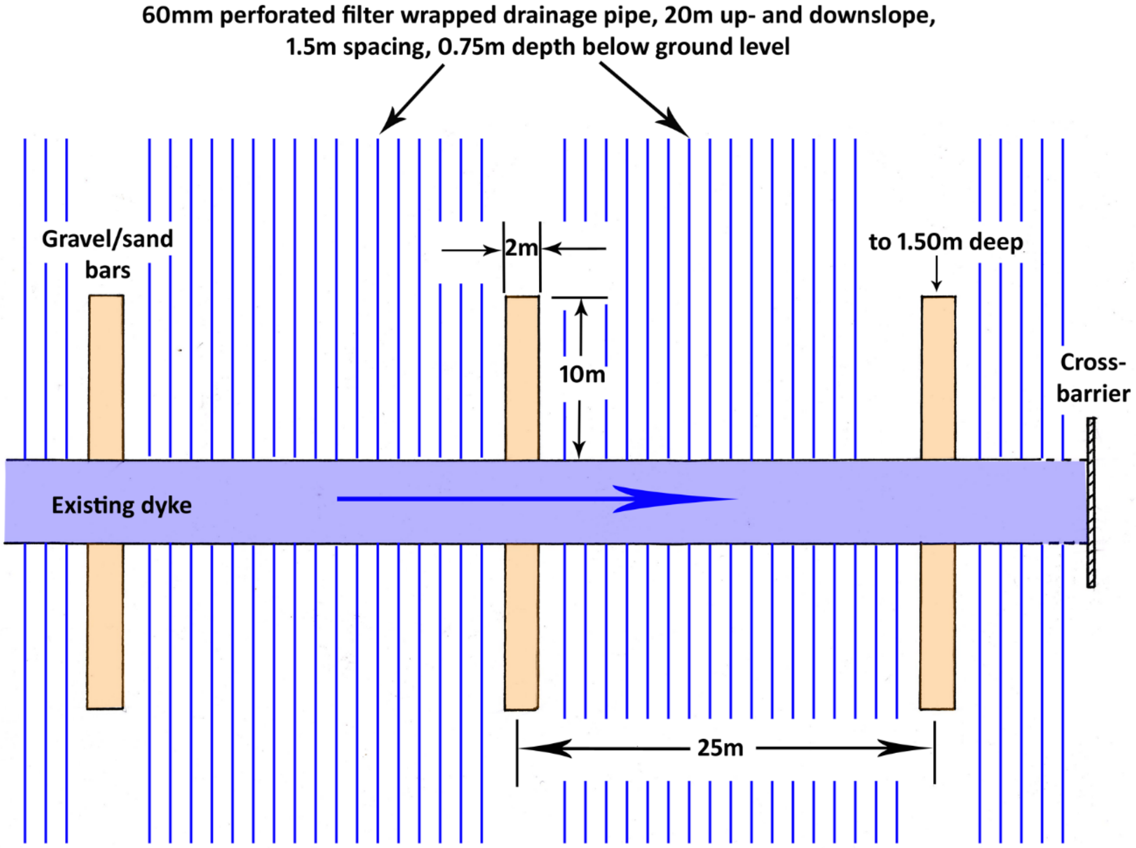
This solution (Figure 25) applies to the western-most section of the west-east catch dyke which will not be infilled. It aims to increase the volume of water seeping from the upland into the fen.

This whole section of dyke should be slubbed to bed and have the sides scraped and fluffed out as shown on Figure 18.

To increase the permeable perimeter, cross bars of permeable fill will be inserted every 25m along the length (at 0m, 25m, 50m, 75m, 100, 125m), a total of 6 locations over the 125m. These should be 2m wide and stretch 10m upslope and 10m downslope from the dyke edge. They should extend from bed to surface, allow for 1.50m depth. Thus each bar will be 2.0 x 1.5 x 10m in size, 30m$^3$ in volume. The fill should be as permeable as possible with sharp sand being the minimum grain size. Material should as far as possible be won locally from materials upslope, the source areas being backfilled with arisings from the dyke work. Some sharp sand-20mm gravel material may need to be imported.

To maximise seepage downslope, irrigating under-drainage should be installed. For 20m upslope and 20m downslope of the dyke perimeter, 60mm filter-wrapped perforated single walled corrugated land drainage pipe should be laid at 0.75m below ground level, at 1.5m spacings. Ideally, gravel fill should be used in the trench but practical difficulties and cost of

**Figure 25. Works to Perforate First Section of the West-East Catch Dyke.** Not to scale. Spacing of drainage pipe is illustrative.



importing such a quantity of material makes filter-wrapping a more practical solution. The pipe should follow the topographic gradient.

Residual arisings from the work should be spread on areas trafficked or excavated. All trafficked and "brown" areas should be sub-soiled and harrowed down on completion of the works.

### 6.2.4 Solution 4: Change upland land use to restore the wetland to dryland transition at the valley margin

The lower slopes are already in low-intensity management designed to improve its nature conservation interest. A change from arable to pasture is not in this case needed. However, the corridor of the catch dyke on both sides has progressed from open fen and grassland to closed canopy scrub. To meet the project's objectives, the land will need to be restored back to fen and grassland.

All scrub and trees should be removed within the catch dyke corridor and across the peat area down slope. Ideally, the conifers at the west end should also be removed. The grazed mosaic of scrub, grassland and bramble up-slope of the catch dyke should be retained. The ash at the far west, which has ash dieback, should be removed.

All roots need to be removed (either pulled or ground out) and all arisings taken from site. The timber should be allowed to the contractor and any value discounted from the price.

Areas of wet woodland south of this corridor should be retained to maintain representation of the habitat on site.

# 7 STAGE 5: IMPLEMENTATION

## 7.1 Tendering

### 7.1.1 Form of Tender

It is recommended that all of the works 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). The Contractor should also be made responsible for liaison with National Power Networks regarding working in proximity to the powerlines.

### 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 powerlines, it is suggested that the works will require oversight through the CDMC regulations.

### 7.1.4 Derivation of Final Tender Designs

There will 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 5 provides an initial bill of quantities. All of the works have been included, although it is anticipated that in-fill of the south-north catch dyke would only take place if the long barrier were shown to be effective. 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 measurement.

A contingency of 15% has been suggested 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 costs 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.

**Table 5. Initial Bill of Quantities.** Subject to Contractors estimates of quantities.

| Item | Quantity | |
|---|---|---|
| **Scrub clearance** | 6.12 ha | |
| **In-fill catch dyke** | 720m | 5.5m wide by 1.5 deep, 5940m$^3$ total,<br>Assume 50% slubbing to remove silt (3,000m$^3$), 115% backfill (6,831m$^3$). |
| **Infill of gateway** | 1 | 1.5m x 5m x 10m = 75m$^3$, assume 100% slubbing (75m$^3$), 115% backfill (86m$^3$). |
| **Length of catch dyke for perforation** | 125m | Slubbing out to 1.5m deep x 5m wide, assume 30% of void is spoil to remove, 281m$^3$ |
| | Permeable bars, 6 pairs, 12 total | 2 x 10 x 1.5m = 30m$^3$ each, 360m$^3$ total. |
| | Field drain irrigation, 20m up- and down slope, 1.5m spacing between permeable bars, (110m width), 60mm perforated filter wrapped drainage pipe. | 2935m of pipe installed to 0.75m below ground level. |
| **Restore toe slope by spoil spreading sub soiling and harrowing.** | Infilled catch dyke: 720m | 3,000m$^3$ spoil, 30m width along catch dyke margin. |
| | Perforated dyke: 125m | 281m$^3$, 30m wide along catch dyke margin. |
| **Track Surfacing** | 759m long, 3m wide, 150mm stone. | 760m of 4m wide geotextile.<br>342m$^3$ + 10% = 375m$^3$ of stone. |
| **Fence removal** | 300m | |
| **New fence installed** | 227m | Like for like replacement, pressure treated softwood, box strainers, 4 strands strained barbed wire. |
| **Field gates** | 5 | Pressure treated standard wooden field gates plus 2m 4-rail post and rail either side. |
| **Short dyke barriers** | 8 | 2.5m depth on fen side, width depending on location |

|  |  |  |
|---|---|---|
| **Long barrier** | 1 | West-East Catch Dyke: 50m x 3m |
| **Long barrier** | 1 | South-north Catch Dyke – 55m x 3m |
| **Excavation of new connector dyke** |  | 6.75m$^2$ x 148m = 999 m$^3$ |
| **Culverts** | 2 | 6m of 300mm twin walled pipe each with 1m 4-rail pressure treated softwood post and rail fence into water at both ends. |
| **Aftercare of scrub clearance and catch dyke corridor** | 30% of 6.12 ha | 0.94ha, three times/year, 3 years, cut and remove. |
| **Contingency** | 15% of sub total |  |

