TWEEN BRIDGE INTERNAL DRAINAGE BOARD

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Thorne, Crowle and Goole Moors SSSI Water Level Management Plan

May 2010

FINAL REPORT

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REVISION HISTORY

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Consultation Draft 11 June 2010		Internal Drainage Boards Local Landowners Local Authorities RSPB, EA, YWT, LWT
Final Report – 27/01/2011		Tween Bridge IDB

CONTRACT

This report describes work commissioned by Tween Bridge Internal Drainage Board (IDB) under Environment Agency letter of 3rd March 2009. Tween Bridge IDB's representative for the contract was Ian Benn. Alex Jones, Kieran Sheehan, Ian Morley and Sam Bishop of JBA Consulting carried out the work.

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PURPOSE

This document has been prepared solely as a final report for Natural England and the partner IDBs. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

ACKNOWLEDGMENTS

JBA would like to thank Natural England for providing vegetation and dipwell data for this study and granting access to the site. Special thanks should also go to the six Internal Drainage Boards who have sponsored the production of this Water Level Management Plan, with financial support from the Environment Agency. The six boards are:

- Black Drain Internal Drainage Board
- Dempster Internal Drainage Board
- Goole Fields Internal Drainage Board
- Reedness and Swinefleet Internal Drainage Board
- Thorntree Internal Drainage Board
- Tween Bridge Internal Drainage Board

JBA would also like to thank the following individuals for their input into this plan: some have provided information based on experience and other technical commentary. All their contributions have added to the sum of knowledge in this report and it would have been all the poorer without their help.

Sam Bishop, JBA Consulting;

Kevin Bull, Natural England;

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Lionel Grooby, Lincolnshire Wildlife Trust;

Tim Kohler, Natural England;

Roger Meade, Roger Meade Associates;

Ian Morley, JBA Consulting;

Susan Wagstaff, JBA Consulting;

Darren Whitaker, Doncaster College.

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EXECUTIVE SUMMARY

Introduction

This report presents the finding of a programme of investigatory studies to inform a revision of the current Water Level Management Plan (WLMP) for Thorne, Crowle and Goole Moors Site of Special Scientific Interest (SSSI). Recommendations are made that, if implemented, will increase the site's ability to maintain high stable water levels, which will improve the ecological condition of the site.

Thorne, Crowle and Goole Moors form the largest lowland raised mire in England and were designated as a SSSI in 1986. Thorne Moors have since been internationally recognised, being designated as a Special Protection Area (SPA) and Special Area of Conservation (SAC). A condition assessment carried out by Natural England on 1st September 2008 found the SSSI to be in unfavourable condition, and cited drainage as a particular problem.

The following methodology was used to determine the recommendations proposed;

- A review of the historic development of the site to aid understanding the current nature of the site;
- Vegetation survey to identify the spatial distribution of habitats, identify key vegetation features, give an indication of the water level height and its fluctuations and inform the levels at which particular areas will achieve the desired vegetation communities;
- Geology, hydrological and hydrogeological conceptualisation was undertaken to understand how water is supplied to and moves through the system and the controls upon the watertable;
- A semi quantitative assessment of the degree to which water level targets are currently being achieved on site;
- A review of the current Hydrological Protection Zone (HPZ) to assess where water level targets might not be achieved due to drainage around the site's periphery.

Vegetation Interest

The main vegetation interest on the site revolves around its restoration into an intact lowland raised mire, with its associated plant communities. At present the vast majority of Thorne, Crowle and Goole Moors do not meet the definition of a raised mire and much of the vegetation can be categorised as poor fen, woodland of various sorts, and open water with some grassland areas around the periphery of the peat mass. This does not mean that the existing vegetation cover does not contain any vegetation interest, in fact, quite the contrary, the moors are home to a number of rare and unusual plants, including many species of moss.

At present the majority of the woodland is concentrated south of the Limestone (Fison's) Road, much of it being birch (*Betula* spp.) pioneer woodland that has developed on the areas of bare peat. There are, however, a few exceptions to this, including the wet woodlands at Pony Bridge and Will Pitts as well as the Oak (*Quercus robur*) woodland at Woodpecker Corner.

Poor fen exists over much of the centre of the site and, in some areas, is taking over from the birch woodland as the site becomes wetter. This habitat is characterised by the presence of soft rush (*Juncus effusus*) and cotton grasses (*Eriophorum* spp.) and thins out northwards where it grades into the peat flats of Goole Moors and its large areas of ephemeral open water.

Crowle Moors is composed of poor fen, birch scrub woodland and wet woodland habitats, although here their distribution is linear, based on the land holding pattern and subsequent peat-cutting that has occurred in the area.

Neutral grasslands are scattered around the periphery of the site, especially in the Inkle Moor area, with isolated patches elsewhere, such as at Elmhurst. The presence of grassland on the site is indicative of the underlying clay being present at the surface, i.e. areas that have previously been warped, cut for peat or, alternatively, areas that have never formed part of the raised mire.

Geography and Geology

The majority of the site is an ombrotrophic raised mire underlain by thick lacustrine clays and silts; this isolates it from the influence of the surrounding agricultural land except in some small areas around the boundary. Due to its size, the ombrotrophic and isolated nature of many of the areas, and the complexity of the site, the conceptualisation divides the site into a number of sub-regions;

- **Northern Goole Moors** – an isolated area of intact raised mire. The area is bordered by ditches on all sides which drain the mire, leading to the establishment of bracken and birch woodland around the edges. In the centre, the watertable is near or at the surface during the winter and some *Sphagnum* is present;
- **The milled area** – this area covers much of Goole Moors, Snaith and Cowick Moors and the northern half of Thorne Moors. It has been subject to mechanical milling peat extraction which has produced large, flat, bare fields of peat surrounded by deep drains. This whole area forms a depression in the centre of the mire; therefore, to ensure that this area does not become what would in effect be a lake, the standing water in the area is pumped out by Natural England into the Swinefleet Warping Drain and discharged into the Humber. This area has been subject to a restoration programme by Natural England, who have installed an extensive series of bunds to aid in rewetting, stabilise groundwater fluctuations and thereby produce conditions that allow the appropriate bog vegetation to colonise;
- **The North West Rand** – this area lies on the western boundary of the milled areas and stands proud of both the milled area and the agricultural land to the west. In the past it has been subject to peat extraction using English hand graving, producing the current ridge-furrow topography. On the edge of the site, a lagg alder thicket exists, which is subject to regular inundation;
- **The Paraffin Works** – in this area peat was historically extracted to produce paraffin. The area is covered by small regularly spaced pools;
- **Inkle Moor** has never been part of the ombrotrophic peat mass, though its western end would have formed part of the lagg around the raised mire, and has been subject to several phases of agricultural reclamation. This unit of the SSSI has been designated for its neutral grassland, interest rather than lowland raised bog;
- **Will Pitts Wood -** this is an area of wet woodland which was subject to extraction before it was unsuccessfully warped. This led to the abandonment of this area for agricultural production and the subsequent establishment of wet woodland;
- **Will Pitts Scrape** is a lake currently home to a large population of water birds;
- **South Thorne** – this area has a complicated history and includes areas subject to Dutch hand graving (the canals), English hand graving and mechanical bulk extraction, *Rhododendron* cultivation and agricultural improvement. This has created a complex topography and microtopography which has changed how water moves through the system. The area is made more complex by the floated roads which divide and isolate areas by acting as low permeability bunds. This has led to a very heterogeneous landscape, with areas of suitable high stable watertables lying very close to drier areas colonised by thick birch scrub;
- **North, West and South Crowle** - this area is bounded to the west by the Swinefleet Warping Drain which isolates Crowle Moors from Thorne Moors. The area has been subject to English hand graving, which has increased the drainage of the surface of the bog. Like the South Thorne area, this area is quite heterogeneous. On its southern boundary an area of woodland, has colonised due to the efficient drainage of the agricultural land that borders the site;
- **Ribbon Row** – this is an area in the centre-east of Crowle Moors. Here the land was historically owned in long narrow strips. These strips have been subject to different degrees of peat extraction which has left some narrow extant strips, bordered by areas where the majority of the peat has been extracted separated by tall peat cliffs. This has left the high areas drained and colonised by birch scrub and the low areas subject to rapidly fluctuating watertables and colonisation by *Juncus* spp.

Water Level Targets and Restoration Aims

In the areas designated under the SSSI citation for their lowland bog interest, target water levels for the site have been defined as follows (JBA Consulting, 2008):

- **The watertable is to be maintained close to the ground surface (ideally c.0.10mbgl (metres below ground level)) and should not fall to more than 0.25mbgl in more than one year in five.**

- **Water levels in the ditches should not fall more than 0.50mbgl in more than one year in five.**

These targets are based on the conditions required to create an ombrotrophic lowland raised mire in favourable condition. Due to the history of peat extraction on-site, the degree to which it has been drained, the topography and the change in the physical properties of the peat, in many areas of the site strict adherence to the water level targets will not be achievable in the short term. However, this study outlines practical, interim restoration aims which will lead to a self-sustaining system which, given time, will achieve the water level targets and be a significant step towards producing a healthy ombrotrophic raised mire system in the future. The principle, practical interim restoration aims consist of;

- Stopping further degradation of the peat mass by raising the watertable to near or at the ground surface throughout the year;
- Removal of scrub in areas where it is inappropriate and ensuring it does not re-establish through raising the watertable;
- The establishment of peat forming vegetation;
- Given the timescales involved in the creation of raised mire peat, restoration measures should have a long life span or lead to the creation of a self-sustaining system;
- The interim restoration aims decided upon should be stepping stones towards the creation of a self-sustaining lowland raised mire system.

Action Required

These principles and the particular nature and water level management issues for each sub-region have informed the restoration aims. The general nature of the action required is outlined in the table below:

Restoration Aims and Actions Required for Thorne and Crowle Moors SSSI

Hydrogeological Sub-Region	Management Compartments	Restoration Aims	Actions Required
Northern Goole Moors	1 and 4	Creation of a sustainable isolated lowland raised mire within decades	Scrub clearance and raising the watertable around the edge of the site.
Will Pitts Wood	28 and 36	Maintain this as an area of wet woodland.	Watching brief
North West Rand	4 and 5	Long term creation of a rand habitat, with a high watertable across the area and low scrub density.	Initial scrub removal and maintenance of a high watertable through appropriate means.
Milled area	2,6,7,8,9,10,11, 13,14,15,16,18, 19,20,21,26,27, 34,35,40 and 43	Initial creation of a poor fen habitat colonised by cotton grass and *Sphagnum* with a high, stable watertable in which peat accumulation can occur.	Creation of an effective drainage system which can ensure that the area is not overwhelmed by standing water. Creation of high, stable watertables through appropriate means. Encourage the colonisation of peat forming flora. Ensuring that areas of permanent standing water are removed to allow colonisation by appropriate vegetation.
Ribbon Row		The creation of sustainable habitats in an area where the degree of degradation and the variation in	Maintain high, stable watertables in the strips of thin peat to create poor fen habitat.

Hydrogeological Sub-Region	Management Compartments	Restoration Aims	Actions Required
		topography is such as to limit the ability of any scheme to produce high, stable watertables across the whole of the area. Reduce the ability of the low lying areas in Ribbon Row to drain the rest of the Crowle Moors peat mass.	Abandon attempts to create a watertable which can match the topography in the higher areas.
North, South and West Crowle.		Long term creation of a raised mire habitat, with a high watertable across the area and low scrub density Creation of lagg habitat on the edge of the raised mire.	Initial scrub removal and maintenance of a high watertable through appropriate means.
Inkle Moor, Durham's Warping Drain and Paraffin Works	32 (Inkle Moor)	The creation of a lagg habitat.	Stop drainage of the area. Allow appropriate vegetation colonisation.
	33	Improving the neutral grasslands. Maintaining the Inkle Moor Ponds.	Removal of encroaching scrub and maintain the grasslands. Watching brief to ensure the ponds are not filling-in.
	31 and 29	Long term creation of a rand habitat, with a high watertable across the area and low scrub density. Maintaining grassland on the area of warping.	Initial scrub removal and a maintenance of a high watertable through appropriate means. Maintain area of grassland.
	30 (Paraffin Works)	Long term creation of a raised mire habitat, with a high watertable across the area and low scrub density.	Initial scrub removal and maintenance of a high watertable through appropriate means.
South Thorne	68 (Pony Bridge Wood)	Maintain and manage the area of wet woodland. Scrub removal and raising of the watertable on the area of hand cut peat. Allow for a natural lateral progression from the raised mire to the wet woodland area.	Watching brief on the area of wet woodland. Initial scrub removal and maintenance of a high watertable through appropriate means on the raised mire section.
	63	Halting the spread of rhododendron and eventual eradication. Create a sustainable topography (i.e. one where the watertable can be maintained at a high level) which can maintain a raised mire habitat.	Removal of rhododendron. Adjusting the topography and installing structures which can raise the water level.
	51 (Woodpecker	Maintaining this area of woodland.	Watching Brief on woodland.

Hydrogeological Sub-Region	Management Compartments	Restoration Aims	Actions Required
	corner)	Reduce scrub and raise the watertable on the rand.	Scrub removal and possibly control structures to increase the water level on the rand.
	37,38,39,44,45, 49,50,51,52,53, 54,55,56,60,61, 63,66,68	Long term creation of a raised mire habitat, with a high watertable across the area and low scrub density. Creation of lagg habitat on the edge of the raised mire.	Initial scrub removal and maintenance of a high watertable through appropriate means.

Recommendations

An options appraisal informed by the table above was then conducted to assess alternative approaches to the actions required. Over the whole site similar restoration techniques are recommended to aid restoration, these include;

- Scrub clearance;
- Bund systems, including contour bunding of hand cut areas;
- Ditch blocking;
- Piling and re-profiling;
- Lagg creation;
- New ditches outside of the mire;
- Levees;
- Pumping and modification of the drainage regime.

The extent, nature and location of where to implement these techniques is discussed in the options appraisal. The preferred option (Option 1) best fulfils the practical interim restoration aims and will aid in leading to the creation of a self-sustaining ombrotrophic raised mire habitat in favourable condition. The overall cost of the preferred option has been estimated to be £3700k. The table below breaks this cost down into where they will be incurred on-site and the type of works that are required.

Costing Area	**Northern Goole Moor**	**milled area**	**South Thorne**	**Crowle**	**North West Rand**	**Inkle, Durham's and Paraffin**
Works	**Costs (£)**	**Costs (£)**	**Costs (£)**	**Costs (£)**	**Costs (£)**	**Costs (£)**
Clearance of woodland and scrub	31,000	112,500	491,000	310,000	38,200	31,000
Reprofiling	N/A	11,800	47,800	113,800	N/A	N/A
Creating and infilling drains and levee creation	10,800	N/A	19,200	10,400	9,200	100
Drain Blocking	1,500	N/A	N/A	2,400	200	1,000
Bunding	N/A	382,000	18,500	47,900	N/A	N/A
Handling Peat and Clay	N/A	12,700	63,500	151,000	N/A	N/A
Piling	N/A	29,600	14,400		N/A	N/A
Adjustable Weirs	N/A	19,100	38,600	16,600	N/A	N/A
EIA	20,000	N/A	N/A	N/A	N/A	N/A
Pumping Station	N/A	815,000	N/A	N/A	N/A	N/A
Preliminaries	8,700	276,600	144,200	130,500	9,500	6,400
Engineer's Fees	3,500	111,200	86,800	52,400	3,800	2,600
Total	**75,500**	**1,770,500**	**924,000**	**835,000**	**60,900**	**41,100**

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ABBREVIATIONS

1-D	One Dimensional (modelling)
1D	One Dimensional (modelling)
ACE	Association of Consulting Engineers
AWC	Available Water Capacity
BCR	Benefit Cost Ratio
CEH	Centre for Ecology and Hydrology
DTM	Digital Terrain Model
FEH	Flood Estimation Handbook
GIS	Geographical Information System
H2	Standardised Test Value (FEH)
HOST	Hydrology of Soil Types
HPZ	Hydrological Protection Zone
IDB	Internal Drainage Board
JBA	JBA Consulting – Engineers & Scientists
JNCC	Joint Nature Conservation Committee
LIDAR	Light Detection And Ranging
mAOD	metres Above Ordnance Datum
mbgl	Metres below ground level
MORECS	Meteorological Office Rainfall & Evaporation Calculation System
NGR	National Grid Reference
NNR	National Nature Reserve
NTS	Northern Telemetry System
NVC	National Vegetation Classification
OS	Ordnance Survey
PSA	Public Service Agreement
RGS	River Gauging Station
SAAR	Standard Average Annual Rainfall (mm)
SAC	Special Area of Conservation, protected under the EU Habitats Directive
SPA	Special Protection Area for birds, protected under the EU Habitats Directive
SPR	Standard percentage runoff
SSSI	Site of Special Scientific Interest
WLMP	Water Level Management Plan

1 INTRODUCTION

1.1 Background

Thorne, Crowle and Goole Moors National Nature Reserve (NNR) form the largest lowland raised mire in England and were designated as a Site of Special Scientific Interest (SSSI) in 1986. Thorne Moors have since been internationally recognised, being designated as a Special Protection Area (SPA) and Special Area of Conservation (SAC).

A condition assessment carried out by Natural England on 1st September 2008 found the SSSI to be in unfavourable condition, and cited drainage as a particular problem. There have also been reports of flooding of farmland caused by runoff from the site.