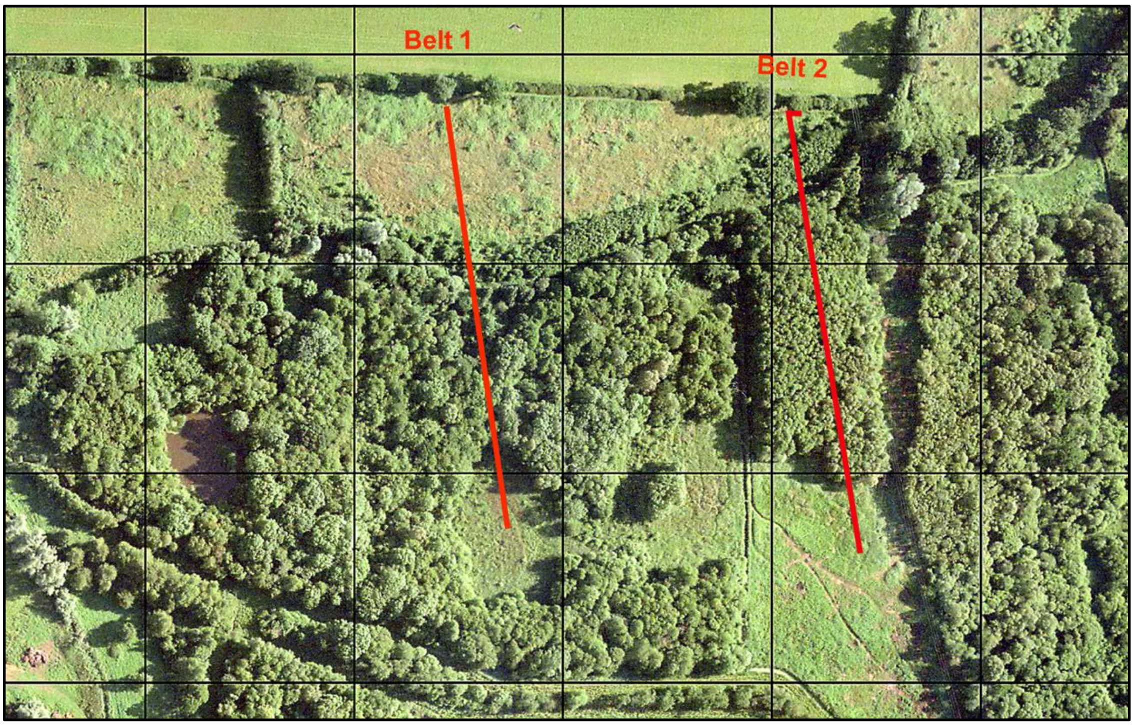
# 8 STAGE 6: REVIEW: PROPOSED MONITORING

## 8.1 Belt Transect Positions

Monitoring is in the form of belts perpendicular to the catch dykes and stretching from the dryland end of the hydrosere to the point in the wetland where the influence of the groundwater margin is extinguished.

The belts would be marked by a post at the start and end of each transect, up- and down-slope of the dyke, 4 posts in all. Each transect starts 2m from the edge of the catch dyke. The belt transect is 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 and silt, 1m in hard ground. The upslope transect will need to terminate at the site boundary where there is a track. There are two transects, shown approximately on Figure 26. All of the transect length is grazed except the downslope section of Belt 1 where the fen is mown.

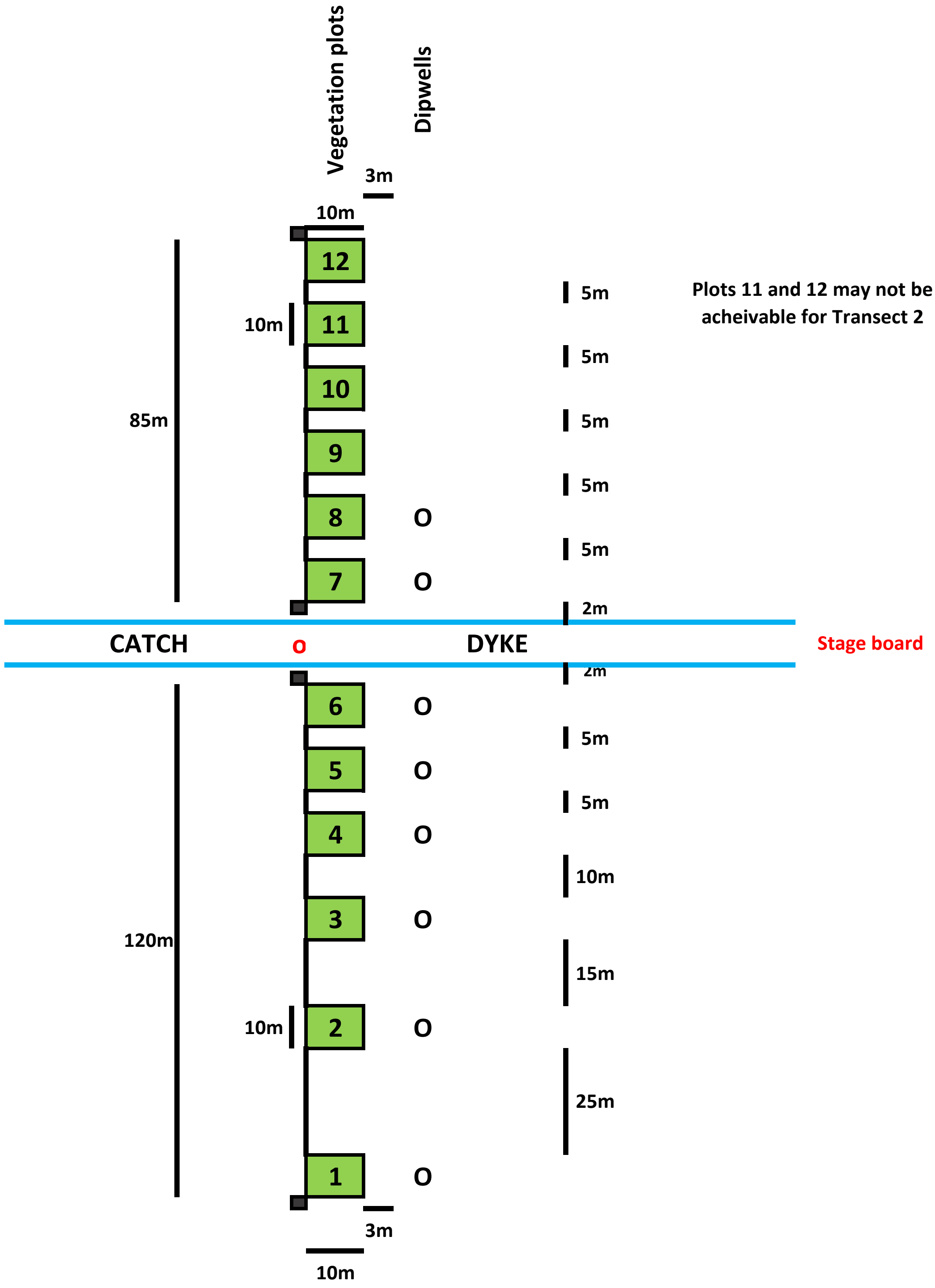
**Figure 26: Approximate Location of Transects.** Some scrub shown has now been cleared.



## 8.2 Vegetation Monitoring Plots

Along the belt, 10m square sample plots will be located at alternate plots, upslope and downslope of the catch dyke (Figure 27). Such a large plot allows for the coarsely structured

**Figure 27: Sketch of Monitoring Belt Transects**



vegetation to be accommodated. It was 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.

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 Decoy Carr Acle 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.

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.

Sub-sampling with small quadrats (say 30 samples of 1 x 1m quadrats) would produce data with greater statistical robustness, but the resources required to survey and analyse such data is thought prohibitive. Also, the trampling associated with such an intensity of recording could itself affect the composition of the vegetation.

There will be six plots each up- and down-slope of the dyke. There is no magic formula for deciding the number of plots – this is a reasonable balance between amount of data collected, and the resources required for data collection and analysis.

It is within the zone proximal to the catch dyke that change will be strongest, quickest to manifest and most likely to be measured through monitoring.

Soil coring has shown the water table is significantly affected by the catch dyke at 25m, but not at around 95m (there were no cores between), so it is safe to assume that the zone of influence is at least 50m. At 95m and beyond, the water table was at fen surface or above in hollows. Coring was undertaken in late autumn after a very wet summer, so the *typical* summer water table profile is not known but is likely to decline below the fen surface for a greater distance into the fen. On restoration, it is hoped that the near surface water table will be boosted, and that summer sags in water levels will be mitigated. Hence, it is likely that at least the first 75m of the area downslope of the catch dyke will benefit. It is prudent to have one plot at greater distance, to catch any unexpected long range effects Transect 1 also has one plot in the mown *Cladium,* which is an SAC feature, at 120m.

Transect 2 has a short upslope run. There may not be sufficient room for the higher vegetation plots.

Because the response of the water table is likely to show a marked distance-decay, the monitoring plots reflect this and are densest nearest to the dyke (Figure 27).

The same principle of spread of monitoring plots from the catch dyke applies up-slope. However, because of the steeper gradient of the upland, the transition to non-fen habitat will be swifter, and the eco-hydrological change effected by catch dyke restoration at the toe slope that much quicker. Hence the monitoring plots are more compressed on the up slope side.

For each 10 x 10m plot, all species including bryophytes should be listed with Domin abundance. If a vegetation plot appears to overlay a vegetation boundary between two communities, or the edge of a dominant stand such as a sedge bed, this will be included. A scale sketch of the vegetation boundary will 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 (Figure 27). There is a dipwell for each plot on the floodplain, a total of eight dipwells per belt transect. A stageboard has been inserted into the catch dyke itself.

Because of the need for a working corridor and the impact of the works, the nearest 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, the data will not be affected. Dipwells are 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 is as close as possible to the centreline of the 10m vegetation plots.

The level of ground and rim of the dipwells, and the zero line on the gaugeboard, has been recorded to OD (Table 6).

Because of a likely short run of data, ideally 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 with 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.

**Table 6 : Dipwell and Gaugeboard Levels to Ordnance Datum**

| Dipwell | Location | GPS Location (all TG) | Rim or GB "0", mAOD | Ground, Approx, mAOD |
|---|---|---|---|---|
| **Transect 1** | | | | |
| **1.1** | Fen | 40569 09380 | 0.98 | -0.01 |
| **1.2** | Fen | 40565 09419 | 1.02 | 0.08 |
| **1.3** | Fen | 40569 09441 | 0.99 | 0.03 |
| **1.4** | Fen | 40559 09457 | 1.07 | 0.17 |
| **1.5** | Fen | 40563 09481 | 1.13 | 0.21 |
| **1.6** | Fen | 40554 09490 | 1.21 | 0.30 |
| | Gauge | Level of "0" | -0.09 | |
| **1.7** | Slope | 40560 09503 | 1.75 | 0.69 |
| **1.8** | Slope | | 1.91 | 0.95 |
| **Transect 2** | | | | |
| **2.1** | Fen | 40738 09427 | 1.04 | 0.09 |
| **2.2** | Fen | 40731 09452 | 1.07 | 0.16 |
| **2.3** | Fen | 40724 09484 | 1.02 | 0.14 |
| **2.4** | Fen | 40727 09506 | 1.03 | 0.01 |
| **2.5** | Fen | 40724 09525 | 1.07 | 0.22 |
| **2.6** | Fen | 40720 09543 | 1.29 | 0.39 |
| | Gauge | Level of "0" | -0.02 | |
| **2.7** | Slope | | 1.68 | 0.76 |
| **2.8** | Slope | | 1.90 | 0.98 |

## 8.4 Data Storage and Analysis

### 8.4.1 Water Level Recording to 1st April 2016

Figure 28 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. Note that the range is modest – around 15cm over the recording period.

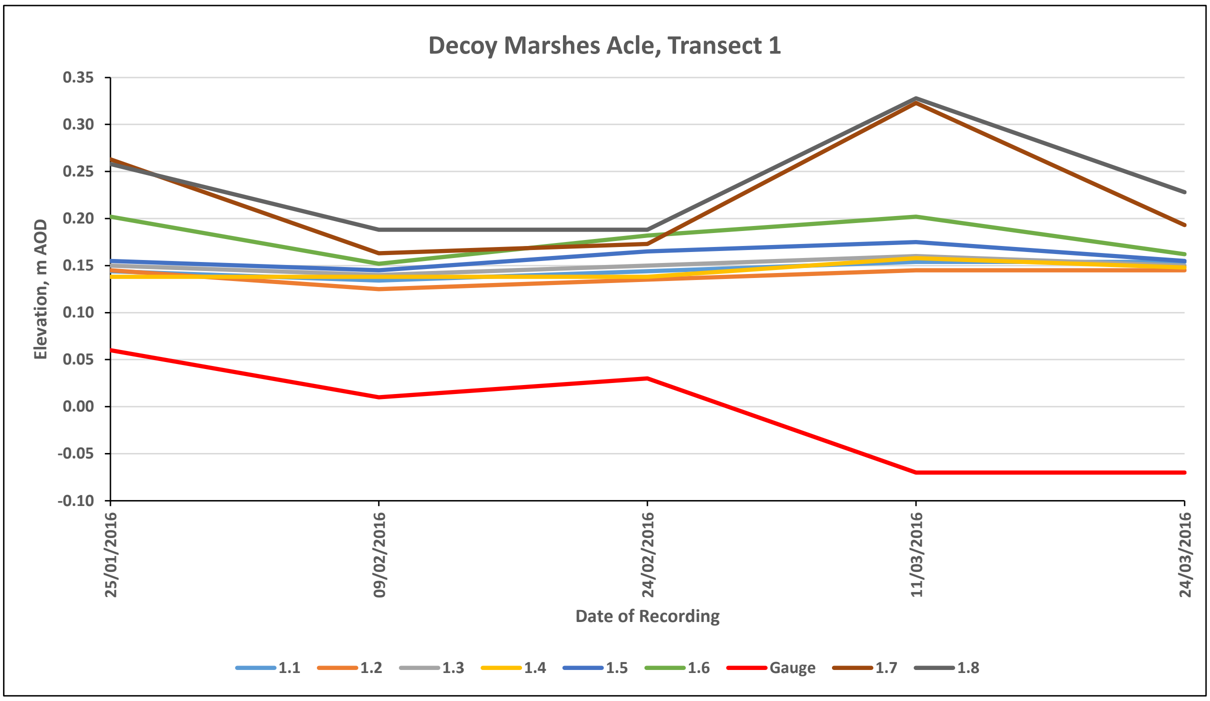
### 8.4.2 Ongoing Arrangemeents

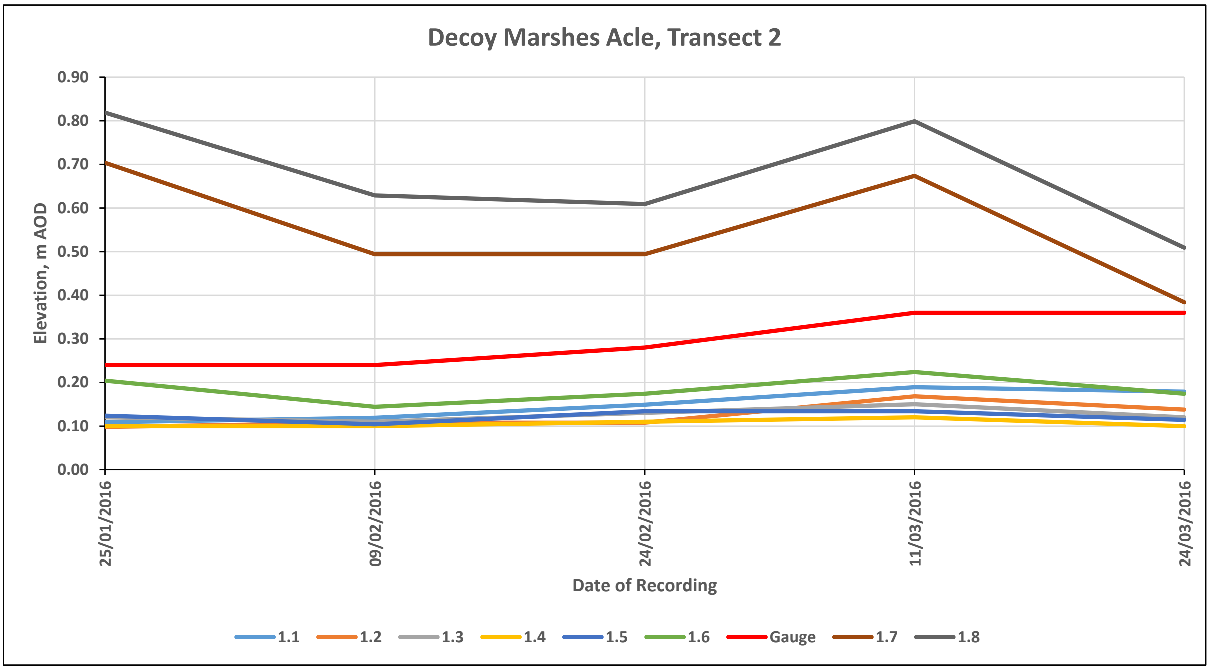
Natural England will collect and collate the data.

Copies will be sent to the landowners and project partners.

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

**Figure 28: Dipwell Records to 1st April 2016.** First graph is Transect 1, the second Transect 2.





# 9 REFERENCES

Arthurton, RS, Booth, SJ, Morigi, AN, Abbott MAW, and Wood CJ (1994) *Geology of the Country Around Great Yarmouth.* Memoir of the British Geological Survey Sheet 162.

Avery, BW (1980) *Soil Classification of England and Wales (Higher Categories)*. Soil Survey Technical Monograph No. 14. Soil Survey of England and Wales.

Boorman, DB, Hollis, JM, and Lilly, A (1995) *Hydrology of soil types: A Hydrologically based classification of the soils of the United Kingdom.* Institute of Hydrology Report No. 126.

BA (2013) *Broadland Fens Condition Assessment 2012 - Bure Valley Fens*. Broads Authority Report. The Broads, UK.

Clayden, B and Hollis, JM (1984) *Criteria for differentiating soil series.* Soil Survey Technical Monograph No.17.

CU (2014) *The Soils Guide.* Cranfield University. Available at www.landis.org.uk.

ELP (2001) *Ochre, salinity and products of drainage in the Brograve Catchment*. Unpublished report to the Broads Authority.

ELP (2010) *Fen Plant Communities Of Broadland: Results of a Comprehensive Survey 2005-2009*. Report to the Broads Authority and Natural England, Norwich.

European Commission (2007) *Interpretation Manual of European Union Habitats*. European Union DG Environment, Nature and Biodiversity, Report EUR27, July 2007.

George, M (1992) *The Land Use, Ecology and Conservation of Broadland*. Packard, Chichester.

Giller, KE and Wheeler, BD (1986) Past peat cutting and present day vegetation patterns in an undrained fen in Norfolk Broadland. *Journal of Ecology* v. 74, 219-47.