The Internal Drainage Boards (IDBs) surrounding the SSSI are required to produce a Water Level Management Plan (WLMP) for the site in consultation with Natural England. The six IDBs involved in this WLMP are:

- Tween Bridge IDB;
- Black Drain Drainage Board (DB);
- Thorntree IDB;
- Dempster IDB;
- Goole Fields IDB;
- Reedness & Swinefleet DB.

1.2 Aims

Target water levels for the site have been defined as follows (JBA Consulting, 2008):

- **The watertable is to be maintained close to the ground surface (ideally c.0.10mbgl (metres below ground level) and should not fall to more than 0.25mbgl in more than one year in five.**
- **Water levels in the ditches should not fall more than 0.50mbgl in more than one year in five.**

The aims of this study are as follows:

1. To investigate the geology, soils, hydrology and hydrogeology of Thorne, Crowle and Goole Moors;
2. To develop a conceptual understanding of the hydrology and hydrogeology of the site;
3. To identify and assess possible management options for achieving and maintaining target water levels;
4. To predict the likely impact of the management scenarios on land surrounding the SSSI.

1.3 Data Sources and Methodology

Data were obtained from the following sources:

- Topography and landscape;
  - Ordnance Survey (OS) mapping,
  - LIDAR data supplied by the Environment Agency,
  - Aerial photography supplied by Natural England.
- Geology and soils;
  - British Geological Survey – 1:50,000 geological mapping and associated memoir,
  - An account of the geology and landscape development of Thorne Moors published in the Thorne Moors Papers (Gaunt, 1987),
  - Soil Survey of England and Wales – 1:250,000 soil mapping,
  - 25 Boreholes across the site (Figure A 10).
- Meteorological data;

- MORECS data supplied by ADAS – rainfall, potential evapotranspiration and actual evapotranspiration for MORECS Square 100 over the period 1971-2000 (for various land uses and vegetation types),
- Rainfall record from a Natural England gauge on site,
- Flood Estimation Handbook (CEH, 2006) – long-term average rainfall.

- Surface water hydrology and drainage;
  - Surveys including extensive site walk overs carried out by JBA,
  - Flood Estimation Handbook (CEH, 2006) – catchment descriptors.
- Water level monitoring network;
  - Existing Natural England boreholes,
  - Boreholes and gauge boards installed by JBA (Figure A 10).
- Hydrogeological testing;
  - Existing hydraulic conductivity data for peat on Thorne Moor (Newson, 1987; Heathwaite, 1994; Bromley *et al.*, 2004).
- Ecology;
  - National Vegetation Classification (NVC) – Joint Nature Conservation Committee (JNCC),
  - SSSI citation (Natural England website),
  - Ecological surveys carried out by JBA,
- History of mire development, drainage and peat extraction;
  - Thorne and Hatfield Moors Papers.

Other sources are acknowledged in the text and listed in the references.

1.4 Structure of the Report

This report lays out the nature of Thorne and Crowle Moors SSSI in terms of it ecology, vegetation, climate, topography, hydrology and hydrogeology. These descriptions are used to inform the hydrogeological conceptualisation of the site. With this in place, an assessment of where the site is currently meeting and failing its water level targets can be established. After which, a review of restoration aims and options is undertaken and preferred options suggested.

1.5 Site Sub-Divisions

Within this report several methods of describing areas on the site will be employed. These methods include;

- SSSI Units (Figure A 1),
- Natural England Management Compartments (Figure A 2),
- Historical Names (Figure 1-1),
- Hydrogeological Conceptualisation Areas (Figure A 3).

These different methods of describing areas are used within different sections of the report as required. It should be noted that the SSSI Units are referred to as 'Units' and the Management Compartments as 'Compartments'.

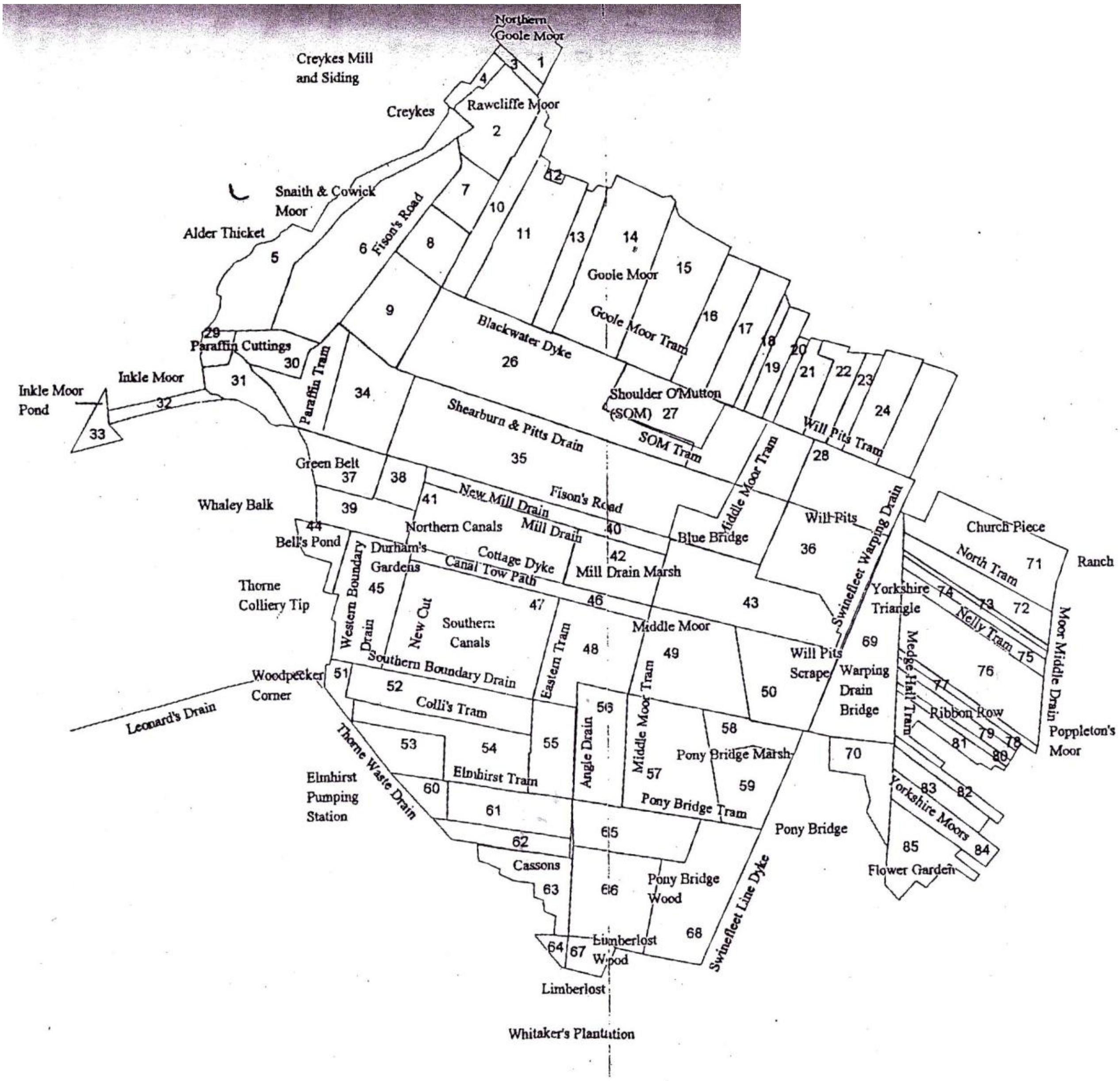

Figure 1-1 Map of Thorne with Historic Names

2 SITE HISTORY

2.1 Introduction

Thorne Moors is a landscape evolved through many historical uses. In order to understand why certain areas are in their current condition it is important to understand the historical development of the site.

2.2 Development of the Raise Mire

This section gives a short overview of the development of the raised bog that forms Thorne Moors. A fuller explanation is given in Buckland and Smith (2006).

Thorne and Crowle Moors is a damaged lowland raised bog. Peat began to form on the low permeability 25 Foot Drift Deposits (see Chapter 4) around 3,000 to 4,000 years BP. Water logging created anaerobic conditions which slowed down the rate of decomposition of plant material and allowed peat to build up. As the peat built up it became isolated from the surrounding catchment and so the primary source of water for the site became rainfall. Before the site was drained, peat extraction started and the surrounding land was claimed for agricultural use (see section 2.3) the site had the following features (Morgan-Jones *et al*. 2005) (Figure 2-1);

- Mire Expanse – a raised area of peat;
- Rand – the drier edge slope of the mire expanse;
- Lagg – wet interface between the bog and hinterland.

Extraction and other works have completely changed the morphology of the site and only remnants of the original dome structure are apparent. On the northern and north western boundaries of the site, the original peat that formed a rand is still present. Within this report these areas are referred to as rand but might be better described as relict rand as they no longer form the slopes of a peat dome.

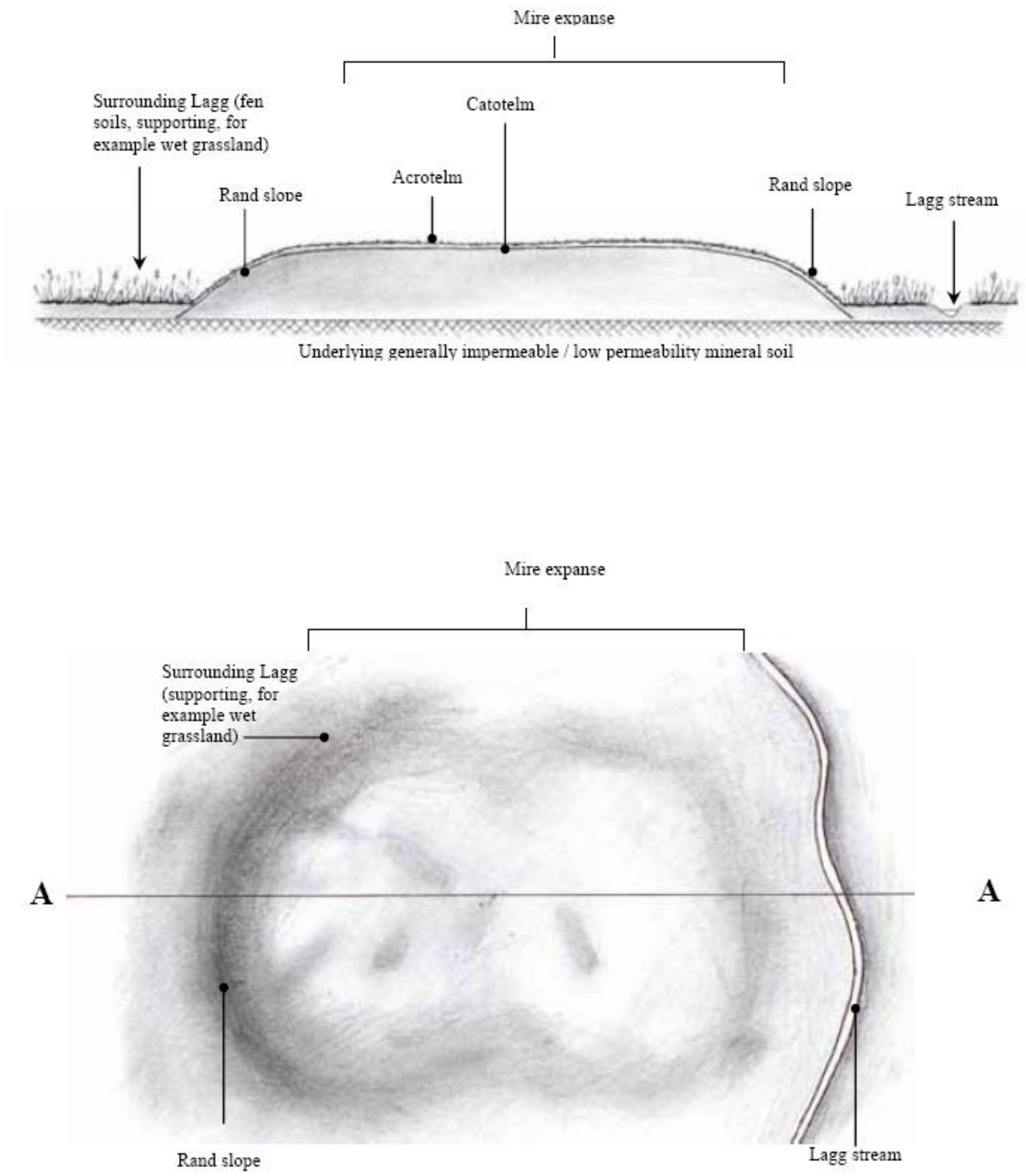

Figure 2-1 Intact Lowland Raised Mire Morphology (from Morgan-Jones *et al.* 2005)

2.3 Human Activity on Thorne Moors

For a fuller history, Limbert (1987) provides a good description of changes to the landscape in the area of Thorne Moors from the 1600s onwards, which is available at: http://www.thmcf.org/downloads/vol1_Landscape_History.pdf

Figure 2-2 summaries the historic land uses which have an eco-hydrological bearing on the SSSI today. This figure is important in the understanding of the hydraulic boundaries around the site, the surface topography and many other eco-hydrological controls which are described within this report.

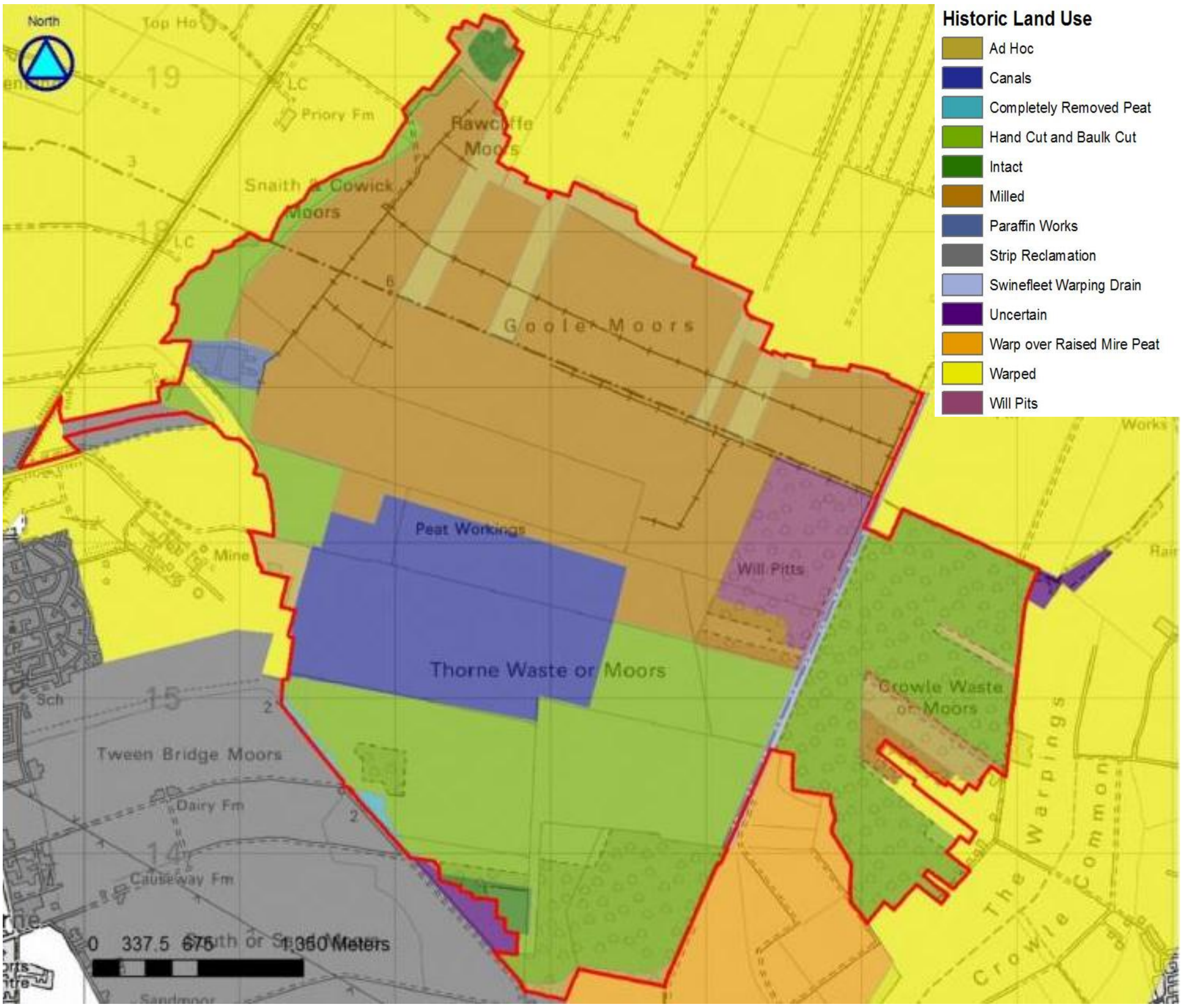

Figure 2-2 Historic Land Use in and Surrounding Thorne Moors

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2.4 Thorne Moors

Thorne Moors was used for peat extraction for many centuries. Plans to drain the bog and warp it were never fully realised, although some warping occurred around Durham's Warping Drain (see paragraph 4.3.2). The large drains, which were created in preparation for warping, drained the bog and made access easier and, therefore, subsequent peat extraction was commercially viable.

There have been a number of phases of peat cutting works on the site. A full description of this can be found in Eversham (1991). As the nature and the age of peat cuttings plays an important role in understanding the current status of many areas of the site, a brief summary of this paper is presented here.