Hazelden, J (1990) *Soils in Norfolk VIII: Sheet TG40 (Halvergate).* Soil Survey Record No. 115. Silsoe

Hodge, CAH, Burton, RGO, Corbett, WM, Evans, WM and Seale, RS (1984) *Soils and their Use in Eastern England*. Soil Survey of England and Wales Bulletin No. 13, Harpenden.

Hodgeson, JM (Ed) *Soil Survey Field Handbook*. Soil Survey Technical Monograph No. 5. Silsoe University.

IGS (1981) *Hydrogeological Map of Northern East Anglia. Sheet 2. Chalk, Crag and Lower Cretaceous Sands. Geological Structure.* Institute for Geological Sciences.

JNCC (2015) *Common Standards Monitoring Guidance for Freshwater Lakes*. (updated from 2005) Joint Nature Conservation Committee, Peterborough.

National Soil Resources Institute (2014) *Full Soils Site Report for location 640500E, 309000N, Decoy Carr Acle*, and *Ebb and Flow Marshes Horning,* 5km x 5km, National Soil Resources Institute, Cranfield University. Accessed via https://www.landis.org.uk/sitereporter

NE (2007) *Conservation Objectives And Definitions Of Favourable Condition For Designated Features Of Interest: Decoy Carr, Acle SSSI*. Unpublished, Natural England Norwich.

OHES (2013) *Broadland Fens Site Hydrology Assessment and WETMEC Development*. Report to the Broads Authority.

OHES (2014) *An Investigation into the Management of Catch Dykes in The Broads* Report to Natural England, Norwich

OHES (2016) *Remedial Works for the Catch Dykes at Ebb and Flow Marshes. March 2016*. Unpublished report to Natural England, Norwich.

Tolhurst, S, McQueen, S, Mahon, H, and Harpley, D., (2000) *Water Level Management Plan For Lower Bure, Halvergate Fleet & Acle Marshes*. Unpublished Report, Kings Lynn Consortium of IDBs.

Wheeler, BD and Shaw, SC (2006) *Ecohydrological Accounts For Fen Sites in East Anglia.* Appendix 3 to WetMecs Report Wheeler et al (2009) below). Environment Agency Science Report Number SC030232/SR1

Wheeler, BD, Shaw, SC and Tanner, K. (2009) *A wetland framework for impact assessment at statutory sites in England and Wales.* Environment Agency Science Report Number SC030232/SR1

# APPENDIX 1 : LOGS OF SOIL CORES

| CORE | DEPTH | DETAILS |
|---|---|---|
| **North Slope from Pilot Phase** | | |
| **1** | | TG 40679 09786. Grass field, ex-arable, next to road. 5.4.1 Typical Brown earth, soils in deep stony drift. **Wick Series,** but with a fine loamy lower horizon**.** 2.10m AOD derived from levels map and original pilot survey. |
| | 0-35 | Mid-brown slightly grey silty fine sandy loam (overall sandy silt loam), some small stones up to 2cm, <5%. |
| | 35- | Pale orangey-brown sandy slightly clayey silt loam (overall sandy silt loam) with occasional siliceous stones, becoming stonier with depth, stones around 5-10% in profile, stiff. Coring ceased at 100cm. |
| | | |
| **2** | | TG 40707 09706. Sheep grazed ex-arable field. 5.4.1 Typical Brown earth, soils in deep stoneless drift Between **Sheringham Series.** 2.00m AOD derived from levels map and original pilot survey. |
| | 0-35 | Mid-brown, silty fine sandy loam (overall sandy silt loam), stoneless. |
| | 35-50 | Orange-pale brownie grey fine sandy silt (overall sandy silt loam), stoneless. |
| | 50-65 | Orangey-yellow fine to coarse soft sand, slightly silty, (overall loamy sand) some small gravel and stones, <1%. |
| | 65- | Orange-pale brownie grey fine sandy silt (overall sandy silt loam), as 30-50, some large stones (5%) and becoming very hard to core with depth. Coring ceased at 100cm. |
| | | |
| **3** | | TG 40743 09565. In alder scrub. 8.3.1 Typical cambic gley soils, coarse loamy soils in stony drift. **Quorndon Series. (similar location to 3.2 in Phase 2)** |
| | 0-30 | Mid-dark brown silt loam, some fine sand (overall sandy silt loam). Some bits of fine charcoal. Becoming clayey with depth. |
| | 30-45 | Mid grey-brown silty fine sand (overall sandy loam) with some brownie-orange mottles and some yellow-grey inclusions. |
| | 45- | Orangey yellow silty fine sand (overall sandy loam), faint mottling, siltiness declining with depth. Some large stones and gravel, increasing with depth, 10-20%. Becoming quite hard to core at depth. Coring ceased at 70cm. |
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| **4** | | TG 40728 09548. Alder woodland. . 8.3.1 Typical cambic gley soils, coarse loamy soils in stony drift. **Quorndon Series. Similar location to 3.3 in Phase 2.** |
| | 0-25 | Dark brownie black humic fine sandy silt loam. |

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|  | 25-45 | Pale greyish brown sandy silt loam with orangey brown mottles. Becoming greyer with depth, increasingly stiff. |
|  | 45-65 | Greyish, very pale brown silty fine sand (overall sandy loam), some orange brown mottling. Occasional small stones 5%. Becoming moister with depth. |
|  | 65-70 | Grey-brown silty coarse sand (overall sandy loam) with dense orange mottling. Becoming saturated, then difficult to pick up. Some fine gravel, c.10% of volume |
|  | 70- | Bluey-grey, sandy silt (overall silt loam), very stiff, some gravel to 10%. Becoming softer after 100cm, with coarse sand. Coring ceased at 110cm. |
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| **5** |  | TG 40687 09436. Water table at 45cm. **Altcar Series. Next to dyke** |
|  | 0-45 | Dark brown fine sandy loamy, humified peat. Some marked sandy and clayey inclusions. Fresh roots. |
|  | 45- | Dark brown fibrous peat, fresh and unhumified. Mostly moss peat in the upper layers with a little reed rhizome. Very wet, soft, loose and difficult to pick up with depth, more grass and sedge peat below 100cm. Coring ceased at 230cm. |
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| **6** |  | TG 40713 09389 Fen WT -20cm. **Ousby Series** |
|  | 0-20 | Black humified peat, silty and very wet, almost gel like in consistency. |
|  | 20-135 | Dark brown fibrous mossy fen peat , minor humification, snail shells frequent, reed rhizomes. Soft and sloppy after 50cm but becoming firm again. |
|  | 135- | Brown moss and sedge, grass peat, very fibrous, no humification. No shells. Becoming very wet, structureless and sloppy, very difficult to pick up. Coring ceased at 230cm |
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| **Transect 1, Phase 2** |  |  |
| **1.1** |  | Edge of scrub, 25m upslope of catchdyke. Dry fen meadow. 1.159m AOD. TG 40409 09536. 5.4.3 Gleyic brown earths, coarse loamy soils in stoneless drift - **Aylsham Series**. |
|  | 0-35 | Mid- to dark-brown slightly sandy silt loam, stoneless, firm. Much fresh root especially towards surface. |
|  | 35-55 | Sandy silt loam, mid- to light-brown, some stones <1cm, but less than 1%, flint, moderately stiff, dry. |
|  | 55-90 | Pale grey-brown, silty fine soft sand (sandy loam). Texture can vary including thin bands of sandy clayey silt. Usually somewhat stiff. Few small (<1cm) stones, but <1% volume. Occasional to frequent brownie-orange mottles, moderate size, diffuse edges, 15% of soil. |
|  | 90-150 | Very sandy silt loam, pale grey-brown, some small stones <2cm, around 2-3% volume, quite stiff. Variable texture sometimes verging on clayey silty sand. Firm even when wet. **WT at 90cm**. |

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|  | 150-210 | Orange-grey silty coarse sand (overall borderline sandy loam) with some stones <1cm, less than 3% by volume. . |
|  | 210- | Sandy clayey silt, mid-grey, stoneless (overall silt loam). Coring ceased at 220cm. |
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| **1.2** |  | Dry fen meadow, 14.5m upslope from centre of dyke, 1.007m AOD, TG 40411 09525. . 5.4.3 Gleyic brown earths, coarse loamy soils in stoneless drift **- Aylsham Series** |
|  | 0-30 | Mid- to dark-brown sandy silt loam, stoneless. Many macro-pores to 10%. Much living root material. |
|  | 30-55 | Light brown coarse sandy clay loam, stiff, mostly stoneless, some flint stones at base, less than 1% volume. Modest macropores 5%. |
|  | 55-85 | Pale grey-brown, sandy silt loam - soft silty sand increasingly silty and stiff with depth. Occasional brownie-orange mottles, often large (<30mm) with diffuse boundaries, 20-30% of area. More or less stoneless. |
|  | 85-190 | Mid grey-brown, stiff, fine sandy clay loam. **WT 90cm**. Becoming more clayey and stiffer with depth. Stoneless. |
|  | 190-210 | Soft, silty coarse sand (overall loamy sand), very weak, wet, stoneless. |
|  | 210- | Pale greyish with blueish tinge, soft sandy, silt , (overall silt loam). Coring ceased at 220cm. |
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| **1.3** |  | Dry margin near edge of catchdyke, 4m upslope of dyke, 0.745m AOD, TG 40410 09518. . 5.4.3 Gleyic brown earths, coarse loamy soils in stoneless drift - A**ylsham Series.** |
|  | 0-40 | Mid-brown silty loam, slightly coarse sandy, (overall sandy silt loam) stiff, a few very small stones <0.5cm, <1% by volume. |
|  | 40-65 | Mid-brown, occasionally grey- or orange-brown. Very sandy silty/clayey loam (overall sandy loam), small brown mottles frequent, 5-10mm, 20-30% of soil. Horizon is variable in colour and sand/clay content. |
|  | 65-120 | Pale grey-brown clayey silty sand (overall sandy silt loam), clay initially increasing with depth, also greyer with depth. Occasional pale brown mottles 10-20mm 10-20%, decreasing with depth. Sand increasing again toward water table. **WT at 110cm.** |
|  | 120-200 | Mid-grey, sticky, clayey coarse sand, no mottles. Stiff to start, becoming soft. Texture quite variable, sometimes tending toward sandy clay (overall sandy clay loam). Some stones, up to 4cm, at 170cm. |
|  | 200- | Soft blue-grey sandy slightly clayey silt, (overall silt loam), clay and silt declining with depth. Coring ends 220cm. |
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| **1.4** |  | Bed of catchdyke. 50cm water over. Bed at -0.15m AOD. **Not reffed to soil series.** |
|  | 0-15 | Organic silt plus plant detritus. Black, structureless. |

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| | 15-195 | Pale grey (becoming pale browny grey at 110cm) stoneless, silty coarse sand (overall sandy loam), varying with medium or fine sand, firm. |
| | 195 | Stiff, mid- to pale-brown firm sandy silty clay (overall clay loam). Stony, 1-3cm, 10%, hard to get through. Coring stopped 230cm. |
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| **1.5** | | Fen side, 3m downslope from centre of dyke, 2m from dyke edge. In eutrophic fen. With dyke spoil? 0.674mAOD. TG 40407 09506. Contains buried thin peat, although upper surface of peat (c. 0.22m AOD) is well below peat surface in fen. 8.7.1 Typical humic groundwater gley soils, in thick, stoneless drift, coarse loamy overall, but with buried peat. Closest to **Hanworth Series** but unusual. |
| | 0-30 | Organic-humose, dark brown, silty loam topsoil (overall humose sandy silt loam). Possibly derived from dyke dredgings. Stoneless. |
| | 30-55 | Orangey-brown with some grey, sandy silt loam with small stones <1cm. Some orangey brown mottling, c.1cm, diffuse boundary, 15% of soil. |
| | 55-85 | Humified brown-black loamy peat. **WT at 75cm.** |
| | 85- | Blue-grey sandy silt, stoneless, moderately stiff. Coring stopped 160cm. |
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| **1.6** | | Fen side in mixed reed. 6m downslope of centre of catch dyke, 0.739m AOD, TG 40409 09503. Still on dyke spoil? 10.2.4 Earthy, eutro-amorphous peat soils in humified peat. **Adventurers Series.** |
| | 0-25 | Dark brown, stoneless, silty peaty loam topsoil. Fresh roots, soft, high macro-pores, 30%. |
| | 25-120 | Dark brown to black, humified, slightly loamy peat with reed rhizomes and some shell fragments. **WT at 85cm**. |
| | 120- | Pale grey, some bluishness, stiff sandy silt. Stoneless. Coring stopped 195cm. |
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| **1.7** | | Fen side in mixed reed fen. 8.5m downslope of catch dyke centre. Off the spoil ridge. 0.679m AOD, TG 40407 09506. 10.12 Raw eu-fibrous peat soils in grass-sedge peat. **Ousby Series,** |
| | 0-35 | Dark brownie-black humified peat. Many fresh roots and reed rhizomes. |
| | 35-95 | Mid-brown fresh peat with reed rhizomes and some fresh roots in upper layers. Fibrous, rubbed fibre around 50%. Shell material present. Slightly anoxic smell. **WT 35cm**. |
| | 95-130 | Dark brown humified peat, still firm, slightly silty and greasy. Only larger plant materials such as reed rhizomes still visible. Hardly fibrous, <2% when rubbed. |
| | 130- | Stiff, bluish grey sandy clayey silt. Some stones for thin, 5cm layer at 170cm, stones <1cm, otherwise stoneless. Coring stopped 220cm. |
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| **1.8** |  | Near to pond, 45m from catch dyke. In fen developing scrub. TG40410 09469, 0.692m AOD. 10.12 Raw eu-fibrous peat soils in grass-sedge peat. **Ousby Series** |
|  | 0-30 | Brownie-black well humified peat, very slightly loamy, with fresh roots. Around 15% fibres when rubbed. |
|  | 30-60 | Fresh peat, mid-brown, with much fresh roots and shell fragments. Around 75% fibre when rubbed. Slightly anoxic smell. **WT 30cm** |
|  | 60-250 | Dark brown to black, variable, semi-humified peat, still firm. Low rubbed fibre, 15-20%. |
|  | 250-310 | Blackish, wholly humified, silty-greasy peat, with some alder wood fragments. Still firm. Fibre when rubbed 1-3%. |
|  | 310- | Bluish-grey sandy clayey silt, stoneless. Coring stopped at 320cm. |
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| **Transect 2, Phase 2** |  |  |
| **2.1** |  | 30m Upslope centre of catchdyke. 1.134m AOD, TG 40559 09528. Bramble/grass/nettle mosaic. Much grass litter on soil surface. 8.3.1 Typical cambic gley soils. Coarse loamy soils in thick drift with siliceous stones. **Quorndon Series** |
|  | 0-28 | Mid-brown, coarse sandy silt loam topsoil. Many macro-fissures and worm activity >20%. Few small stones <1% volume, <1cm size. Many fine roots. |
|  | 28-65 | Pale brown slightly silty coarse sand (overall sandy loam), stony c.20% 0.5-4cm, large diffuse orange-brown mottles c.30%, becoming moister with depth, rather structureless. |
|  | 65- | Orange-brown, coarse but soft sand, structureless, weak and increasingly wet with depth to water table. Stoniness variable, mostly small <1cm, in layers but mostly <5% but rarely to 30% when can become rather gravelly. Mottling faint in upper layers and difficult to see against background colour. **WT 100cm**. Coring stopped at 160cm when too wet to hold. |
| **2.2** |  | 0.848m AOD. 15.5m Upslope from centre of catch dyke. TG40549 09515. Alder scrub. Tree leaf and nettle litter. Intermediate 8.2.1 Typical sandy gley/8.3.1 Typical cambic gley soils. Soils in thick sandy drift with siliceous stones. Sandy/coarse loamy soils in thick drift with siliceous stones. Intermediate **Quorndon/Blackwood Series.** |
|  | 0-28 | Dark brown, loamy coarse sand. Slightly stony, <2%, stones flinty, up to 2cm. Well aerated with macropores 20%.. Significant roots of grass and trees. |
|  | 28-70 | Pale grey-brown, slightly silty and slightly clayey coarse sand (overall sandy loam), stony, 0.5-3cm, around 10% volume. Macropores around 10-15%. Large but diffuse orange-brown mottles, 20-30%, clear but becoming diffuse and faint with depth. Granular. |
|  | 70- | Pale brownie-grey coarse sand with very little silt (overall loamy sand). Weak, structureless (granular), becoming weaker with depth, sloppy and difficult to pick up below water table. Very stony in upper layer, 0.5-3cm, 20-30%, then declining to around 5% at around 90cm bgl. Coring stopped at 160cm. **WT 85cm**. |

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| **2.3** | | 0.784m AOD 4m upslope of centre of catchdyke. TG 40543 09502.Light alder scrub near strainers of fence. Light grass over mineral soil. Some tree leaf litter. 8.3.1 Typical cambic gley soils. Coarse loamy soils in thick drift with siliceous stones. **Quorndon Series** |
| | 0-28 | Mid- to dark-brown silty sandy loam (overall sandy loam). Sand medium to coarse, with some small stones <2%, <1cm size. Macropores >15%, moderate organic material, moist. Becoming sandier with depth. |
| | 28-60 | Mid- to pale-greyish-brown coarse silty sand (overall sandy silt loam). Stones to 10%, some large to 3cm, Macropores around 20%. Frequent orange-brown mottles, 20% of area, well defined but declining with depth. Grades to next layer. |
| | 60-115 | Mid-brownish grey silty coarse sand. (overall sandy loam). Occasional pale brown mottles, 15% of soil area, declining with depth. Slightly stony, up to 2cm, 10% volume. **WT at 90cm**. Silt declining with depth, stones increasing at 90cm to 15-20%, 0.5-3cm, then declining again to 10% at 100m then 5% below. Few macro=pores to WT, structure weak and granular, becoming very weak and sloppy below WT. |
| | 115- | Coarse pale brown sand, very little silt and more or less “running”. Very difficult to lift. Coring stopped 150cm. |
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| **2.4** | | -0.143m AOD. Core in ditch bed. TG 40542 09495. Soil series not defined. Gravelly layer at break of slope? |
| | 0-25 | Leaf mould and black organic structureless ditch silt. |
| | 25-85 | Grey, stoneless, fine-medium sandy soft silt. |
| | 85- | Coarse, very stony, slightly silty sand. Stones 0.5-2cm, 30%, coming close to 50% after 120cm. Reasonably soft but hard to core through stones. Coring stopped at 180cm. |
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| **2.5** | | 0.533m AOD. 4m downslope of catchdyke. TG 40545 09501. Edge of ditch, possibly on spoil. Open area in young alderwood, mixed tall herbs but not fen. 8.3.1 Typical cambic gley soils, coarse loamy in deep drift, marginal stony/stoneless. Intermediate **Quorndon/Sustead Series. (Both Host 10)** |
| | 0-30 | Dark brown fine sandy silt loam, with much organic material including some woody fragments (possibly turned out of ditch?). Some tiny snail shells. Becoming very wet with depth. Macropores c.20%. Some stones at depth, c.5% in lower half. |
| | 30-48 | Mid-brown fine sandy silt loam, soapy and stoneless. Macropores around 15% some fine roots. Small, defined orange-brown mottles 5-10% of soil. Soft, structureless. |
| | 48-60 | Mid-grey, fine sandy silt loam, no mottles, macropores around 15%, largely stoneless, soft and structureless. |