There has been a number of extraction techniques employed on the site (see Figure 2-3:):

- Dutch Hand Graving – i.e. the canals area of Thorne (1890s -1940s);
- English Hand Graving – this produced the ridge and furrow topography seen on much of the south of Thorne Moors and Crowle Moors (19^{th} and early 20^{th} Century);
- Paraffin Works – circa 1880 deep pools to provide dense black peat for fuel were cut at the Paraffin Works;

- Mechanical Block Cutting – this produced a similar topography to the English Hand Graving Method but the cuttings were longer and denser in their cover. This appears to be limited to some areas in the south of Thorne Moors (1970-80s) (Figure 2-3);
- Peat Milling – as seen on Goole Moors and other areas (1980s-90s) (Figure 2-4).

These techniques have produced different hydrological conditions and ecological niches of varying suitability to achieve favourable conditions of site. The Canals Area was the first area to be adopted as a National Nature Reserve because of the ecological niches that the extraction technique had allowed to establish. In contrast, areas of English Hand Graving and Mechanical Block Cutting produce different topography and are often drier than the Canals. How pronounced the ridge and furrow topography is today often has a great impact on the water levels on an area and the ecological niches available. Restoration plans and the deployment of different restoration techniques have to take account of such factors.

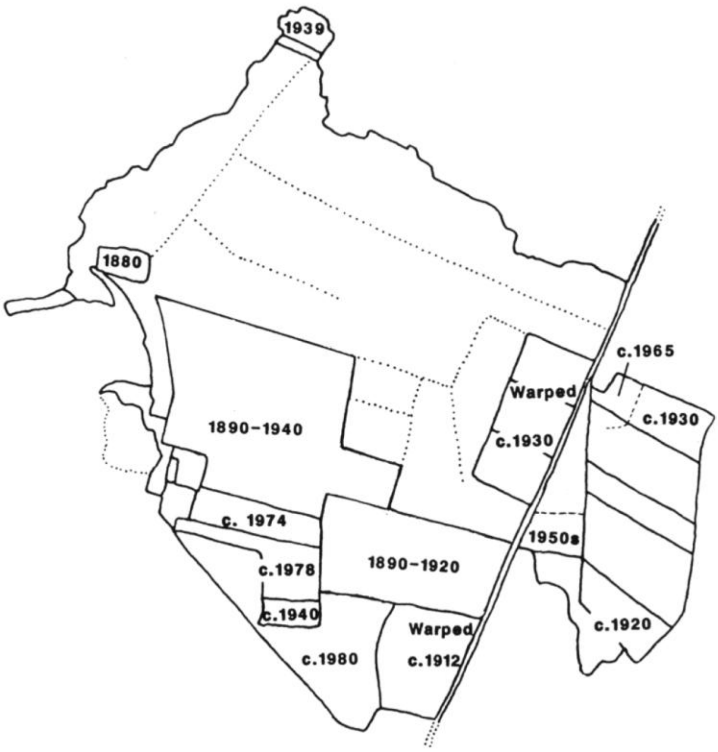

Figure 2-3: Last Peat Cutting Dates for Vegetated Area on Thorne Moors in 1991 (from Eversham 1991)

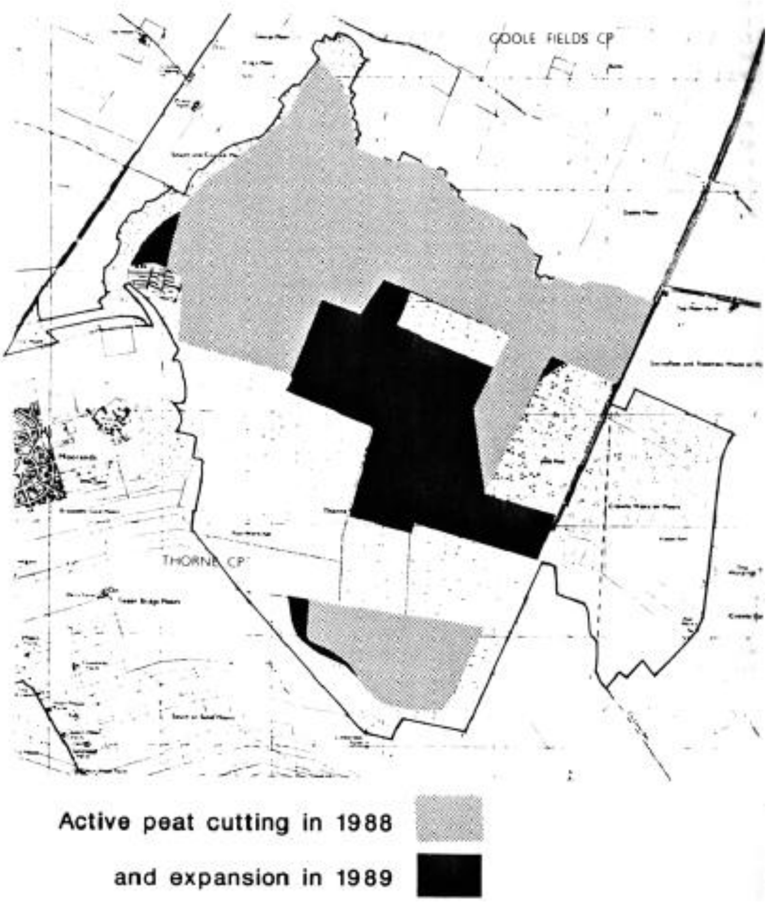

Figure 2-4 Active Peat Cuttings on Thorne Moors in 1988-9 (from Eversham 1991)

There are other notable features in the site's history relevant to this study, including:

- The development of gardens for Rhododendron *Rhododendron ponticum* cultivation along Thorne Waste drain, leading to the improvement of this area and the removal of the peat layer;
- Evidence of accidental or unsuccessful warping is present in Will Pitts Wood and Pony Bridge Woods (Figure 2-3);
- The areas south of the Yorkshire Triangle and Flowers Garden to Medge Hall were once part of the raised mire but cut over by the English Hand Graving Method and then warped (Eversham 1991);
- Drains on site have be created, maintained and abandoned over different periods of the site's history (Figure 2-5).

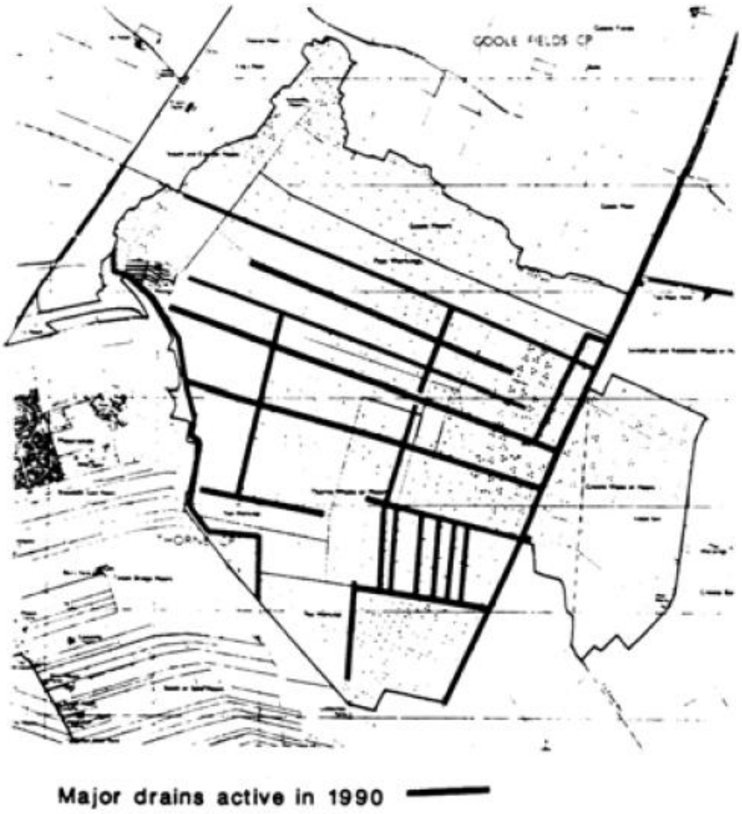

Figure 2-5 Main Drains Active on Thorne Moors in 1990 (from Eversham 1991)

2.5 Inkle Moor

The following sections combine observations from historical maps (Old.Maps no date) with LIDAR.

Before 1883 Inkle Moor consisted of strips of agricultural land improved for farming in a similar manor to the area at Elmhurst cottage (NGR 471649, 414407) and had a similar field system in the historic maps as the system around Elmhurst has today. Strip reclamation (Limbert, 1987) involved digging parallel drains to lower the watertable and then removing the peat from the narrow strips of land between the drains.

A bund was put in along the modern northern boundary between 1853 and 1892 to stop flooding of the land to the north, but the land to the north was not raised significantly. In 1892, Inkle Moors consisted of four strips, including two to the south of the modern boundary which show as light blue on the LIDAR (Figure 2-6). At this time all four strips were not warped and low lying.

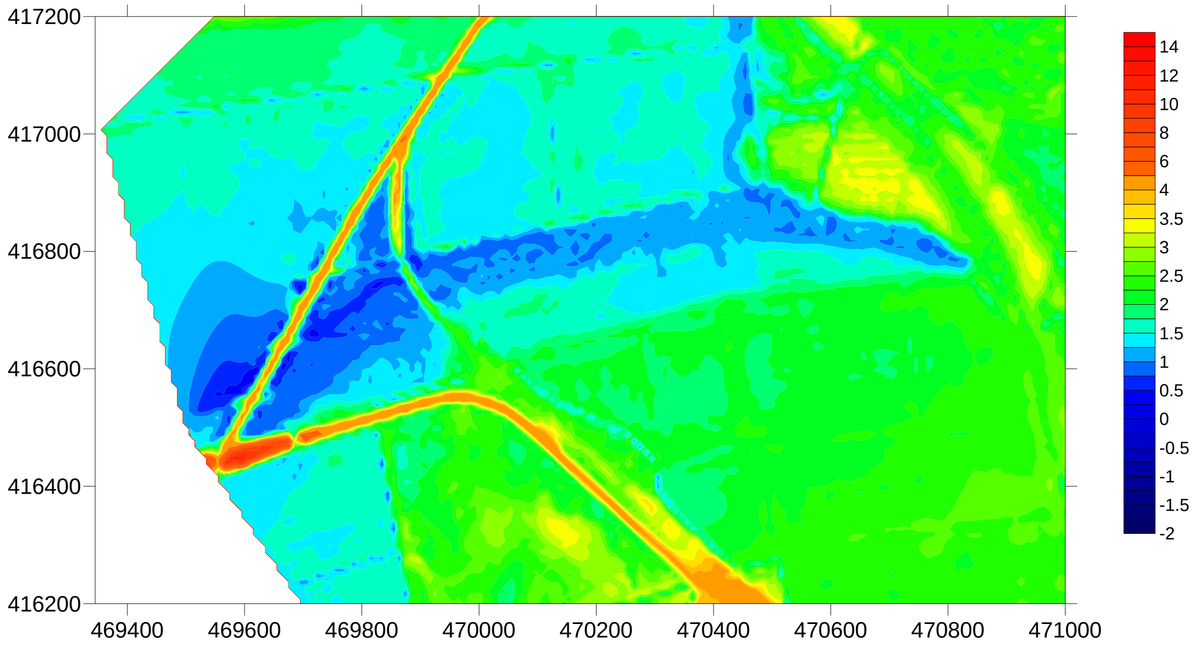

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Figure 2-6 LIDAR Topography Map of Inkle Moor (mAOD)

The main railway line was built between 1953 and 1892. In 1893 Durham's Warping Drain was excavated and the land to the north and south of Inkle Moor was raised though warping.

At some point during the period where the land was warped to raise it, the now abandoned colliery railway was installed forming the arrow head. The reason for suggesting that this occurred part way through the warping process is that the land to the west of the colliery railway is lower.
This means that Inkle Moor does not represent an area of intact lagg fen; rather it represents an area of strip reclamation which flooded too often for successful agricultural use and was therefore abandoned.

3 TOPOGRAPHY, CLIMATE AND VEGETATION

3.1 Site Location and Boundaries

Thorne, Goole and Crowle Moors are located between Doncaster and Goole and form part of the Humberhead Levels. The combined area of the moors is approximately 19km^2. The outer boundary of the area consists of about 30km of drainage ditches.

3.2 Topography

LIDAR data (Figure 2-6) show that ground surface elevations on the moors range from -0.5 to 5mAOD, with most areas having elevations between 0.5 and 4mAOD. Much of the existing topography is an artefact of peat cutting works, although there is an area that protrudes from the north-west corner at Northern Goole Moors that appears to have an intact ‘hummock and hollow’ surface.

In general the southern half of the area has a higher elevation than the northern half: the lowest area being in the north-eastern corner. Along the western and north-western boundaries of the moss, a ridge or ‘rand’ stands approximately 2m above the surrounding bog and farmland. Crowle Moors is separated from the rest of the site by the Swinefleet Warping Drain, which perches within its dykes above the surrounding land.

The detailed topography of the area reflects the presence of drainage ditches, dykes and bunds, and also differences in the method of peat extraction. In the south of Thorne Moors, hand cutting and mechanical baulk cutting methods have led to a more irregular surface than in the areas to the north, which were subject to mechanical methods of peat removal and are characterised by wide flat areas with regular drainage ditches. In Ribbon Row on Crowle Moors, more *ad hoc* methods of have led to a relief consisting of thin parallel strips of alternately high and low ground.

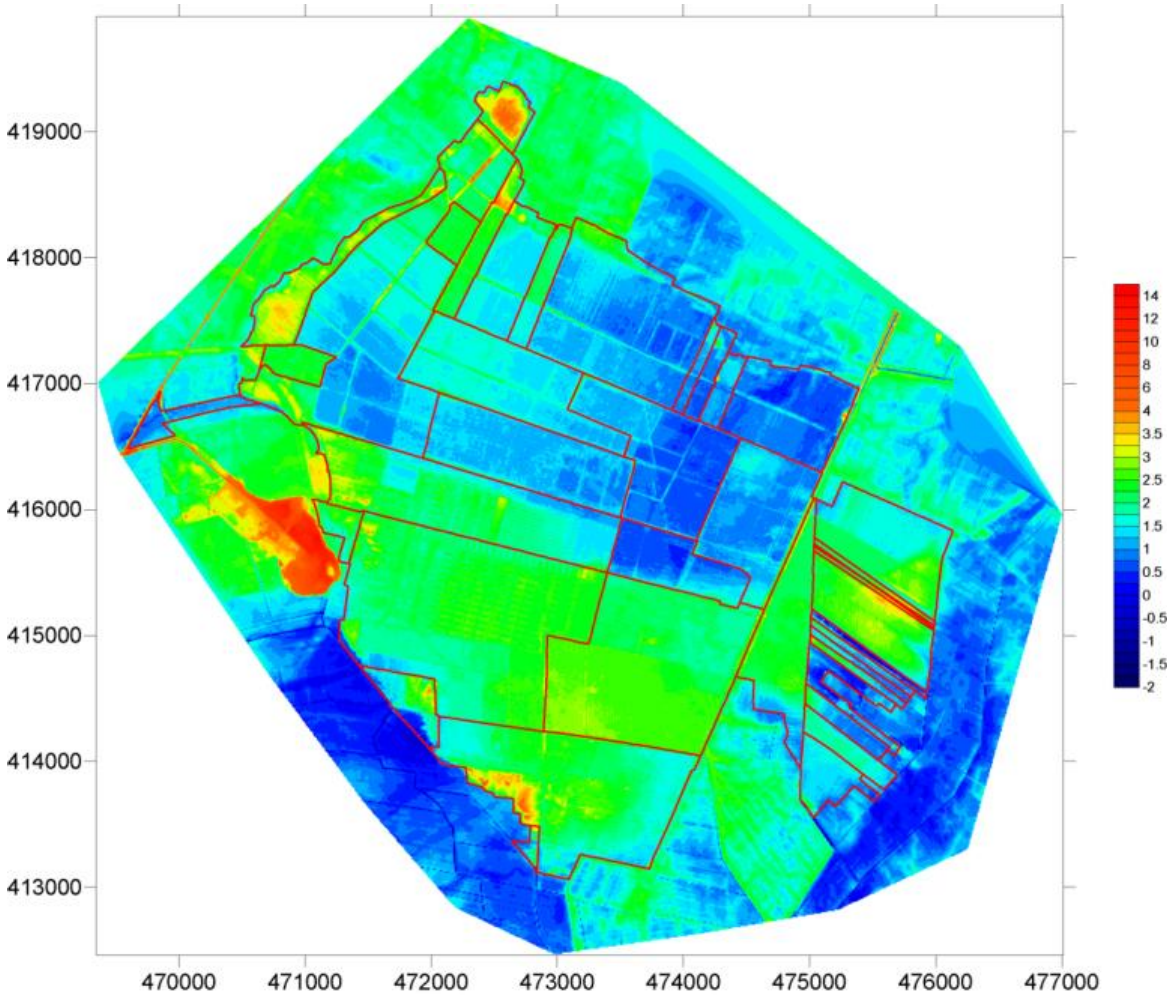

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Figure 3-1 Ground Surface Elevations on Thorne Moors SSSI

Much of the land surrounding Thorne, Goole and Crowle Moors has been subjected to warping (see Section 4.3.2). Where warping has been carried out it has increased the level of the ground. This, together with peat cutting, means that much of the raised mire is no longer higher than the surrounding land. Warp is absent to the southwest of Thorne Moors (Gaunt, 1987, 1994). Here the land was reclaimed in strips (Limbert, 1987), and the peat removed, leaving the land lower.