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| | 60-75 | Becoming stiff, mid-brown sandy silt loam, largely structureless, moist, faint and small mottles, 10-15%, orangey-brown, poorly defined. **WT 75cm**. |
| | 75- | Dark ashy grey-brown silty coarse sand (overall loamy sand). Small <0.5cm flint stones up to 5% in upper layer, becoming stonier with depth to 10-15% and with some larger stones to 5cm. Soft but coherent to begin with, oose and liquid to base, becoming running sand at end of coring, 180cm. |
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| **2.6** | | 0.409m AOD, 12m downslope of the centre of the catchdyke, open alder scrub some thin reed and grass, non-fen tall herbs. 8.7.1 Typical humic groundwater gley soils, in thick, stoneless drift, coarse loamy overall, but with buried peat. Closest to **Hanworth Series** but unusual. |
| | 0-15 | Mid- to dark-brown, coarse sandy, peaty loam, slightly silty (sandy silt loam overall, humose) stoneless, structureless. Organic material entirely humified. |
| | 15-40 | Mid-brown, sandy silt loam, moderately humose. Some small (<3mm), reddish-brown mottles around root cavities, <5%, macropores high, >20%, Almost stoneless <1%. |
| | 40-68 | Mid-brown, mossy fen peat, fibrous, only slightly humified ,Von Post 3, open loose with very high macro-pores. Quite abrupt transition to next layer. **WT 55cm** |
| | 68-120 | Mid-grey to pale brownish. Stiff, silty coarse sand (overall loamy sand), saturated, very few <1% small stones. |
| | 120- | Grey, very coarse sand with c.20% stones, mostly 0.5-3cm. Soft, becoming sloppy, structureless, difficult to raise. Coring stopped at 180cm. |
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| **2.7** | | 0.221m AOD, TG 40541. Fen edge, gap between trees, in Calamagrostis/reed, 23.5m downslope of centre of catchdyke. 10.12 Raw eu-fibrous peat soils in grass-sedge peat. **Ousby Series** |
| | 0-15 | Dark, brownie-black, humified loamy peat, no sand, stoneless, much fresh root material. |
| | 15-110 | Mid-brown, soft, fibrous (75% when rubbed) fen peat with visible rhizomes and much moss, firm wet, little decomposed (Von Post 3), Spongy and open texture. Becoming very wet and soft below water table, loose, difficult to bring up. **WT 25cm**. |
| | 110-130 | Dark brown, soft rather structureless, rather humified peat, Von Post 7, plant fibre especially roots still visible but <10% when rubbed. |
| | 130-160 | Dark brown, firm dryish humified peat, Von Post 7, 10% fibre when rubbed, still porous with 30% macropores, becoming sandy at base. |
| | 160- | Greyish, coarse, silty sand, stony up to 10%, firm but becoming soft rapidly with depth. Coring stopped at 2m. |
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| **2.8** | | 0.127m AOD. TG 40568 09400 Mown Cladium bed. 95m from edge of dyke. 5cm litter of sedge leaves. Very uneven surface. 10.12 Raw eu-fibrous peat soils in grass-sedge peat. **Ousby Series** |

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| | 0-15 | Black-brown, soft loamy peat. Well humified (Von Post 8) with fresh roots, <5% fibre when rubbed. **WT 0cm.** |
| | 15-115 | Mid-brown fen peat, fibrous (>80% when rubbed), little humified Von Post 2-3), large leaf and root fragments of grass and sedge, moist but firm. |
| | 115-250 | Soft structureless peat, very wet and loose and difficult to pick up. Mid-brown but with much soft greasy silt in strata. |
| | 250- | Dark brown, firm, humified peat, Von Post 7, rubbed fibre 10-20? No silt. Core ends 320cm. |

# Transect 3, Phase 2

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| **3.1** | | 1.478m AOD, 37m upslope of catchdyke, TG 40741 09577, edge of track. Grassy on margins of brambly scrub. 5.51 Typical brown sand, sandy soil in thick stony drift, **Newport Series.** |
| | 0-15 | Dark brown sandy loam, stoneless. |
| | 15-120 | Pale grey-brown soft coarse loamy sand with some flint stones, 5-8cm 10%. |
| | 120- | Pale brown, very coarse to gritty sharp sand with small stones and pebbles to 20%. Hard to penetrate. Coring ceased 140. |
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| **3.2** | | 1.185m AOD. 16m upslope of catch dyke. TG40740 09562. Grassy area within scrub. 8.3.1 Typical cambic groundwater gley soils, coarse loamy soils in deep stoneless drift. **Quorndon series.** |
| | 0-25 | Mid- to dark-brown sandy silty loam. Some small stones <5%. |
| | 25-50 | Pale brown coarse sandy silt loam with occasional small stones to 1cm, <5%. Occasional small orange brown mottles. |
| | 50-120 | Pale grey-brown silty soft sand (overall sandy loam), occasional brownish mottles. Silt declines with depth, soil becomes more sandy. Moist, firm but crumbles easily. Occasional stones 1-5%. |
| | 120-40 | Pale grey to beige, coarse gritty sand with small stones <5%, very soft, very difficult to return below water table. **WT 130cm.** |
| | 140-215 | Pale blue-grey, very firm to stiff, clayey silt with some coarse sand toward upper limit, becoming less clayey and less stiff with depth. (overall silty clay loam). |
| | 215- | Silty orange brown sand. Coring stopped 220cm. |
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| **3.3** | | 0.958m AOD. 4m upslope of catch dyke. TG 40744 09545. Grassy patch within brambly scrub. 8.3.1 Typical cambic groundwater gley soils, coarse loamy soils in deep stony drift. **Quorndon series.** |
| | 0-25 | Mid-dark brown sandy silt loam with occasional stones 0.5-2cm <5%. |
| | 25-55 | Stiffish, grey brown sandy silt loam with frequent orange brown mottles. Slightly stony, <5%. |
| | 55-110 | Pale grey-brown, soft, fine silty sand (overall sandy loam), occasional brown mottles. Stones occasional (<5%) becoming abundant (20-25%) up to 3cm at 75cm, then becoming difficult to core. **WT 110cm** |

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| | 110-185 | Quite stiff, somewhat sticky pale grey slightly fine sandy clayey silt (overall silty clay loam), stoneless, becoming sandier at base. |
| | 185- | Slightly silty orange-brown coarse sand with stones <10%. Silt content variable. Becomes very soft and sloppy, difficult to lift. Coring stops at 220cm. |
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| **3.4** | | 0.277m AOD Centre of catchdyke. Dry part, near gateway. TG40740 09542. Soil series not determined. |
| | 0-45 | Dark brown silty, peaty organic layer, stoneless, dyke silt. **WT 5cm.** |
| | 45-130 | Initially brownish but soon becoming light grey, initially silty coarse sand, silt declining with depth. Weak, saturated, structureless, soon sloppy and difficult to pick up. Stony, 0.5cm-2cm. |
| | 130-145 | Tan soon becoming grey slightly sandy stiff silt, stony around 1cm, 20%, to base. |
| | 145-175 | Grey coarse sandy clayey silt, 20-30% stone 1-5cm, becoming silty sand after 160cm. |
| | 175- | Orange-brown coarse sand, soft, some small stones c.1cm, <5%. Coring stopped at 190cm. |
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| **3.5** | | 0.892m AOD, 5m downslope of centre of catchdyke, TG407040 09538, grassy path under alder. 8.3.1 Typical cambic groundwater gley soils, coarse loamy soils in deep stony drift. **Quorndon series.** |
| | 0-20 | Dark brown sandy silt loam, small stones 1cm, <5%. |
| | 20-65 | Mid tawny-grey sandy silt loam with strong brown mottles frequent, c.20% soil area. Slightly stony with 1-3cm stones, around 5%. Rather stiff to begin with, becoming sandier and softer with depth, grading to: |
| | 65-140 | Pale grey-brown silty coarse sand (overall sandy loam), rather soft and becoming softer with depth. Initially faint brownish mottling c. 20% of soil. Stones initially sparse but becoming stonier to 15% with depth, up to 4cm. **WT 85.** Very soft, structureless and sloppy below the water table. |
| | 140- | Grey-blue, very stiff, clayey silt. Initially very sandy with gritty sand, becoming cleaner with little sand. Coring ends 200cm. |
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| **3.6** | | 0.463m AOD, 15m downslope from centre of catchdyke. TG 40743 09533. Fen edge with reed and rush. Does not easily resolve due to shallow peat but somewhere between 10.2.4 Earthy eutro-amorphous peat soils and 5.4.1 Typical brown earths, Host Class 10 or 11 |
| | 0-35 | Dark brown wholly humified loamy peat with some fine sand, becoming very peaty below but always wholly humified. Fresh roots and rhizome. Very few small stones, <1% |
| | 35-70 | **WT 40**. Brownie-orange silty sand (overall sandy loam), coarse, stoneless. Soft and loose lower down. |