3.3 Climate

3.3.1 Rainfall

The Standard Average Annual Rainfall (SAAR) for Flood Estimation Handbook (FEH) catchments within and immediately adjacent to the moors ranges from 582 to 587mm/yr for the period 1961 to 1990 (CEH, 2006). The moors are located in MORECS Square 100. For this square the average annual rainfall over the period 1971-2000 was 600mm/yr.

3.3.2 Evapotranspiration

Evapotranspiration is highly sensitive to land use and vegetation, and also dependent on the moisture retention characteristics of the soil. MORECS provides evapotranspiration values (potential and actual) for various vegetation or land use types, and for soils of high, medium and low Available Water Capacity (AWC). The AWC is the amount of water held in the soil between field capacity and permanent wilting point, and represents the amount of water available for plant growth (Reeve and Carter, 1991). Peat has a high AWC.

Table 3-1 presents actual evapotranspiration data for MORECS Square 100 for the period 1971-2000. The values highlighted in grey are those considered applicable to the peatlands of Thorne, Goole and Crowle Moors.

Table 3-1 Actual Evapotranspiration Data for MORECS Square 100, 1971-2000

Land Use	Average Annual Actual Evapotranspiration (AE)	
	AE for high AWC soil [mm/yr]	AE for medium AWC soil [mm/yr]
Open water	708	708
Deciduous woods	567	553
Oilseed rape	549	518
Short grass	527	499
Winter wheat	513	471
Riparian†	508	508
Potatoes	493	445
Rough grazing	457	426

Notes
The highlighted values are considered applicable to Thorne, Goole and Crowle Moors.
*AWC = Available Water Capacity (see text for definition).
† For riparian land it is assumed that potential evapotranspiration = actual evapotranspiration.

Birdsall (2000) carried out a study into evapotranspiration on Thorne Moors and noted several important points:

- In undamaged raised mires, the watertable is near or at the surface, therefore, the water supply for actual evapotranspiration is always abundant and the different species adapted to these conditions have little effect on the evapotranspiration rate;
- In damaged raised mires the watertable is deeper; therefore, the water supply and vegetation cover exert a much greater control over the evapotranspiration rate.

On damaged mires with uniform stands of vegetation and with species type having a greater control on the actual rate of evapotranspiration, it is important for management strategies to take into account the effect different species have on the rate of evapotranspiration.

Actively growing *Sphagnum* maintains a high watertable through forming peat with high storativity near the surface which reduces the fluctuations in the watertable. This peat also decreases in hydraulic conductivity with depth as it becomes more degraded. Therefore, as the watertable falls, it becomes harder to draw out the water from the ground to evapotranspirate. This system acts to conserve water by 'shutting off' evapotranspiration when the water level drops.

On degraded mires without active *Sphagnum* growth, and with a lowered watertable, the properties of the peat differ and vascular plants with root systems such as such as birch *Betula spp.* and heather *Calluna vulgaris* can invade. Birdsall's (2000) work concludes that, independent of the watertable, vascular plants cause a greater rate of evapotranspiration on Thorne Moors than *Sphagnum* species would. Evapotranspiration is increased by vascular plants due to the:

- Increase in the surface area of the canopy;
- The number of routes by which water can be drawn upwards from the unsaturated zone to the surface in roots, including the provision of preferential flow paths through layers of low hydraulic conductivity;
- Increased surface roughness.

The level of the watertable is also an important control on the rate of evapotranspiration. In general, the lower the watertable, the lower the rate of evapotranspiration as lower watertables reduce the supply of water for the process. The relationship between watertable depth and the rate of evapotranspiration is modified by plant species. On Thorne Moors, for vascular species, a rise in water level to above 20 cmbgl (centimetres below ground level) can cause a reduction in the rate of evapotranspiration (Birdsall 2000). This is because water logging can cause stress to the root systems of vascular plants and stomatal closure which reduces the rate of evapotranspiration.

When comparing different species with each other, in general the rate of evapotranspiration is greatest for birch, then heather, then cotton-grass, with the least evapotranspiration occurring on peat covered by *Sphagnum*.

Birdsall's (2000) work has implications for water management on Thorne. It suggests that the removal of heather and birch scrub is important in reducing the water loss from the site. However, if the watertable is regularly lower than 60 cm below the surface (cmbgl), then the water supply is the most important factor on the rate of evapotranspiration and the vegetation cover has little influence. This means that, in the driest areas, works such as ditch blocking should take precedence over scrub clearance (until the water levels are sufficiently high for clearance to have an effect) or these should be undertaken together. In the wettest areas, (where the watertable is stable above 20 cmbgl) where birch and heather still occur, scrub clearance is not required to maintain a high watertable. In fact the high watertable is likely to inhibit the growth of scrub and result in a reduction in their land cover. This effect should be noted in woodland areas which have been inundated by high water levels, such as those on the eastern boundary of Crowle Moors (Figure 3-2).

Figure 3-2 Area of Inundated Birch Woodland on the Eastern Boundary of Crowle Moors

In the very driest areas where, due to factors like topography, the likelihood of being able to raise the watertable above 60 cmbgl would pose extreme difficulties, discussion should be had to assess whether heather and birch scrubland should not be routinely cleared if it provides ecological value in its current state (e.g. for nightjar *Caprimulgus caprimulgus* habitat).

3.4 Vegetation/Ecology

Almost none of the original raised mire vegetation on Thorne, Crowle and Goole Moors is now in existence although there are one or two small areas which still preserve some of the original raised mire surface, although this is no longer pristine. These remnants are on Northern Goole Moor, Cassons and parts of Crowle Moors. The remainder of the moors is composed of a number of seral ecosystems that represent various stages in the succession from bare peat to mature woodland. The locations of all these broad habitat types are shown in Figure 3-3.

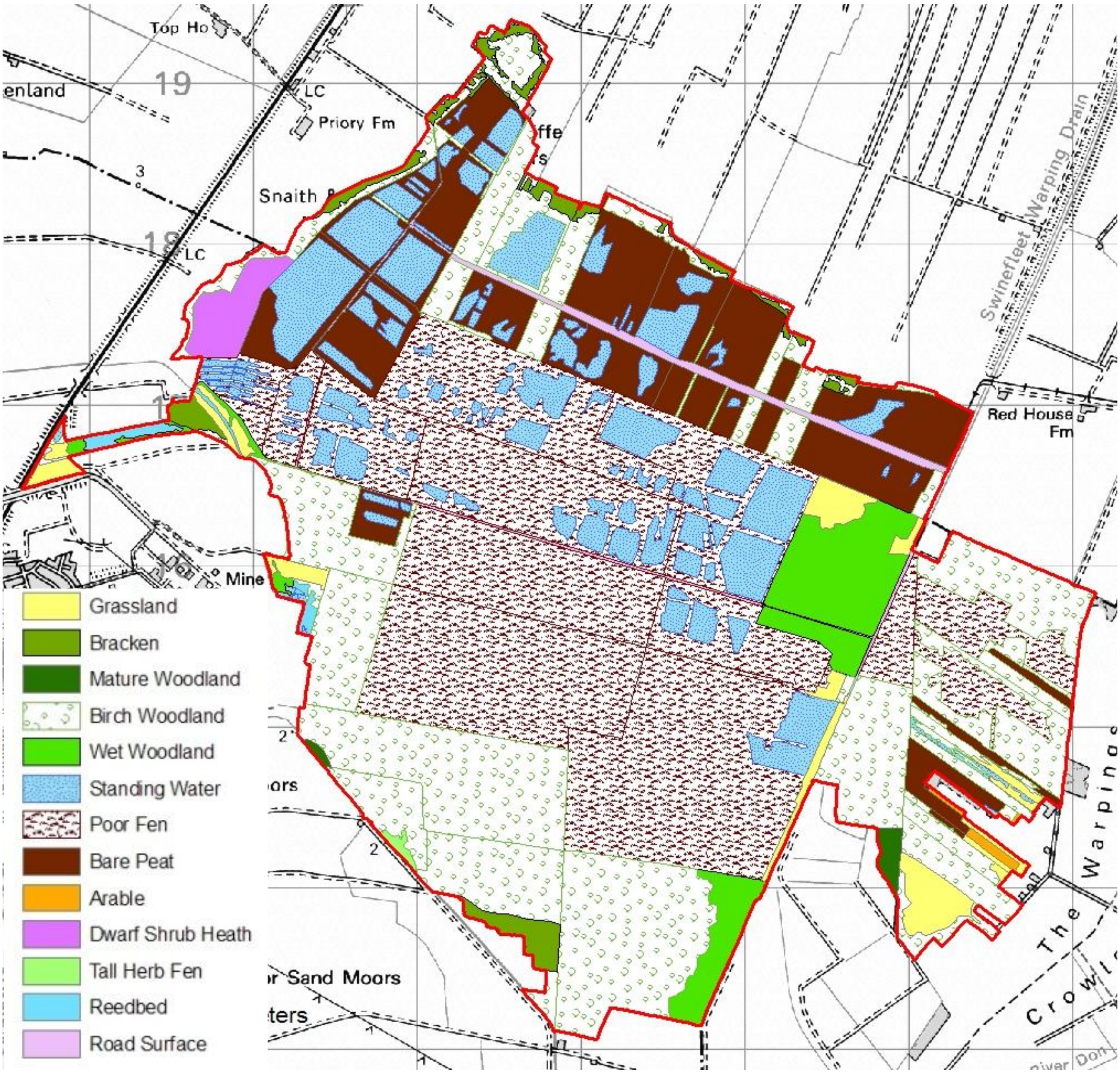

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Figure 3-3 Broad Habitat Types on Thorne Moors (JBA Survey 2009)

3.4.1 Grassland

There are a number of grassland types on Thorne Moors and these are situated around the periphery of the moors, typically where land has been reclaimed, post peat production. The grasslands on Ribbon Row are neutral in nature and are typical of those that develop on ungrazed land. These grasslands have developed on land reclaimed from peat production that was once used for arable and silage production, however, since this time they have tumbled-down to rank grassland dominated by false oat-grass *Arrhenatherum elatius* and cock's-foot *Dactylis glomerata*. Here and there within this there are patches of nettles *Urtica dioica* where there has been tipping and the abandonment of machinery, and illegal dumping of farm equipment and unwanted peat working materials. This has made these areas not only a very varied habitat but also a health and safety hazard with buried and covered machinery lying unseen in the grass.

In the Flower Garden area of Crowle Moors there is a large open area of acid grassland, dominated by purple moor-grass *Molinia caerulea* and soft rush *Juncus effusus*. This is currently being grazed by Hebridean Sheep to control the growth of birch *Betula* spp. which are invading the area. This grass cover has developed over wet heath that has been worked for peat in the past.

On Thorne Moors there are a number of grassland areas that are varied in type. *Molinia* grassland, such as that present in the Flower Garden area of Crowle Moors, can be found at the north-western and north-eastern corners of Will Pitts as well as to the west of the Natural England shed north of Will Pitts Scrape (see Figure 3-4).

Figure 3-4 *Molinia* grassland on Crowle Moors

The remaining areas of grassland on Thorne Moors occur on the western margin of the moss: at Bell's Pond and Inkle Moor. These are neutral grassland types similar to those on Ribbon Row in Crowle Moors but covering a larger area, especially in the old field system on the 'arrowhead' at Inkle Moor. Elsewhere, deer grazing takes place although these animals tend to find the adjacent arable fields more to their liking as they contain more nutritious and palatable species than the grassland areas. Finally, just to the south of the Paraffin Works there is an extensive area of species-rich neutral grassland that has been re-fenced and grazed by sheep in recent years. This grassland is damp and has common reed *Phragmites australis* growing through and around it but the sward here is varied and is benefitting from the implementation of the grazing regime.

3.4.2 Mature Woodland

There are two areas of dry, mature woodland on the designation. The first of these on the west side of Thorne Moors is at Woodpecker Corner where there are a number of tall English oak *Quercus robur* trees forming a grove at the edge of the bog, Here the tall canopy gives a very different feel to the area and the ground flora echoes this difference with woodland species, such as the occasional bluebell *Hyacinthoides non-scripta* making an appearance (see Figure 3-5). The other area is an area of mixed canopy woodland, including English oak, white willow *Salix alba* and silver birch *Betula pendula*, in the Pony Bridge area to the west of the Yorkshire Triangle area of Crowle Moors. This has a ground flora dominated by brambles *Rubus fruticosus* and bracken *Pteridium aquilinum*.

Figure 3-5 Oak Woodland at Woodpecker Corner

3.4.3 Birch Woodland

In total, the area of birch woodland on the SSSI is more than six square kilometres and, even this, is probably an under-representation as this habitat is ubiquitous and occurs in many other habitat classifications in small patches, and in drowned and felled areas. The majority of this habitat is composed of downy birch *Betula pubescens* with some silver birch within it (see Figure 3-6).

Figure 3-6 Birch woodland on Crowle Moors

This woodland is extremely varied and has an understory that varies from bracken on much of the rand to tufted hair-grass *Deschampsia cespitosa* in some of the wet areas with occasional hare's-tail cotton-grass *Eriophorum vaginatum*. The varied nature of this woodland and the fact that birch are the colonising species shows that most, if not all, of these woodland areas are undergoing change. In some places, such as the rand, the bog has become dryer in recent years allowing the growth of bracken and the formation of birch woodland, however, the evidence from many parts of the centre of the moss, where the birch woodland has a wet grassland understory is different. Here the vegetation suggests that these areas are becoming wetter: the birch originally developed on dry ground but, once the area had been drained for peat extraction, it began to be overwhelmed by the rising of the level of the groundwater. Indeed, in many areas that are now open water or poor fen, dead or dying birch trees can be seen lending some weight to this hypothesis. In spite of the seral nature of much of this woodland it does contribute significantly to the appearance of the SSSI and its loss may have a detrimental effect on a number of the faunal species living there, in particular roe deer *Capreolus capreolus* and nightjar.

3.4.4 Wet Woodland

This is a habitat that exists in two large blocks on the eastern edge of Thorne Moors, adjacent to the Swinefleet Warping Drain and the Swinefleet Line Dyke. The most northerly of these, Will Pitts and a part of Will Pitts Scrape, is mostly secondary woodland that has grown up following the removal of peat in the past. Whilst this woodland does contain birch species, it is composed in the main of willow (*Salix spp.)* with some oak, especially along the eastern side of the wood where there is no peat and some of the crack willow *Salix fragilis* trees are a few hundred years old. The ground flora in this area is characteristically wet, although there are grassy rides through the woodland with Yorkshire fog *Holcus lanatus* usually the dominant grass. The ground is wet, there are often pools of water and the canopy is generally open, although it is closed and dark where there are large groves of ancient crack willows (See Figure 3-7). Within these pools, common reed is dominant along with branched bur-reed *Sparganium erectum* and floating sweet-grass *Glyceria fluitans*, which also grows along the rides through the Yorkshire fog.

In places, the tree cover is a little sparser and here there is a lush growth of tall fen vegetation with the above species as well as great willowherb *Epilobium hirsutum* and hairy sedge *Carex hirta*. This area is very species-rich, with a mosaic of habitat types in close proximity. For this reason it supports a number of faunal species, including numerous dragonflies, hobby *Falco subbuteo* and roe and red deer *Cervus elaphus*.

Figure 3-7 Wet Woodland in Pony Bridge Wood

The other large area of wet woodland is in the south west of the site at Pony Bridge Wood. Here the canopy is dominated by large specimens of crack willow, white willow and alder *Alnus glutinosa*, whilst the ground flora is covered with mosses and rough meadow-grass *Poa trivialis*. Here the ground is soft and there are large, deep pools of water, many of which have extensive stands of yellow flag *Iris pseudacorus*. This area has the appearance of being undisturbed for some time and the age and size of the trees contribute to this conclusion. Unlike the wood at Will Pitts, this area is not cut by rides and it is difficult to cross as the pools are numerous, uneven in shape, deep and treacherous. As a result it is left undisturbed and is home to large mammals, such as red deer and badger *Meles meles*.

3.4.5 Standing Water

There are nearly 250 hectares of standing water on Thorne Moors and this varies in character across the site. North of the Blackwater Dyke these areas are shallow, ephemeral and dystrophic. Here the waterbodies are surrounded by worked peat with a covering of cotton-grasses and the water is devoid of species. There are patches of soft rush throughout but nowhere is this the dominant species and, in one or two favoured localities, *Sphagnum capillifolium* and even *Sphagnum cuspidatum* have colonised the waterbodies. These are peat-forming species and their presence here indicates that active peat accumulation has re-started in this area following the cessation of peat working.

South of the Blackwater Dyke and north of the Limestone (Fison's) Road, the waterbodies are large and numerous and here they are deep with lines of soft rush marking the old peat working baulks. Between these there is little vegetation and the waterbodies have large numbers of ducks and geese on them. These areas are exemplified by the large waterbody at Will Pitts Scrape, which is very similar in character and has been set aside as a bird reserve.

Inkle Moor Pond is unique: this is a common reed fringed pond in the corner of a railway junction and, thus, is completely isolated from Inkle Moor and Thorne Moors beyond. This pond is large and mesotrophic and holds a population of fish and it is regularly fished by local people.

In Ribbon Row there are a series of connected ponds running from Medge Hall Tram to Poppleton's Moor (see Figure 3-8). These are deep and still and filled with dystrophic water in which there are no aquatic plants. The sides are steep and there is very little emergent or marginal vegetation, although a few clumps of soft rush are present.

Figure 3-8 Pools of water at Ribbon Row

Bell's Pond is a small, shallow pond that fluctuates seasonally, as does its ephemeral neighbour to the south. There are no aquatic plants here but there is marginal vegetation which, like that at Inkle Moor, is composed almost entirely of common reed.

3.4.6 Poor Fen

This is a very widespread habitat on Thorne Moors and is the result of the flooding of much of the low-lying centre of the moor, following peat extraction. Much of this flooding has been designed to encourage the growth of *Sphagnum* mosses; however, these are few and far between in this habitat. Much of the area south of the Limestone Road is made up of this habitat and it is dominated by soft rush and hare's-tail cotton-grass tussocks protruding out of the water (see Figure 3-9). These tussocks sometimes have pools between them and occasionally *Sphagnum cuspidatum* is present. Many of the tussocks are raised enough above the average water level to support the growth of birch saplings, however, when the roots of these penetrate to the level of the watertable their growth stops with the result that many of these trees are either stunted or dead.

Figure 3-9 Poor cotton-grass Fen on Snaith and Cowick Moors

This is one of the habitats on Thorne Moors that is currently expanding its area as the cotton-grass and rush habitat is beginning to invade adjacent areas of birch scrub as the watertable in these compartments rises. This rise in the water level will eventually kill the birch trees and they will be replaced by this type of poor fen vegetation. This process is being hastened in some compartments, for example in the Collis' Tram area, where large areas of birch have been recently felled.

To the east of the Paraffin Works there is a similar area to this where much of the birch woodland has been felled and the area is now being colonised by soft rush and hare's-tail cotton-grass.

Lastly, on Crowle Moors there are extensive patches of this same habitat to the east of the Yorkshire Triangle and along the North Tram. Here the increase in the watertable has in places been supplemented by the felling of the birch scrub, thereby enhancing the development of this species-poor habitat.

3.4.7 Bracken

This species occurs commonly on Thorne Moors in particular and is associated with the birch woodlands in the drier locations. In places, such as on Northern Goole Moors, the northwest rand and in Cassons, it has become the dominant species and grows almost to the exclusion of everything else. These areas are extensive and extremely species-poor, with rhododendron sometimes its only companion.

3.4.8 Bare Peat

There are over five square kilometres of this habitat on Thorne Moors, making it the largest habitat type by area. Most of this habitat is concentrated to the north of the Limestone Road where mechanical milling ceased in 2005. There are also small outliers in Crowle Moors, just to the south of Ribbon Row.

On Thorne these area are characterised by large expanses of bare, milled peat with scattered tussocks of soft rush and cotton-grass with the occasional small clump of birch (see Figure 3-10). In between the compartments there are often raised banks of uncut peat with a covering of heather and the occasional birch sapling. The vegetation cover in these areas is variable, however, there is always areas of bare peat between the tussocks which themselves are gradually spreading over the surface as it succeeds to the Poor Fen habitat mentioned above.

These areas,both within them and around their margins, grade into stretches of open, peaty water, some of which are very large and contain *Sphagnum cuspidatum*, where the conditions are sheltered.

Figure 3-10 Bare peat along the Shearburn and Pitts Drain

On Crowle Moors the situation is slightly different, here the general level of the moss is higher than on Thorne, and deep cuttings right down to the clay (or aeolian sand) have been excavated, removing almost all the peat from these sites, leaving them completely devoid of vegetation. Because of the nature of the land ownership in this area, these cuttings are linear and deep and have totally destroyed the former raised mire landscape, and replaced it with one that in places resembles a moonscape.

3.4.9 Reedbed

This is a widespread habitat on Thorne Moors in and along drains and in 'wet corners'. However, here and there it forms extensive patches, such as on Inkle Moor where it forms a mosaic with willow carr and around Bell's Pond and Inkle Pond where if forms a large fringe of reeds to these waterbodies.

3.4.10 Other Habitats

This includes the Swinefleet Warping Drain with its swamp communities, mostly reed sweet-grass *Glyceria maxima* and branched bur-reed as well as the roadsides. These latter habitats have typically been created by the tipping of limestone (and other) chippings on the peat substrate, often creating an alkaline environment in and around the road (see Figure 3-11). This has led to the development of a calcareous flora along the edge of many of the roadways, in particular along the Limestone Road, the Swinefleet Warping Drain and parts of Goole Moor Tram. This ruderal habitat bears some similarity to calcareous grassland and contains species such as mouse-ear hawkweed *Pilosella officinarum* and glaucous sedge *Carex flacca*.

Figure 3-11 Limestone (Fison's) Road looking West

3.5 Ecological Description of the SSSI Units

This section describes the ecological feature of the SSSI by unit.

3.5.1 Unit 1

This area, which is mainly composed of Northern Goole Moors and a linear strip of woodland, has been classified as 'Unfavourable declining' by Natural England (2009) due to low water levels (3m or so below ground level at the western edge of the unit), birch and bracken invasion and inappropriate management for shooting and pheasant rearing. However, the presence of heather and the wet surface of this area, away from the boundary drains suggests that there is potential for raising water levels within this area to a level to allow favourable ecological condition to be achieved.

3.5.2 Unit 2

A linear strip of woodland running North-South from the northern boundary of the site to Will Pitts Tram. This area is dominated by bracken and birch and surrounded by boundary ditches. It has been classified as 'Unfavourable declining' (Natural England 2009) on account of the growth of these species and the presence of a low watertable.

3.5.3 Unit 3

This is two linear areas of woodland running North–South from the northern boundary of the moor. These are composed mainly of birch and willow and intersected and surrounded by drainage ditches. Once again Natural England have assessed this area as 'Unfavourable declining' (Natural England 2009) on account of the invading scrub and the low watertable.

3.5.4 Unit 4

Unit 4 comprises large parts of Goole Moors that have been flooded in recent years and are now showing good signs of recovery (Natural England 2009) with cotton-grass and *Sphagnum* spp. present. Classified as 'Unfavourable recovering' (Ibid), the water levels in these compartments seem to be managed effectively although they may, at certain times of the year, be a little high.

3.5.5 Unit 5

A large portion of Snaith and Cowick Moor that has been flooded in recent times encouraging the growth of cotton-grasses and soft rush. Not all of the peat has been re-vegetated, however, *Sphagnum* spp. have been recorded in this unit and it believed by Natural England (2009) to be in 'Unfavourable recovering' condition.

3.5.6 Unit 6

This area includes the rand on the Snaith and Cowick Moors as well as the Alder Thicket. This compartment supports dense stands of birch and bracken. On the rand particularly, a number of drains have been filled-in, although any effects of this have not been noticeable. Nevertheless, probably in view of its location overlooking the arable fields to the west, it has been classified as 'Unfavourable recovering' by Natural England (2009).

3.5.7 Unit 7

The Paraffin Works: here there are a number of deep cuttings that have recently been flooded to promote the growth of raised bog vegetation. This area, on account of the implementation of these measures as part of the WLMP, has been classified as 'Unfavourable recovering' (Natural England 2009).

3.5.8 Unit 8

Inkle Moor: this is a piece of the SSSI that juts out to the west that does not possess any peat deposits. Here the habitats are mainly rank, mesotrophic grassland and willow and birch scrub habitats that, according to Natural England (2009), are not appropriate for the present descriptions of the site, although they do seem appropriate along the edge of a lowland raised bog. Because of this and fact that the area is well drained and rank, Natural England (2009) have classified the unit as 'Unfavourable declining'.

3.5.9 Unit 9

The small western compartment North of Goole Moors Tram, and separated by a large drain from Compartment 1, has been getting wetter in recent years and it is now dominated by soft rush, common cotton-grass *Eriophorum angustifolium* and other wetland species, with heather on the baulks and along the drain sides. All the scrub has now been removed and, as a result, this unit has been classified as 'Unfavourable recovering' (Natural England 2009).

The second area, South of the Blackwater Dyke, is now quite well vegetated with heather a common component of the sward, especially on the old peat baulks. Elsewhere, wetland species dominate with cotton-grasses and soft rush being dominant with patches of common reed in old drains and deeper corners. As above, this area is classified as 'Unfavourable recovering' by Natural England (2009).

3.5.10 Unit 10

Very similar in a number of respects to Unit 9, this compartment lies immediately to the south of it. Here, however, the water levels are higher and soft rush is more dominant. Here there are large open areas of water and a number of species of *Sphagna* have been recorded. As with Unit 9, this unit has been classified as 'Unfavourable recovering' by Natural England (2009).

3.5.11 Unit 11

An area just to the west of Will Pitts in which much management work has been carried out in the form of scrub removal and bund creation. This has achieved the desired results and the water levels have been raised creating large areas of open water and wetland dominated by soft rush. Despite the fact that no *Sphagnum* spp. have been recorded to date, Natural England have classified this unit as 'Unfavourable recovering' (Natural England 2009).

3.5.12 Unit 12

This is a large area of wet woodland, known as Will Pitts, that is vary variable with some areas being drier and others with the water level above the surface so that it is difficult to walk through. No *Sphagnum* species have been found here. In this compartment there are also a number of ancient crack willows which may once have bounded the lost decoy pond in the area (Bull, K. pers. comm.). Much of the area had been subject to unsuccessful warping which now impacts on the nature of the vegetation in this area. Natural England (2009) have categorised this unit as 'Unfavourable recovering'.

3.5.13 Unit 13

This area, just to the southwest of Will Pitts, is covered with soft rush and open water that is used by gulls for nesting. The water levels vary across the compartment and in some places are fairly deep. Overall Natural England (2009) has classified this unit as 'Unfavourable recovering'.

3.5.14 Unit 14

A large compartment that comprises most of the Northern Canals and Mill Drain Marsh. As with Unit 13, the area is composed of open water and large areas which are being colonised by soft rush, with patches of common reed. Here and there, there are areas of heather but very little in the way of birch scrub. In view of this Natural England (2009) have classified this area as 'Unfavourable recovering'.

3.5.15 Unit 15

A large area of the Southern Canals that is difficult to access and has poor visibility. Overall most of the compartment appears wet, with birch woodland (some felled) and hare's-tail cotton-grass dominating the vegetation. Natural England (2009) has categorised this unit as 'Unfavourable recovering' and there is strong evidence for this in places, especially where the birch has been cut in the past and any remaining saplings are drowning as a result of the higher water levels.

3.5.16 Unit 16

A small compartment near Elmhirst Pumping Station. Here there are extensive stands of bracken and birch and a large area of tall herb fen. In general the area is dry and there is no evidence of peat-forming vegetation. Because of this, and the presence of invading rhododendron, Natural England (2009) has classified this unit as 'Unfavourable declining'.

3.5.17 Unit 17

A large compartment that encompasses a range of habitats. Here there are extensive areas of birch, although these appear to by dying in response to the rise in water levels. Elsewhere there are extensive areas of soft rush and hare's-tail cotton-grass with *Sphagnum* spp. growing between the tussocks. The vegetation cover here is changing and Natural England (2009) has classified the unit as 'Unfavourable recovering' on this basis.

3.5.18 Unit 18

A densely wooded area in the main, although it is open in places at its western end, where there are extensive patches of soft rush and cotton-grasses with *Sphagnum* species in the mix. Elsewhere the woodland is dense, wet and impassable with pools of water and patches of reeds and other emergent vegetation throughout. Natural England has taken the view that, because of the presence and increase in the area of cover of the peat forming vegetation in this unit, it is in 'Unfavourable recovering' status (Natural England 2009).

3.5.19 Unit 19

This area is colloquially known at the Yorkshire Triangle and is composed of very wet birch woodland. These conditions favour the growth of cotton-grasses and other peat-forming vegetation and, as a result, this area has been categorised as 'Unfavourable recovering' (Natural England 2009).

3.5.20 Unit 20

A large area of Crowle Moors that is covered by birch scrub and areas of developing poor fen, where this has been cleared. One or two small areas of bare peat are still present but these are beginning to vegetate over. Whilst not all of this unit is plainly in recovering condition, on balance it has been classified as 'Unfavourable no change' (Natural England 2009).

3.5.21 Unit 21

A varied unit with bare peat at its eastern end and poor fen with cotton-grass tussocks at its western end. The west end is improving and the east is not. Overall the unit has been categorised as 'Unfavourable no change' (Natural England 2009).

3.5.22 Unit 22

A strip of bare, worked peat stripped right down to the sandy deposits underneath. Classified as 'Unfavourable declining' (Natural England 2009) on account of inappropriate management of ditches, drainage, scrub invasion and peat extraction.

3.5.23 Unit 23

Another narrow strip, this time one where peat-winning has ceased. Now dominated by birch woodland in the west and neutral (rank) grassland in the east it has been categorised as 'Unfavourable declining' as a result of inappropriate ditch management, poor scrub control and drainage (Natural England 2009).

3.5.24 Unit 24

Another linear strip of worked peat. This has been flooded and is now composed of a series of linear ponds full of dystrophic water. The unit has been classified as 'Unfavourable declining' on account of inappropriate ditch and scrub management as well as air pollution (Natural England 2009).

3.5.25 Unit 25

A long stretch of thick birch woodland with the remains of an old tramway through it. The woodland is generally dry and bracken has colonised the ground layer. As a result of the lack of management, especially of ditches and scrub, Natural England (2009) has classified this unit as 'Unfavourable declining'.

3.5.26 Unit 26

A large area of bare peat that has been stripped down to the underlying clay. Locally there are still mounds of milled peat and the remains of the old bog oaks and pines that have been discovered. No restoration has taken place and this has necessitated the instigation of enforcement action by North Lincolnshire Council. In view of the above Natural England (2009) has categorised this unit as 'Unfavourable declining'.

3.5.27 Unit 27

Composed of birch woodland, with a stand of acid grassland in the middle, the area is presently being grazed by sheep. Generally the unit is perceived to be too dry to encourage the growth of peat and scrub clearance may be needed. Because of the good drainage, the unit is classified as 'Unfavourable declining' by Natural England (2009).

3.5.28 Unit 28

Very similar to Unit 27, this compartment is birch covered and well drained with plentiful bracken present in the field layer. Natural England (2009) has classified this unit as 'Unfavourable no change' due to inappropriate drainage, ditch and scrub management and weed control

3.5.29 Unit 29

Bell's Pond and part of Whaley Baulk. Here some damage has been done by the construction of an access track. However, elsewhere the compartment is a mosaic of rank grassland, willow scrub and reedbed. In general, however, it is wet although much of it is on mineral soil. The area is currently classified as 'Unfavourable declining' as a result of drainage and inappropriate weed and scrub control (Natural England 2009).

4 GEOLOGY AND SOILS

4.1 Solid Geology and Structure

4.1.1 Solid (Bedrock) Geology

The solid geology of Thorne, Goole and Crowle Moors is illustrated in Figure A 7 and the regional stratigraphy is detailed in Table 4-1. Table 4-2

Table 4-2: Thorne Colliery No. 1 Shaft

and Table 4-3 are stratigraphic logs for nearby deep boreholes.

The bedrock directly beneath most of the moors area belongs to the Triassic Sherwood Sandstone Group and consists mainly of reddish brown fine to medium-grained sandstone (IGS, 1971; Gaunt, 1987, 1994). The eastern third of the area, including virtually the whole of Crowle Moors, is directly underlain by rocks of the Triassic Mercia Mudstone Group, which overlie the Sherwood Sandstone (IGS, 1971; Gaunt, 1994). The Mercia Mudstone Group is dominated by reddish mudstone with some siltstone (Gaunt, 1994).

Table 4-1 Stratigraphy

	Age		Unit	Description	Thickness
Superficial (Drift) Deposits	Quaternary	Holocene	Warp (C19th and younger)	SILT and CLAY	Present around the edges of Thorne, Goole and Crowle Moors (Observed to be 0.6 – 1 m thick in places)
			Topsoil/peat	PEAT	0-5 m approx
		Pleistocene	Blown sand	Fine-grained, well sorted SAND.	-
			25-Foot Drift	SILT and CLAY	< 12 m
				SAND	< 8.8 m (mostly < 4 m)
			Sand and gravel beneath 25-Foot Drift	SAND and GRAVEL	Up to 4.3 m thick within incised valleys
Bedrock	Triassic		Mercia Mudstone Group	Reddish brown (locally greenish grey) MUDSTONE with some SILTSTONE beds ('skerries'). Locally dolomitic and variably gypsiferous.	Overlies the Sherwood Sandstone in the eastern third of the area and thickens eastwards
			Sherwood Sandstone Group	Reddish brown (locally greenish grey) fine- to medium-grained (locally coarse-grained or pebbly) SANDSTONE with a few impersistent layers of reddish brown, or greenish grey, silty MUDSTONE.	c.250 m
Information from IGS (1971), Gaunt (1987, 1994) and Site Investigation					

Table 4-2: Thorne Colliery No. 1 Shaft

Geology	Depth mbgl
Quaternary	0 – c.10.5
Triassic Sherwood Sandstone	c.10.5 - 279.10
Permian strata	279.10 - 460.60
Carboniferous Coal Measures	460.60 + ?Brierley Coal at 467.41 Shaton Coal at 562.51 Inferred Aegiranum MB at 678.21 Barnsley Coal at 844.70
Sunk 1909-24 by Cementation Co. Ltd SE 7066 1588, Ground Level 3.30 mAOD. Data from Gaunt (1994).	