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| | 70-110 | Pale brownie-grey coarse sandy silt (overall sandy silt loam) with small gravel to 1.5cm at depth, 1-5% overall. |
| | 110- | Blue-grey very stiff silt with clay and coarse sand at first (overall silty clay loam). Stony initially to 10%. Sand and stones decline to a cleaner, moister and softer clayey silt below, but even then still stiff. |
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| **3.7** | | 0.527m AOD TG 40741 09527. 25.5m from centre of catch dyke. Fen edge. Shallow peat but just qualifies as 10.2.4 Earthy eutro-amorphous peat soils, **Adventurers Series.** |
| | 0-50 | Dark brownie black humified peat with some fresh roots. Slightly loamy at the surface then a little silty and greasy. Stoneless. **WT 35cm**. |
| | 50-80 | Bluey grey and brown sandy silt (overall sandy silt loam), increasingly stiff, becoming quite hard with stones at around 65cm, then becoming sandy. |
| | 80-95 | Soft, silty coarse sand (overall loamy sand) with gravel and small stones to 20%. |
| | 95-170 | Blue-grey fine sandy, slighty silty clay (overall sandy clay loam), soft and saturated but still coherent. |
| | 170- | Grey-brown silty coarse sand becoming softer and sloppy at depth. Also becoming greyer and sandier. Overall loamy sand. Coring stopped at 210cm. |
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| **3.8** | | On fen peat, 0.06m AOD, TG 40756 09430, under powerlines. Within scrub trees. 95m from catch dyke. 10.12 Raw eu-fibrous peat soils in grass-sedge peat. **Ousby Series** |
| | 0-25 | Black-brown, soft, slightly loamy, humified peat. Dense with living roots. |
| | 25-110 | Soft, mid-brown fen peat with visible sedge/grass remains and much moss. Abundant macro-pores >50%, rubbed fibre c.80%, Von Post 3. |
| | 110-250 | Pale to mid-brown, rather humified peat, little strength, often quite sloppy. Often with some silt. Little root fibre, <20% when rubbed, Von Post 7. |
| | 250- | Mid-brown, firm, rather humified peat with rubbed fibre 10%, Von Post 6-7. Firm if wet, holds in the auger. Coring stopped 320. |
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| **3.9** | | 0.10m AOD. 145m from dyke edge. TG 40764 09398. In the fen under the powerlines. 10.1.2 Raw eu-fibrous peat soils in sedge and grass peat. **Ousby Series.** |
| | 0- | Fresh mid-brown peat, undecomposed, Van Post 2, fibrous, rubbed fibre >80%, with root leaf and moss remains evident. Surface not humified. Firm to begin, becoming weak to sloppy after 110cm and progressively more difficult to return, rather watery. Some siltiness at depth. Coring stopped at 310cm. |
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| **Transect 4, Phase 2** | | |

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| **4.0** | | 1.13m AOD. In dense scrub with leaf litter over. TG 40819 09628. 70m upslope from catch dyke. 8.31 Typical cambic ground water glay in deep stony drift. **Quorndon Series.** |
| | 0-25 | Grey-brown, stiff, stoneless fine sandy silt topsoil (overall sandy silt loam). Much roots but not humic. |
| | 25-60 | Pale grey-brown, fine sandy silt (overall sandy silt loam) mottled with fine distinct brown mottles 20mm, 10-20% of soil. Stony, 10-20% of soil. |
| | 60-130 | Pale grey-brown, stiff, clayey fine sand (overall sandy clay loam), , strongly orangey brown mottling, initially distinct, latterly diffuse, 20% of soil. Very stony, 20%+, siliceous stones variable in size up to 7cm. Very hard to core but porous. |
| | 130- | Moist, pale orangey brown coarse sand, some stones in upper layers up to 3 %, but declining rapidly overall <1%. **WT at 160cm**, then starts to become very wet and weak eventually sloppy. Coring ends 200cm. |
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| **4.1** | | 0.72 m AOD. 25.5m upslope from catch dyke.TG40841 09593. In scrub. Much leaf litter on ground. 8.2.1 Typical sandy ground water gley soils in thick stony drift and with a predominantly sandy texture. **Blackwood Series.** |
| | 0-19 | Pale brown silty fine sand (overall sandy loam), stoneless. Macropores low, 10%. |
| | 19-32 | Pale brown silty and clayey fine sand (overall sandy silt loam), faint small orangey mottles <5mm, 10% of area. Stoney to 2cm, 10% vol. |
| | 32-55 | Pale yellow-brown fine sand, no cohesion, stony with large stones 3-5cm to 20%, making coring arduous. Occasional mottles, 5%, small, brownish, 5-10mm, distinct. |
| | 55-130 | Pale orangey brown, fine, soft sand with no cohesion, very occasional small flint stones, with occasional layers of dense pebbles as above overall c.5% stone. Some faint orangey-brown mottling, <10%. Becoming moister with depth. |
| | 130- | Moist, pale orangey-brown coarse sand, mostly stoneless, <1%, but some large pebbles below 175cm, **WT 180**. Thereafter becoming very weak and sloppy, coring stopped at 220cm. |
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| **4.2** | | 0.72m AOD, TG 40856 09582. 9.5m upslope of dyke. Woodland edge, tree leaf litter over soil. 8.2.1 Typical sandy gley soils, sandy soils in deep stony drift. **Blackwood series.** |
| | 0-20 | Mid-grey brown silty loamy coarse sand (overall sandy loam) stoneless, dry and very friable, porous with high macro-pores about 20%. |
| | 20-35 | Pale brown, slightly silty coarse loamy sand (overall sandy loam) Reasonably cohesive, macro-porous around 15%. |
| | 35-60 | Pale yellow brown fine soft sand, stony with large flints 3-5cm, 25% by vol. Very occasional small pale brown mottles, 5%. |
| | 60-140 | Orange brown fine sand, colour becoming brighter with depth. No cohesion. Some mottling, orangey-brown small c.1cm, around 15% of |

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|  |  | soil. Often stone free but with layers 15-20cm thick of large stones 3-5cm, overall around 5-10% stone by volume. |
|  | 140- | Pale grey-orangey brown medium sand, moist becoming saturated with **WT at 180cm.** Then becomes very soft, almost sloppy and difficult to return. Coring stopped 200cm. |
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| **4.3** |  | -0.49m AOD. TG 40857 09581. Bed of catchdyke. 4m wide, vertical sided, embankment on fen side. **WL at -0.16 m AOD** |
|  | 0-15 | Black silt, soft plant detritus and twigs. |
|  | 15-30 | Mid-grey, firm, fine sandy silt. |
|  | 30- | Soft, mid-grey silty medium sand, becoming stiffer with some clay at 60cm, becoming dryer at 70cm. Sand becoming coarser and softer, clay and silt reducing, at 150cm. Coring stopped at 175cm.. |
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| **4.4** |  | 0.34m AOD. TG 40872 09585 8.7m downslope from centre of catchdyke, fen side. Scrubby, grassy vegetation, not fen, just off the embankment. 8.3.1 Typical cambic gley soils, in deep stoneless drift. **Sustead Series.** |
|  | 0-18 | Mid-grey brown coarse sandy silt loam dense with roots with macro-pores at 10%. Stoneless. |
|  | 18-47 | Pale beige-grey coarse sandy silt loam with many shell fragment and some entire, tiny (2mm) white whole shells. Stoneless. Occasional orangey brown mottles around old roots, 1% of soil area. Small, 3-4mm, distinct macropores around 10% of soil. |
|  | 47-75 | Pale orangey brown, with patches of grey, silty coarse sand (overall sandy loam) some faint, diffuse, orangey-brown mottles, 10% of soil. Stony, up to 5-6cm, 15%. |
|  | 75-115 | Pale orangey-brown, stiff, coarse sandy silt loam, moist. Some stones, <5%, up to 3cm. Faint mottles continue in first 30cm then stop. |
|  | 115- | Pale olive-grey brown silty soft fine sand, stoneless. Becoming mid-orangey by 140cm. **WT 155**. Becoming wet and soft and difficult to return after WT. Coring stops 220cm. |
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| **4.5** |  | 0.314 mAOD TG40886 09581, near to Piezo 3. Grassy fen margin, 22.5m from centre of catchdyke. 8.3.1 Typical cambic gley soil in a deep stoneless drift. **Sustead Series** |
|  | 0-22 | Darkish grey-brown sandy silt loam. Very small orange-brown mottles around old roots, <5mm, sharply defines, <1% of soil. Stoneless. Frequent small shell fragments. |
|  | 22-55 | Pale grey-brown coarse sandy silt (overall sandy silt loam) with frequent small rusty brown mottles 5-10mm, 5% of profile. Stoneless. |
|  | 55-72 | Pale orangey brown silty coarse sand (overall sandy loam) with some stones to 5cm, 10% by volume. Faint orangey-brown mottles, 10% of soil. |