Table 4-3: Top House Borehole

Geology	Depth mbgl
Quaternary	0 – 28.00
Triassic Sherwood Sandstone	28.00- 321.50
Permian strata	321.50 – 527.70
Carboniferous Coal Measures	527.70 + Shaton Coal at 564.00 Inferred Aegiranum MB at 676.60 Dunsil Coal at 857.36
Drilled in 1975 by Thompson Drilling Ltd, SE 7112 1910, Ground Level 5.50 mAOD. Data from Gaunt (1994).	

4.1.2 Structure

The Triassic strata dip eastwards at an angle of about 1° (Gaunt, 1987). Beneath the western part of the area, rocks of the Sherwood Sandstone Group are cut by extensional faults trending WNW-ESE and NE-SW (Figure A 7).

4.2 Superficial (Drift) Geology

Overlying the bedrock in the area are superficial deposits of clay, silt, sand, gravel and peat (Figure A 6 and Table 4-1). The older deposits are of Pleistocene (Devensian) age and reflect the influence of glaciations. The younger deposits are of Holocene, or Recent, age and are post-glacial.

Most of the moorland area is directly underlain by peat of Holocene age (IGS, 1971). It is likely that, across most of the area, the peat rests on Pleistocene silt and clay belonging to the 25-Foot Drift (Gaunt, 1987, 1994; Dinnin *et al*., 1997).

4.2.1 Pleistocene

Sand and Gravel Deposits

The oldest superficial deposits are concealed sands and gravels that rest on a buried landscape carved from the Triassic bedrock. These deposits are generally thin and impersistent, but locally reach a thickness of 4.3 m under the southern part of Goole Fields and the northern part of Thorne Moors (Gaunt, 1987). They are probably of fluvial origin (Gaunt, 1987).

The older part of Thorne is built on a ridge consisting of glacial sand and gravel (IGS, 1971; Gaunt, 1989, 1994). A small patch of glacial sand and gravel crops out on the south-western edge of Thorne Moors [SE 7275 1342] (IGS, 1971).

25-Foot Drift

The 25-Foot Drift consists mainly of laminated silt and clay, although deposits of sand occur below, flanking or overlying the silt and clay; these sands are referred to as the "lower sand", "marginal sand" and "upper sand", respectively (Gaunt, 1994).

Beneath Thorne Moors the lower sand thickens southward from 3 to about 6 m, and also thickens eastwards, reaching a maximum thickness of 8.8 m in a borehole on the north-eastern corner of Crowle Moors [SE 7617 1585] (Gaunt, 1994). The sand is mostly fine-grained and is commonly silty and clayey (Gaunt, 1994).

Overlying the lower sand is the "silt and clay" division of the 25-Foot Drift; this passes beneath Thorne Moors, reaching a thickness of up to 12m (Gaunt, 1987). It is dominated by bluish grey to reddish brown laminated clay, but also contains some thin beds and lenses of silty sand (Gaunt, 1994).

The "silt and clay", and most of the lower sand, are interpreted as having been deposited in Lake Humber, a proglacial lake impounded by the blocking of the Humber Gap by North Sea Ice (Gaunt, 1987; Aitkenhead *et al*., 2002). Lake Humber existed from about 18,000 years BP to 11,000 years BP, although there is evidence that it drained during this time and was re-impounded (Gaunt, 1987; Aitkenhead *et al*., 2002). The lacustrine silts and clays contain sporadic "dropstones" deposited by floating ice (Aitkenhead *et al*., 2002). Some of the lower sand may be aeolian, i.e. deposited by wind (Gaunt, 1994).

The upper sand of the 25-Foot Drift forms low mounds and ridges in the Thorne-Moorends area to the west of Thorne Moors, and is generally not more than 2.5m thick (IGS, 1971; Gaunt, 1994). It was probably deposited as river levées along channels that developed on the former lacustrine plain after Lake Humber had silted up (Gaunt, 1987, 1994). Similar deposits may be present beneath the peat and alluvium on Thorne, Goole and Crowle Moors.

Blown Sand

After Lake Humber disappeared, but before much vegetation could become established, wind-blown sands were deposited in a periglacial setting (Gaunt, 1987, 1994; Aitkenhead *et al*., 2002). The sands are fine-grained and well sorted and commonly have an undulating upper surface reflecting the burial of dune bedforms (Gaunt, 1994).

Blown sand is present on Crowle Hill to the southeast of Crowle Moors (IGS, 1971). Excavations on Crowle Hill [SE 778 117] have shown that the sand fills ice-wedge casts that intrude into the Mercia Mudstone (Gaunt, 1994). Boreholes in the Crowle area have proved up to 4.6m of sand (Gaunt, 1994).

4.2.2 Holocene

Alluvium

On the one-inch drift geology map of the area (IGS, 1971), natural alluvium and artificial warp are grouped together. Warp is discussed in Section 4.3.2.

Natural alluvium may consist of clay, silt, sand and/or gravel. Alluvium is associated with existing river channels (the River Don and Dutch River) and also occupies former river channels such as the old course of the River Don that passes to the south of Thorne Moors and to the east of Crowle Moors (Gaunt, 1987, 1994). Alluvium may be present locally beneath the peat on the moors, and also beneath the warp surrounding the moors.

Peat

Peat covers virtually all of the study area (IGS, 1971; Soil Survey of England and Wales, 1983), although its thickness has been greatly reduced by peat cutting. Parsons (1878) recorded peat thicknesses of 6.1m on Thorne Moors, but at present the maximum thickness does not exceed about 3m (Gaunt, 1987, 1994). Radiocarbon dating of tree material from the base of the peat suggests that the peat began forming over 3,000 years BP (Gaunt, 1994); the oldest date (4,545 years BP) is for peat on Rawcliffe Moors (Buckland and Dinnin, 1997). The formation of a raised mire was encouraged by a wetter climate and by poor drainage in low-lying areas, the poor drainage reflecting both the low permeability of the underlying lacustrine clays and the higher post-glacial sea level.

4.3 Soils and Warp

4.3.1 Soils

Thorne, Goole and Crowle Moors are underlain by the very acidic peat soils of the Longmoss Soil Association. Surrounding the moors there are mineral soils, as described in Table 4-4.

Table 4-4: Soils Associations and General Properties (Soil Survey of England and Wales 1983)

Soil Association	Soil Survey Number	Description	Direction relative to Thorne Moors
Longmoss	1011a	Thick very acid peat soils. Largely undrained and perennially wet. Many areas cut over or partly burnt.	Within the SSSI
Blacktoft	532a	Deep stoneless permeable calcareous fine and coarse silty soils. Some calcareous clayey soils. Flat land. Groundwater controlled by ditches and pumps.	West to northwest (clockwise)
Romney	532b	Deep stoneless permeable calcareous coarse and fine silty soils. Flat land. Groundwater controlled by ditches and pumps.	North to southeast (clockwise) and south-southwest
Conway	811b	Deep stoneless fine silty and clayey soils variably affected by groundwater. Flat land. Risk of flooding.	South
Foggathorpe 2	712i	Slowly permeable seasonally waterlogged stoneless clayey and fine loamy over clayey soils. Some similar course loamy over clayey soils.	Southwest
Based on Soil Survey of England and Wales (1983)			

4.3.2 Warping

Much of the land surrounding Thorne, Goole and Crowle Moors has been subjected to warping (Gaunt, 1987; Limbert, 1987; Gaunt, 1994). This is a method of agricultural land improvement that involves the artificial (or artificially-induced) deposition of silt and clay, forming a deposit known as warp. There are two types of warping: floodwarping and cartwarping. Gaunt explains floodwarping as follows:

> *The area to be warped is embanked and a warping drain cut from it to the nearest river. Sluice gates at the river end of the drain are opened at high tide, allowing the sediment-rich water to flood the embanked area and deposit its load; at low tide the water is allowed to drain gently back into the river. Each flood deposited an average of 2mm of silt or silty clay, and up to 0.3m could be accumulated in a warping season, generally between spring and mid-autumn. A warping programme could last for several seasons, and some ground has been subject to more than one programme. The thickest known floodwarp is 1.5m [thick].* (Gaunt, 1994, p.130).

Cartwarping involves the manual spreading of silt and clay onto land: its name refers to the transportation of the sediment by rail in carts or wagons (Gaunt, 1994). Floodwarping was by far the dominant method of warping employed in the area, with cartwarping being restricted to the southern part of Crowle Moors (Gaunt, 1994).

Warping was carried out all around the moors, with the exception of the southwest, where the land was reclaimed not through warping, but by the earlier method of strip reclamation (Figure 4-1) (Limbert, 1987). This involved digging parallel drains to lower the watertable and then removing the peat from the narrow strips of land between the drains. Within the study area, warping was restricted to a small area adjacent to Durham's Warping Drain along the western edge of Thorne Moors, and narrow strips on Crowle Moors (the latter may also be cartwarped).

There are a number of warping drains in the area, some of which are named: Durham's Warping Drain (eastern edge of Thorne Moors), Earnshaw's Warping Drain (running northwards from the northern edge of Goole Moors) and Swinefleet Warping Drain (separating Thorne Moors from Crowle Moors) (Gaunt, 1987).

In the field, warp commonly takes the form of a pale brown, silty and generally 'light' soil displaying lamination (below plough level) and overlying a pre-existing soil (Gaunt, 1987).

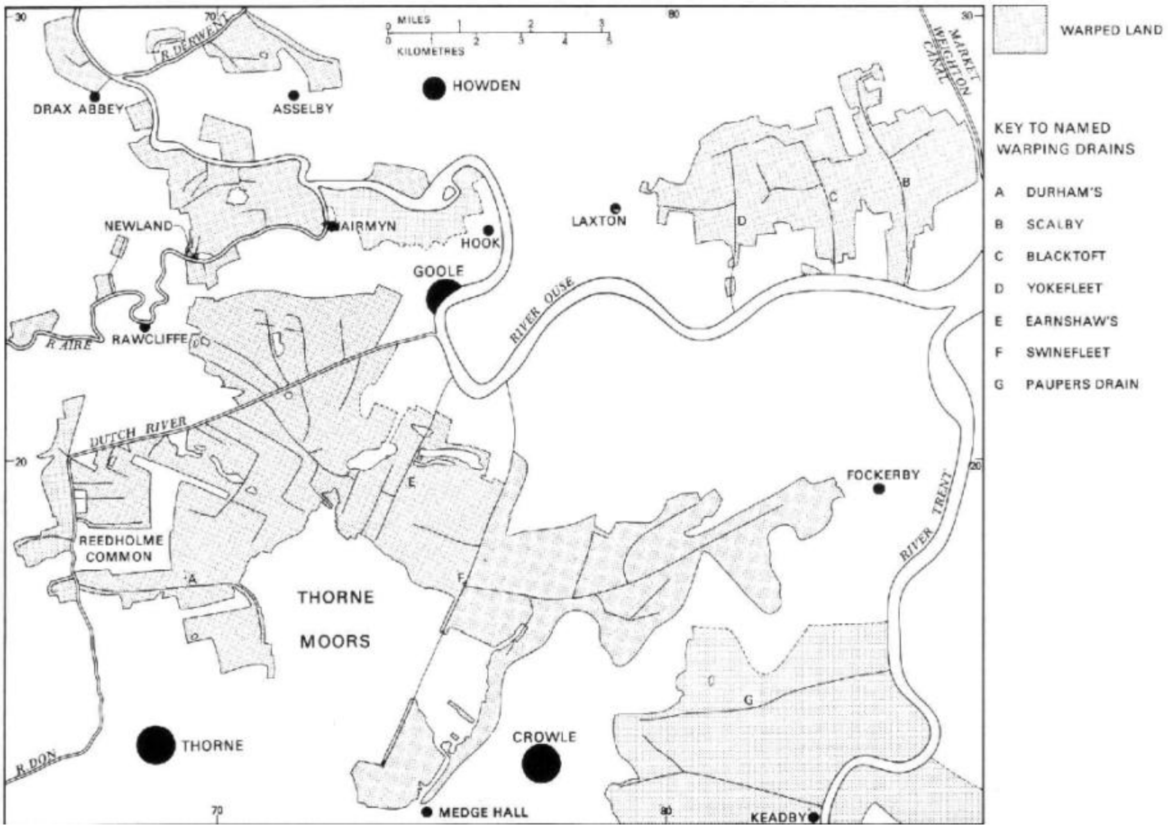

Figure 4-1 Extent of Warping around Thorne Moors (from Gaunt 1992)

4.3.3 Gardens

There is historical evidence that there were a number of gardens and a rhododendron nursery along the southern edge of Thorne Moors (Gaunt, 1987; Limbert 1998). Cassons Garden was the largest and forms the area between the SSSI boundary and Thorne Waste Drain in the southern part of the site. There is also evidence for gardens in the northern half of SSSI in Units 16 and 18. The creation of gardens implies the improvement of the soil and the removal of the peat in these areas.

5 SURFACE WATER HYDROLOGY

This section aims to outline the current understanding of the hydrological characteristics of the site. Due to its long history of peat extraction, there have been a number of phases of drainage on site. This has created a complex drainage network with drains of varying sizes and in various states of repair. Recent phases of restoration have focused on ditch blocking though control structures which adds another level of complexity to those attempting to understanding the system.

5.1 Catchment Characteristics

Without the influence of man, a raised mire forms a mound from which water drains in all directions from the centre.

In the case of Thorne and Goole Moors there is some still drainage away from the mire, however, the direction of this drainage has been modified by the working of the mire for peat extraction. This includes the dissection of the mire by drainage ditches and changes in the surface topography as a result of peat cutting. In general, the centre of Thorne Moors forms a topographic low with watersheds on all boundaries preventing most surface run-off generated on site from having the ability to drain off site under gravity. Only a number of specifically designed drains breach the Thorne boundary watersheds allowing water to discharge from the interior to the boundary drains.

The Swinefleet Warping Drain hydrologically isolates Thorne Moors from Crowle Moors. The *ad hoc* strip extraction of peat over much of Crowle Moors has lead to the small, narrow, straight catchments on Ribbon Row and the rest of the site being controlled by the relict hand cut drainage pattern.

5.1.1 Sub-catchments

The *ArcGIS* Hydro Tool was used to derive surface water catchments based upon topography alone (Figure 5-1 and Figure A 9). This analysis does not take into account artificial drainage networks (unless represented in the topography) or the pumping regime and, therefore, does not truly reflect the catchments as they are. However, the analysis is of use as it shows several key features:

- The topography of Thorne and Goole Moors (notably the rand and the Swinefleet Warping Drain) means that most run-off will not discharge to the surrounding land. Instead most water drains towards the interior;
- A number of drains cut through the rand to allow water, which otherwise could not, discharge out of the site;
- Within the milled area the pattern of ‘rivers’ that the Arc programme derived are fragmented and do not form a clear network and the raised track ways through this area act as watersheds. This is in line with field observations suggesting that the milled area forms a series of isolated compartments bounded by drains and bunds;
- Within the southern half of Ribbon Row in Crowle Moors East (approximately the area covering Unit 26), the catchment analysis shows this area forms a basin. There are however a number of drains which allow this topographic low to drain off the site;
- The southern half of Unit 19, which was observed (on site walk-overs between July-December 2009), to be relatively dry is shown to drain off site;
- The watershed along the North West Rand (Unit 6) is shown not to follow a simple pattern (confirmed in the field), and at points strays some distance into the site. The watershed is controlled by the historic drainage pattern inherited from when the area was subject to hand extraction (or possibly baulk cutting). The line of the watershed can vary between being under 5 m from the site boundary to over 200 m from the edge;
- Without drainage ditches breaching it, the small rand on the northern boundary would create a watershed, stopping surface water discharging off site along most of the boundary. There is however a small catchment in the north east corner (Units 3 and 4) whose topography will naturally allow water to discharge off-site;

- In the southern part of Thorne Moors, an area where the *Arc* derived streams are shown not to discharge to the site boundary, tallies with an area shown to be very wet. The topography in this area does not allow it to drain effectively and water pools there as a result.

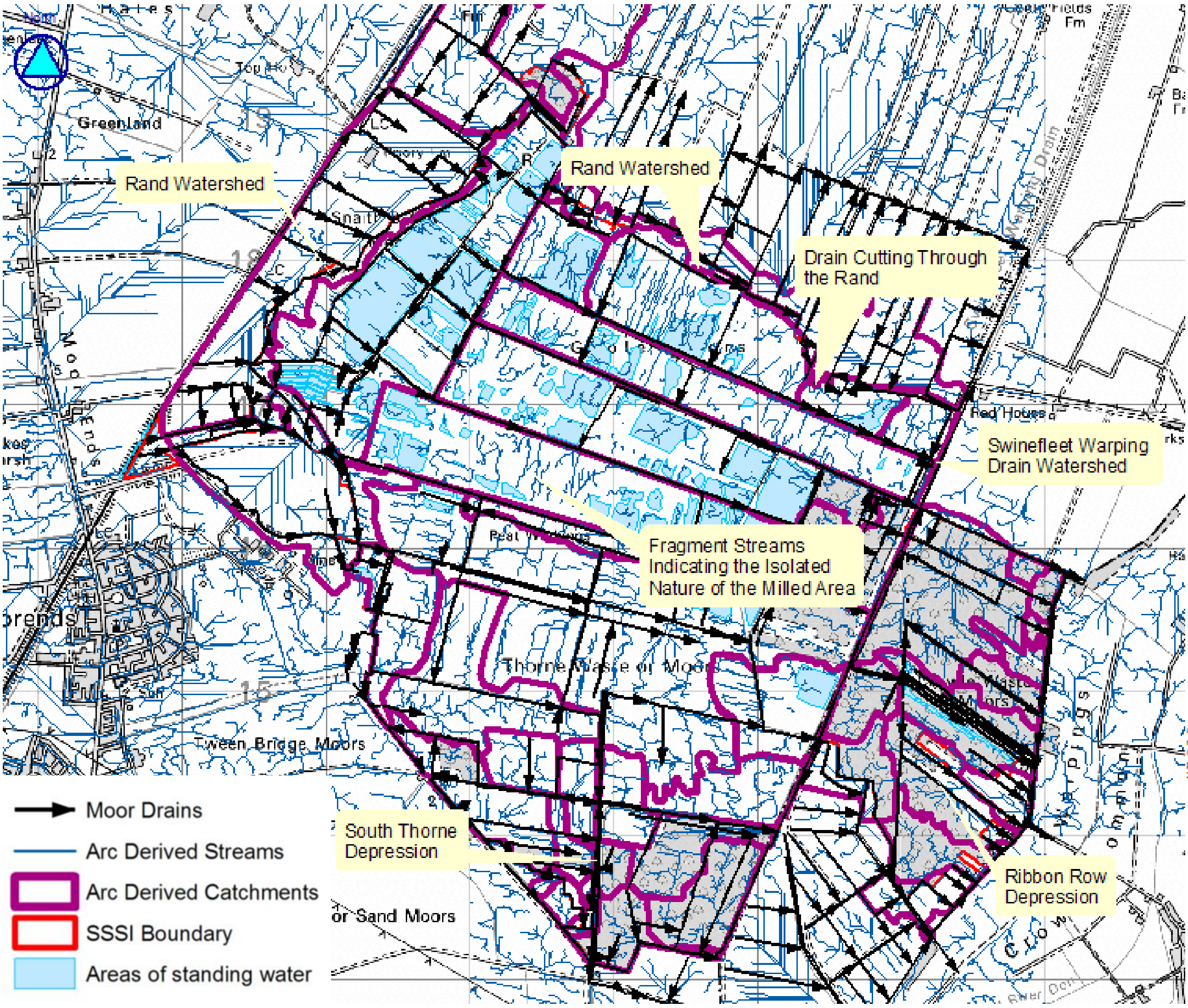

Figure 5-1 ArcHydro Tool Result for Thorne Moors

5.2 Drainage Network

The drainage network on site is complex and has been highly modified from its natural state through peat cutting and drainage works, warping, earlier phases of restoration works and recent attempts at habitat improvement.

Due to the relatively flat topography and the bunds already constructed, the velocity of the flow in all the ditches on the site appears to be relatively low.

Figure 5-2 (and Figure A 8) shows the major and minor drains on site and indicate the directions of flow. There are a number of control structures already onsite which influence water levels the flow of water onsite (see section 5.2.1).

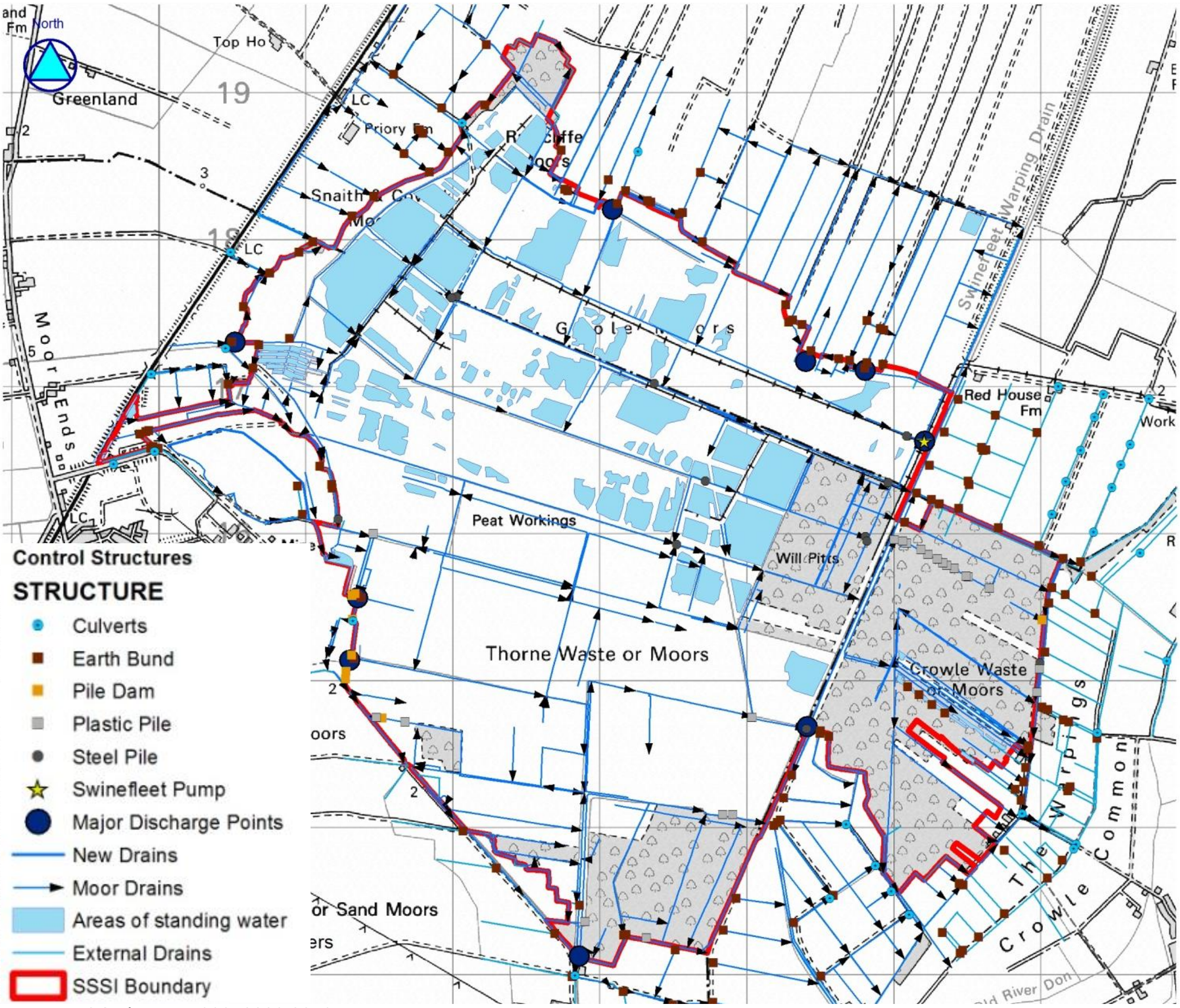

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Figure 5-2 Flow Direction of the Drain on Thorne Moors and the Location of Control Structures

5.2.1 Control Structures

The control structures on site and in the boundary drains have been constructed to control the height of water in the drains and the flow of water through them. Within this report it would be difficult to discuss all the control structures on site but a number of key structures are worth mentioning.

Balley Bridge Weir (NGR 474400 414685)

The Balley Bridge Weir controls the level of water in Angle Drain before it discharges to the Swinefleet Warping Drain. It was constructed by Natural England. The weir here maintains a high water level within Angle Drain and Will Pitts Scrape. By maintaining a high water level in the drain, the rate of drainage from Pony Bridge Marsh is reduced, allowing a high watertable to be maintained (see section 7.1.1).

Figure 5-3 Balley Bridge Weir (NGR 474400, 414685)

New Mill Drain Weir (NGR 473320, 415227)

New Mill Drain forms the boundary of the Dutch Hand Graved Canals in the south of Thorne with the milled areas to the north. The drain flows eastwards and the weir is constructed at the point where the canals end and the drain continues east with milled areas both to the north and south. The weir maintains a higher water level within the drain and reduces the rate of drainage from the Canals area. Between the New Mill Drain and the milled area to the north lies the Limestone Road (AKA Fison's Road). This road is likely to reduce the influence of the drain on the water levels within the milled area.

Figure 5-4 New Mill Drain Weir Looking Westwards

North Rand Breach Plastic Pile Dam (NGR 473113, 418248)

This control structure is a plastic pile dam constructed on a drain which breaches the North Rand on Goole Moors.

Gauge board data collected as part of this study shows that, although the moor in this location lies lower than the agricultural land to the north, the hydraulic gradient is such that in winter water in this drain flows northwards from the moor.

Figure 5-5 Plastic Pile Dam on the North Rand

Compartment 74 Steel Pile Drain (NGR 475993, 415120)

This structure is on the eastern end of Compartment 74 on Crowle Moors. It effectively blocks a large drain which runs straight into the peat mass. The compartments on either side show signs that the water level within them is too low (scrub encroachment), therefore, a review of the height of this structure may be required as part of the WLMP.

Figure 5-6 Steel Pile Dam at the Eastern End of Compartment 74

Milled area Steel Pile Dams – (e.g. NGR 471993, 417602 and 474968, 416348)

Within many of the large drains within the milled area, Natural England has installed weirs (with a similar construction to the Balley Bridge Weir) to increase the water levels in the drains along their entire length.

Eastern Boundary Drains Structures

Along the eastern boundary of Thorne Moors between the Green Belt and Woodpecker Corner, there are a number of control structures on the drains which form the boundary (see Figure 5-7). These structures are set at a level beneath the top of the drains and are not always effective in keeping a satisfactory water level in the peat mass on site. This is usually because the drains have to be effective in draining the surrounding agricultural land, therefore, the water level in these can not be too high.

Figure 5-7 Control Structure on the Boundary Ditch South of Bell Pond (NGR 471343, 415390)

5.2.2 External Discharge Points

There are several key discharge points for the drainage network across Thorne Moors (Figure 5-8):

- Angle Drain (below Will Pitts Scrape) (NGR 474405, 414697) (Point 1);
- Angle Drain (to Thorne Waste Drain (NGR 472861, 413113) (Point 2);
- Pumped from Blackwater Dike (NGR 475226, 416618) (Point 3);
- Drain on the north edge of the paraffin works (NGR 470527, 417271) (Point 4);
- Discharges through the North Rand (NGR 474850, 417150, 474350, 417250 and 473081, 418215) (Points 5, 6 and 8);
- Though the Southern Boundary Drain is blocked by an earth bund (NGR 471282, 415150), this regularly overtops (Point 7)
- Other minor discharge points (e.g. Point 0).

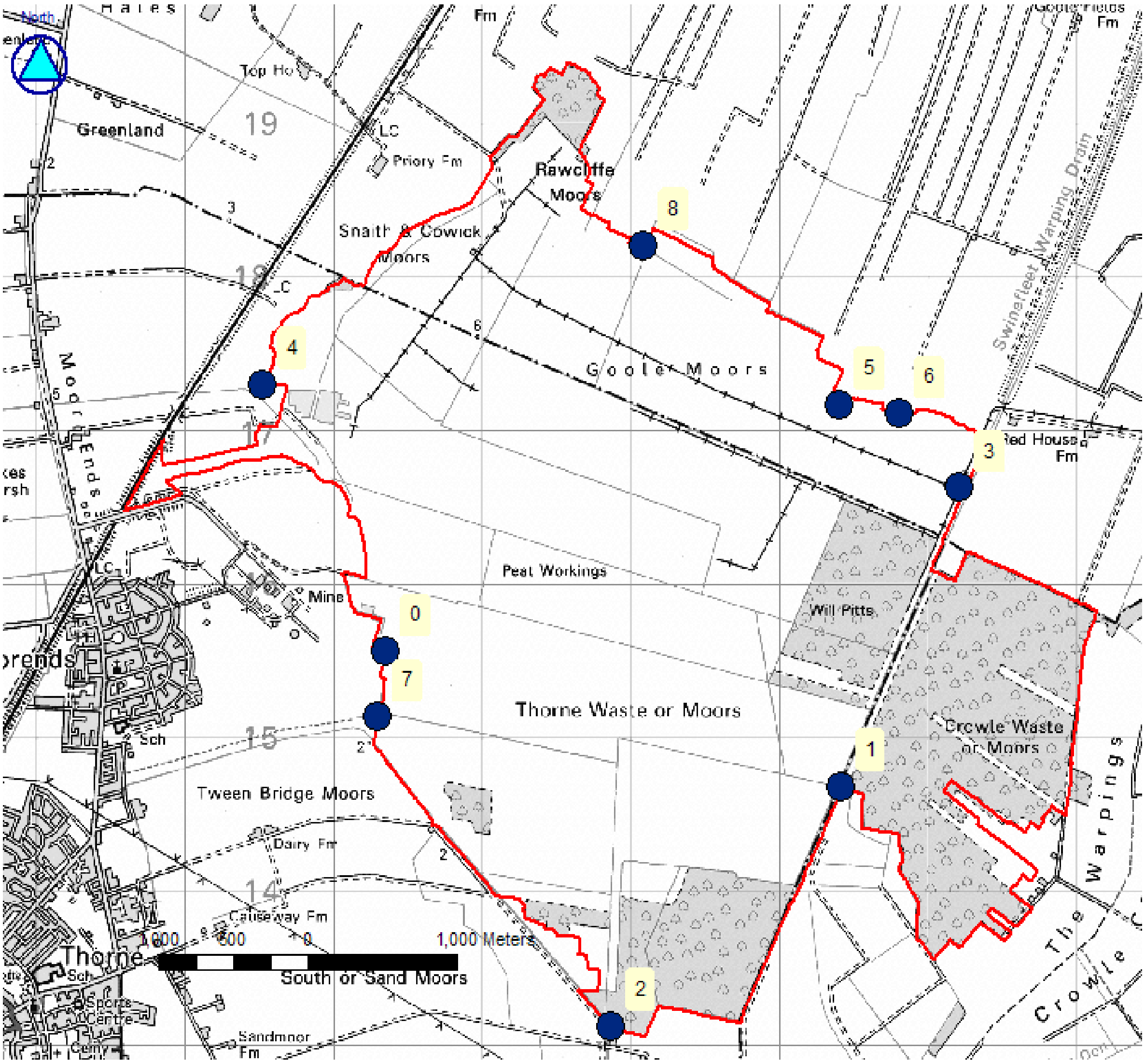

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Figure 5-8 Drain Discharge Points from Thorne Moors

5.2.3 Local Drainage Networks

The drainage pattern of an area is often the result of the type of peat extraction method used; the following sections aim to describe the major type of drainage patterns seen on site;

Canals (Dutch Hand Graving Area)

Narrow deep linear drains bound the areas of the canal peat workings and there are no drains. Here there is a comb-like pattern of slightly higher ground surrounded by lower areas (the canals).

Figure 5-9 Aerial Photograph of a Typical Area of Canal Workings Showing the Comb-like Pattern (Natural England (C))

Ribbon Row

Due to the differing management and ownership of the numerous strips that form Ribbon Row, the type and degree of drainage is spatially highly varied. The varied topography forms narrow linear valleys which effectively drain the higher ground, creating high, dry areas in close proximity to low, wet areas (Figure 5-10).

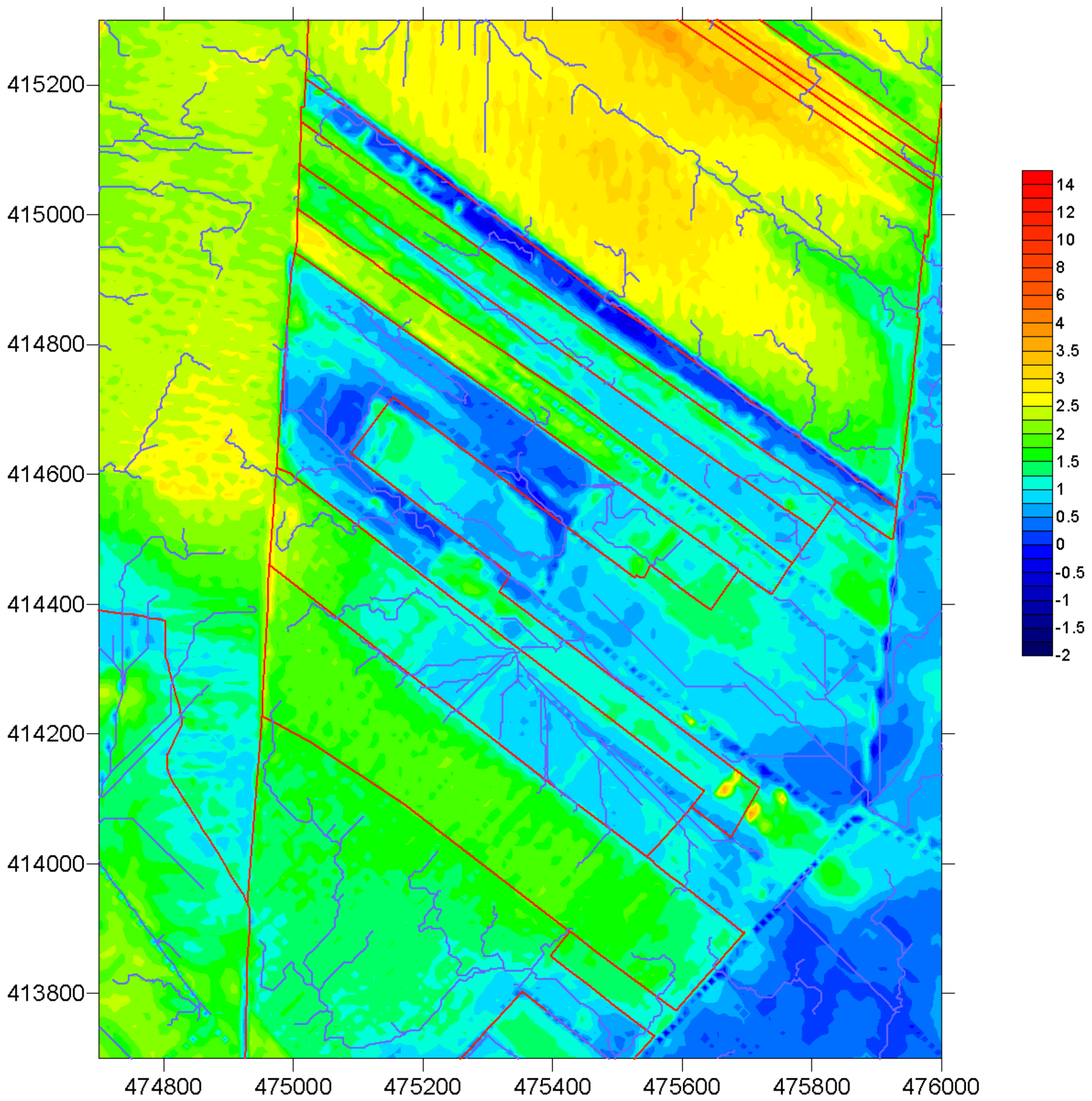

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Figure 5-10 LIDAR Colour Contour Map of Ribbon Row with the SSSI Unit boundaries and Arc drainage network overlaid.