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| | 72-96 | Orange-brown clayey sandy silt (overall silty clay loam), becoming sticky. **WT 85.** |
| | 96- | Pale grey coarse sandy silt, (overall sandy silt loam) few stones <3%, becomes very sandy with some silt within 20cm (overall loamy sand), saturated and rather soft to begin with, becoming very soft and loose and difficult to return. Coring stopped at 220cm. |
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| **4.6** | | **0.12m AOD**. 37.5m downslope. TG 40898 09585. Fen edge – rushes, herbs, grasses and sedges. 8.7.1 Typical humic groundwater gley soils in deep stoneless drift. **Hanworth Series** |
| | 0-20 | Mid- to dark-brown humic fine sandy silt (overall sandy silt loam). Stoneless, much root material. |
| | 20-35 | Pale brown, slightly fine sandy silt (overall stiff sandy silt loam), much small white shell fragments, Mottled with fine brown mottles 2-3cm mostly around roots. Speckled appearance. Stoneless. |
| | 35-45 | Grey-brown, silty, fine sand (overall loamy sand). Mottled with distinct but small brown mottles around 5mm, 10% of soil. Stoneless. |
| | 45-55 | Mid- to pale brown silty clay (overall silty clay loam) with strong brown mottles . |
| | 55-150 | Pale browny-grey becoming grey withy depth, fine to coarse sandy silt (overall sandy silt loam), saturated but coherent, stony 3%, 1-3cm . Mottled for 55-65, not after. Variable texture. **WT 55cm.** |
| | 150- | Mid grey, slightly silty coarse sand (overall loamy sand), granular, soft and sloppy when very saturated, becoming fine sand with depth and greyish-brown. Then very soft and difficult to return. Coring stops 230cm. |
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| **4.7** | | -0.01m AOD. TG 40910 09585 48.5m downslope. Middle of Fen, **WT 0cm**, M22 rushes and sedges. 8.7.1 Typical humic groundwater gley soils in deep stoneless drift. **Hanworth Series** |
| | 0-20 | Humic, dark brow fine sandy silt with much fresh roots. Stoneless. |
| | 20-140 | Pale grey silty fine sand (overall sandy silt loam), firm, fine brown mottles <3mm creating speckled effect, 5% of soil. At 80cm, becoming stony and mottling ceases, colour becoming mid-grey. |
| | 140- | Pale grey, slightly silty sand (overall loamy sand), stoneless, very wet and soft, becoming difficult to return. Coring to 230cm. |
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| **4.8** | | 0.10m AOD. 10m from edge of Landspring dyke, 70m from catch dyke. Rushy fen margin. TG 409312 09589. 8.7.1 Typical humic groundwater gley soils in deep stoneless drift. **Hanworth Series** |
| | 0-20 | Blackish wholly humified peat, much small white shell material, also much fresh root. Slightly silty. **WT 20cm**. |
| | 20-48 | Stiff, rather buttery dark brown humic slightly fine sandy silt (overall silt loam). Stoneless. Fibrous plant inclusions – roots and leaf. Mottled fine brown mottles c.3mm, 10% of soil. |

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| | 48- | Brownish mid-grey, stiff, silty fine sand (overall sandy silt loam), unmottled, cohesive. Stoneless. Becoming coarser with depth and softer. Coring stopped at 220cm. |
| **Damgate Marshes Cores Feb 2016** | | |
| **A** | | 0.46mAOD. Marsh side bank of the Landspring. Marsh dyke very ochreous. TG 40951 09603. |
| | 0-25 | Dark brown, stoneless slightly fine sandy clayey silt (overall silt loam). Much fresh root. |
| | 25-50 | Mid- to dark brown stiff stoneless silty clay. |
| | 50-80 | Light brown stoneless slightly fine sandy silty clay. Mottled with red-brown mottles, 1-2cm, 10% of soil. |
| | 80-130 | Grey to grey-brown sticky, buttery silty clay, stoneless. Slightly mottled with fine red-brown mottles <0.5cm, 10% of soil. |
| | 130-150 | Dark brown, fibrous peat, Von Post 5. Dryish. **WT at 140cm.** |
| | 150- | Pale grey to mid grey fine sandy silt (overall sandy silt loam), stoneless, variable strength from stiff to soft, eventually becoming too soft and saturated to lift. Increasingly salmon-brown stained. Coring stopped at 290cm. |
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| **B** | | -0.24m AOD TG 40969 09603. Unmanaged marsh, reed/pond sedge/*Calamagrostis* over rough grass. |
| | 0-25 | Mid-brown humic clayey silt topsoil, dense roots including reed rhizomes. |
| | 25-50 | Grey brown, silty clay with peaty inclusions. Fine mottling with brown mottles <1cm, 15% of soil. **WT 30cm.** |
| | 50-75 | Mid-grey, slightly silty clay, with mottles <1cm, 20% of soil, some roots and peaty inclusions. |
| | 75- | Mid-grey, slightly very fine sandy clayey silt, soft, saturated, some old root material. With depth becoming sandier with agradual transition to weak very silty sand. Salmon brown staining from 100cm, at first patchy and then continuous after 220cm. Material at base becoming sloppy and difficult to lift – coring stopped at 260cm. |
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| **C** | | -0.23m AOD. Marsh in Damgate Level. Grass and rush, mostly *J. inflexus.* TG 40979 09564. |
| | 0-20 | Mid-brown silty clay loam, stoneless, with much living root material. |
| | 20-35 | Grey brown, silty clay (overall silty clay loam), some small <0.5cm chalk pieces, infrequent. Brown mottles, defined, <1cm, 20% of soil. **WT 35cm** |
| | 35-90 | Browny mid-grey, stiff but buttery slightly silty clay (overall clay loam). Becoming stiffer with depth. Transition via organic clay then clayey peat to the peat below. |
| | 90-140 | Mid-dark brown semi-humified peat, Von Post 7. |

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| | 140- | Mid-grey fine to medium sandy silt (overall sandy silt loam). Mostly stoneless, but with occasional bands with fine stones <1cm, <10%. Usually stiff but variable and occasionally soft. Below 2.7m very soft and becoming stained light reddish brown. Coring stopped 320cm. |
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| **D** | | 0.24mAOD. Marsh side bank of the Landspring. Marsh dyke not ochreous. TG 40967 09550. |
| | 0-25 | Mid-brown clayey silt loam (overall silt loam), stiff, stoneless. |
| | 25-70 | Mid- to light brown, very stiff, silty clay (overall clay loam). Frequent brown mottles to 1cm, 20-30% of soil, slightly gritty in places. |
| | 70-90 | Blackish brown, organic, silty clay. |
| | 90-170 | 20cm of blackish brown silty clayey humified peat progressing to mid brown peat of variable humification from VP 6 to VP9. **WT 135cm.** |
| | 170- | Pale grey to mid grey fine sandy silt (overall sandy silt loam), stoneless, variable strength from stiff to soft, eventually becoming too soft and saturated to lift. No significant reddish-brown staining. Coring stopped at 280cm. |
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| **E** | | 0.22m AOD. Marsh side bank of the Landspring. Marsh dyke not ochreous. TG 40987 09486 |
| | 0-20 | Mid-brown, silty clay loam, stoneless, much fresh root. |
| | 20-95 | Pale brown silty clay (overall clay loam), stoneless, mottled with small-medium brown mottles 1cm, 20% soil, declining with depth. |
| | 95- | Mid-dark brown peat, silty in first 20-30cm. Initially humified (VP 8) then becoming fresh to semi-humifieed (VP 5), firm. Coring stopped at 310cm. **WT 120cm.** |
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| **F** | | -0.25m AOD. Marsh in Damgate Level. Grass and rush, mostly *J. effusus.* TG 40999 09492 |
| | 0-20 | Dark brown humic to peaty silt loam, much fresh root, stoneless. |
| | 20-45 | Dark grey-brown, soft, silty clay (overall clay loam), infrequent brown mottles, <0.5cm, 10% of soil. **WT 22cm.** |
| | 45-275 | Dark brown semi-humified peat, Von Post 6-7, firm, dryish to moist, fibrous, 20-30% when rubbed. |
| | 275- | Mid-grey slightly fine sandy silty clay (overall sandy clay loam). Stiff. Coring stopped at 320cm. |
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| **G** | | 0.17m AOD, TG 41000 09432. Marsh side margin of Acle Landspring bank. |
| | 0-40 | Mid-brown, slightly crumbly slightly fine sandy clayey silt loam, dense roots. Transition to: |
| | 40-255 | Mid-grey brown silty clay, moist, stiff to very stiff. Some brick fragments in the upper section. Becoming slightly very fine sandy at |

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| | | 200cm. Becoming organic to slightly peaty at 230cm. **WT** 108cm. Transition to: |
| | 255- | Mid-brown fibrous peat, relatively fresh with modest humification (Von Post 4-5) dryish. Coring stopped 300cm |
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| **H** | | -0.43m AOD. TG 41016 09431. Grassy, mixed rushes, no ochre in dykes. Despite being lower elevation, looks and feels dryer. Bounded to south by IDB Main Drain. |
| | 0-30 | Dark brown humic silt loam, stoneless, dense fresh roots. Transition to: |
| | 30-60 | Brown silty/clayey humified peat, weak, very moist. **WT 45cm.** Transition to: |
| | 60-160 | Mid-grey, silty clay, very smooth, very wet and very weak, closing core hole when worked. Transition to: |
| | 160-315 | Mid-brown, initially clayey, semi-fibrous, semi-humified peat. Von Post 5-6. 30% fibre when rubbed. Initially firm and dryish but increasingly wet and soft with depth. |
| | 315- | Mid-grey, soft silty clay, weak and very wet. Coring ceased at 325cm. |
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