Milled Drains

Within the milled areas of Goole and Thorne Moors large linear ditches (approximately 2 m deep by 4 m wide) were constructed to lower the watertable in the peat to allow heavy machinery on site to extract the peat. These drains are still functioning although weirs have been installed to control the rate at which water can drain from the area. The milled area forms a topographic low so the drains are maintained to ensure that the area does not fill with standing water.

Hand Cut and Mechanical Baulk Cut Peat Extraction Areas

Hand cut and mechanical baulk cut peat extraction has occurred over a large part of the site. These areas include:

- South Thorne Moors (excluding the Canals Area);
- Northwest rand of Thorne Moors;

- North of Crowle Moors;
- The Yorkshire Triangle (Crowle);
- South Crowle.

A similar drainage network has developed in these strips of long narrow straight ridges and furrows. The furrows form channels to drain the areas. Often the direction of the furrows means that surface water does not drain in the direction of the general topographic trend, i.e. the furrows are not parallel to the slope.

Paraffin works

The drainage network within the Paraffin works is unique on-site. There are regular small, closely spaced, rectangular, isolated ponds of varying depth across the whole area. These ponds appear to be isolated from the drains which border the area.

5.2.4 Pumping regime

In the centre of Thorne Moors, a series of bunds produce a number of large shallow areas of impounded water. These occur in a large depression in the peat so that water drains to these from the west and south. The impounded cells of water are connected to one another through pipes. Though shallow, these lakes are often too deep in their centre to support *Sphagnum* species. As part of the current management strategy, the water levels in these bunded cells are not allowed to rise too high. Currently this means that water is pumped out of the Blackwater Dike and up into the Swinefleet Warping Drain, pre-emptively, before forecasted rainfall events, to increase the capacity of the lakes before the forecast rain arrives. The disadvantage of this system is that forecasts may not be accurate, which may lead to over-pumping and the subsequent drying out of the cells.

A fuller description of the pumping regime is provided in Section 8.1.

5.3 Lakes and Ephemeral Open Water

Across the milled areas of Thorne and Goole Moors, peat cutting and subsequent restoration works have produced a number of bunded areas of ephemeral open water. The bunds in the area between the Shoulder of Mutton and Will Pitts are large with wide spacings. The water depth in the centre of these areas is frequently too deep to support raised mire vegetation.

The Paraffin Works area in the west of Thorne Moors is now composed of a series of small (approximately 5 m wide) man-made ponds.

Historically there were a number of ponds across the site referred to locally as ‘wells’ (Limbert 1998). These ponds appear to have been infilled by vegetation or removed through peat extraction. The only remaining example is in Will Pitts Scrape (Will is a corruption of Well), and this is currently managed as a pond (NGR 474475, 415385).

Inkle Moor Pond is a common reed fringed pond in the corner of a railway junction and is, therefore, completely isolated from both Inkle Moor and Thorne Moors beyond.

In Ribbon Row there are a series of connected ponds running from Medge Hall Tram to Poppleton’s Moor (see Figure 3-8). These are not natural features and were created by flooding of an excavated strip on Ribbon Row, through a number of stepped weirs. The height of the weirs has created deep water behind them which, due to its depth and dystrophic nature, has not been colonised by aquatic plants.

5.4 Pumping Stations

Nine pumping stations occur within 4 km of the site; these form part of the drainage system controlled by the six Internal Drainage Boards (IDBs) that surround the SSSI (Figure 5-11); Tween Bridge IDB, Black Drain DB, Thorntree IDB, Dempster DB, Goole Fields IDB and Reedness & Swinefleet DB.

Tween Bridge IDB operates Elmhirst Pumping Station on the south western boundary of the SSSI and Medge Hall Pumping Station located 1.2 km to the south east of the other. The catchment of

Elmhirst Pumping Station takes water from Thorne, Moorends and arable areas to the south west of the moors. Water from the pumping station is pumped along the IDB-adopted Thorne Waste Drain, to the Environment Agency operated New Zealand Pumping Station, which then discharges into the North Soak Drain (Main River). Approximately 14 ha of the pumping station catchment falls within the SSSI, and the pumping station receives water from the site via the Southern Boundary Drain which regularly overtops the dam at the end of this drain, and then reaches the pumping station via the Western Boundary Drain. To a lesser extent water from the Moors also reaches Thorne Waste Drain via Angle Drain (though this drain is blocked by a dam approximately 30 m upstream of the confluence).

The catchment of Medge Hall Pumping Station includes agricultural land to the west of Crowle and also a significant area of Crowle Moors. As Crowle Moors is hydrologically separated from the rest of the site, Medge Hall Pumping Station only receives water draining from this section of the designation. It reaches the pumping station via a series of IDB-adopted watercourses and land drains. Water from Medge Hall is also discharged into the North Soak Drain.

Cross Drain Pumping Station operated by the Goole Fields IDB and Reedness Junction Pumping Station operated by Reedness and Swinefleet DB are located to the north of the SSSI and discharge into the Swinefleet Warping Drain. The catchment of Reedness Junction Pumping Station is located adjacent to the SSSI, but does not overlap with the designated site. However, water from Crowle Moors drains north east wards from the Blackwater Dike at the north of the site into the un-named and unadopted drain adjacent to Rainsbutt Moor and into Dike 60 from whence it flows via a number of possible routes into Bank Side and eventually into the Swinefleet warping Drain at the Reedness Junction Pumping Station.

The catchment of Cross Drain Pumping Station covers approximately 175 ha of Goole Moor Tram and arable areas to the north of this. However, this pumping station receives little water from the SSSI itself as water from Goole Moor Tram drains in a general southerly direction into Blackwater Dyke, which then discharges into the Swinefleet Warping Drain. There are however three points through the North Rand of the SSSI, which discharge northwards during the winter when water levels on site are very high (see section 5.2.2), though these are relatively minor. There are no limitations on Swinefleet Warping Drain, other than the tidal doors located at the outfall into the River Ouse.

Dempster DB has one pumping station, located some distance from the SSSI (NGR 473582, 422510) and discharging into the Dutch River. A series of land drains link this pumping station with Northern Goole Moors, however little water from this area can reach this drainage network as the drains in this area are defunct.

Thorntree IDB has one pumping station adjacent to and discharging into the Dutch River. This station is linked via an intricate network or field drains to the Snaith and Cowick area to the west of Thorne Moors. It is unlikely that this pumping station will exert an influence on the moors as it mainly drains arable land.

Other pumping stations with close proximity of the moors, include the three pumping stations operated by the Black Drain DB (Inlet, Outlet and Rawcliffe Pumping Stations) which are located to the west of the site. The catchment of these three pumping stations does cover the southern portion of the SSSI, however, water was previously discharged from the site via Durham's Warping Drain to the north of Inkle Moor. This drain is now bunded and little water exits the site at this location. These three Black Drain DB pumping stations, therefore, exert little influence on the site.

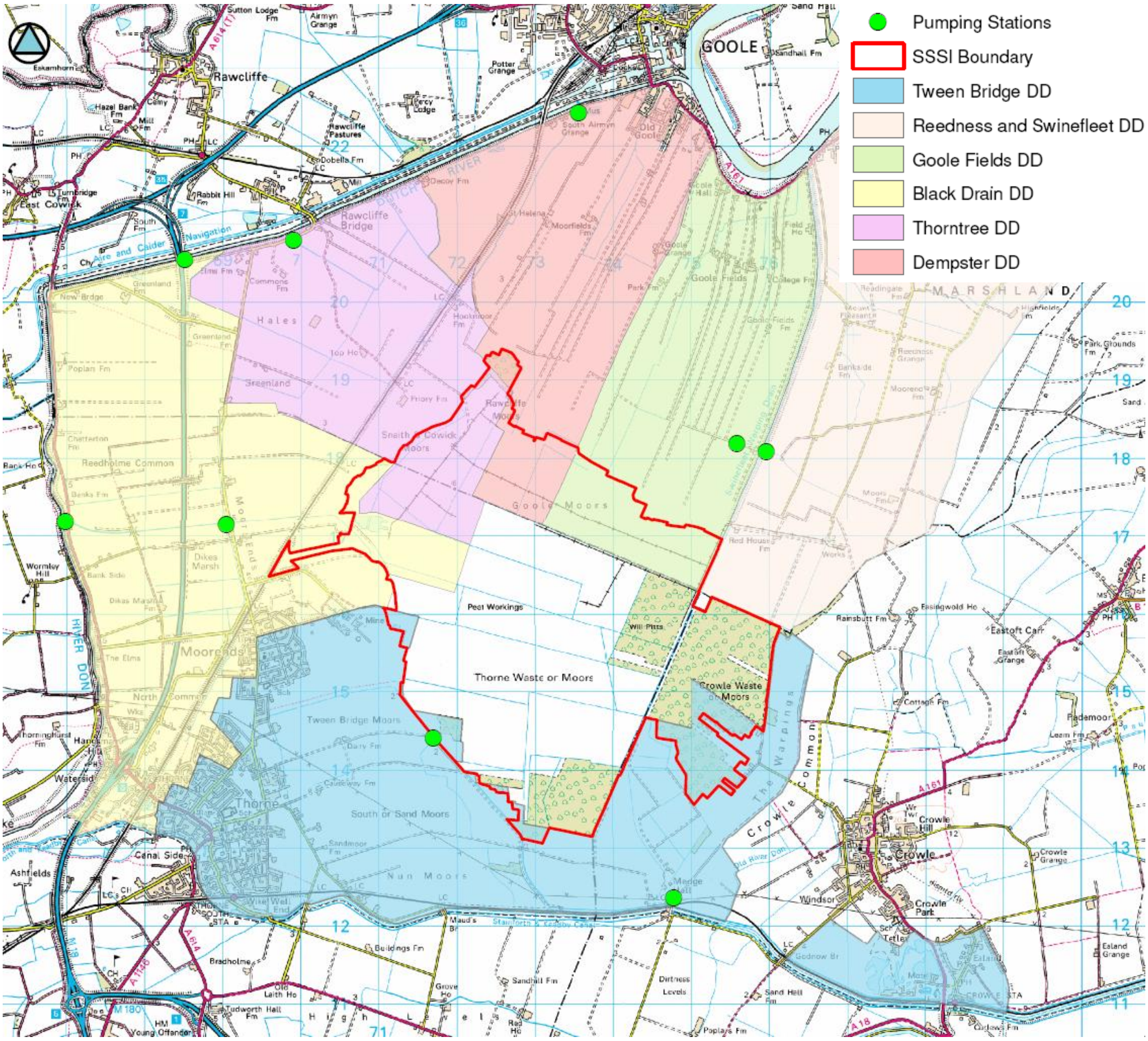

Figure 5-11: Internal Drainage Boards and Pumping Stations Surrounding the Site

5.5 Surface Water Quality

In most of the ditches on site the water appears to have a high Dissolved Organic Carbon (DOC) content, shown by the very dark, almost black colour (dystrophic). The source of the DOC is the surrounding peat, the degree to which the peat leaches carbon is likely to have increased with its degradation and draining. Figure 5-12 illustrates how the water on site differs considerable from the surface water surrounding it; the water from on-site has been stained by the peat and does not have the suspended mineral content of the surrounding drains.

Figure 5-12 External Drain Water from Thorne Waste Drain mixing with on-site water from Western Boundary entering from the left

Some drains within the milled area have turbid light brown waters indicating that these drains cut through to the underlying clays.

6 HYDROGEOLOGY

6.1 Introduction

Underground water occupies void spaces (pores) within soils, sediments and rocks. Below the watertable all the interconnected voids are completely filled with water: this is the saturated zone. Above the watertable is the unsaturated zone in which the voids generally contain both air and water.

Groundwater is water located within the saturated zone. Most groundwater is derived from rainwater that passes through the soil, although water can also "leak" from surface water bodies into the ground. Groundwater typically moves slowly from areas of replenishment (recharge) towards areas of discharge (e.g. seepage lines, springs, rivers and drainage ditches). Often the flow broadly follows the topography, with the direction being from topographic highs towards topographic lows. Usually the shape of the watertable is a subdued version of the topographic profile: in general the depth to the watertable is greater beneath hills than beneath valleys.

Peatlands are characterised by very shallow watertables and by soil profiles that are largely saturated with water. In an intact raised bog, the groundwater typically forms a mound (Meade, 1992; Morgan-Jones *et al*., 2005). Within the mound, groundwater flows down-gradient towards the margins of the bog, where it may discharge into surface watercourses. The groundwater body is replenished by rainfall recharge. Typically the bog will have built upwards from a low permeability mineral substrate (e.g. clay), so the groundwater mound within it will be largely isolated from the deeper groundwater system.

Peat cutting and the installation of artificial drainage networks can drastically alter the groundwater hydrology of a raised bog (Morgan-Jones *et al*., 2005). Drains lower the watertable, allowing the upper, active, part of the peat profile to dry out and shrink, changing its hydraulic properties. Removal of peat exposes deeper, denser, parts of the peat profile (or even the underlying mineral substrate), increasing surface runoff. Vegetation changes accompanying drainage and peat cutting may alter the amount of evapotranspiration and thereby affect the water balance.

Thorne, Crowle and Goole Moors were originally raised bogs, but have been degraded by peat cutting and drainage. The groundwater regime in the moors will have been affected by the network of drainage ditches and pipes, the topography resulting from peat extraction, and the invasion of scrub and woodland vegetation.

6.2 Aquifers and Aquitards

An aquifer is a saturated permeable layer of rock or sediment that can store and transmit significant quantities of water. An aquiclude is a low permeability rock or sediment that cannot transmit significant quantities of water. An aquitard is a low permeability rock or sediment that allows slow groundwater seepage, i.e. it has properties intermediate between those of an aquifer and those of an aquiclude. Table 6-1 describes the hydrogeological units present in the vicinity of Thorne, Goole and Crowle Moors.

Table 6-1 Hydrogeological Units

	Age		Unit	Properties	Hydrogeology
Superficial (Drift) Deposits	Quaternary	Holocene	Warp (C16th and younger)	Low permeability silt and clay	Aquitard
			Topsoil/peat	Highly variable – see Section 6.3	Aquifer/Aquitard
			Alluvium	Low permeability silt/clay and high permeability sand/gravel	Aquitard (silt/clay) or aquifer (sand/gravel)
		Pleistocene	Blown sand	High permeability sand	Aquifer
			25-Foot Drift	Low permeability silt and clay	Aquitard
				High permeability sand	Aquifer
			Sand and gravel beneath 25-Foot Drift	High permeability sand and gravel	Aquifer
Bedrock	Triassic		Mercia Mudstone Group	Low permeability mudstone and siltstone	Aquitard or aquiclude
			Sherwood Sandstone Group	Sandstone with moderate to high permeability	Major aquifer
Information from IGS (1971) and Gaunt (1987, 1994)					

6.3 Hydraulic Conductivity

6.3.1 Definition and Importance

Darcy's Law (Darcy, 1856) is an empirical law describing fluid flow through a porous medium such as soil, sediment or rock. In one dimension it can be written as:

$$Q = -KA\frac{dh}{dl}$$

where Q = discharge or volumetric flow rate [L^3/T], K = hydraulic conductivity [L/T], A = cross-sectional area of flow [L^2], h = hydraulic head [L] and l = distance along the flow path [L]. The hydraulic head is the mechanical energy of the water per unit weight; it is measured in units of length [L] and is equal to the level that water can raise itself above a datum. The quantity dh/dl is the hydraulic gradient. The hydraulic conductivity, K, is the proportionality constant relating the rate of flow to the hydraulic gradient. It is a measure of the ease with which water can flow through the porous medium: the greater the K value, the easier it is for water to flow through the medium.

Table 6-2 lists typical K values for selected sediments and rocks. K is a very variable parameter, so the values are given to the nearest order of magnitude.

Table 6-2 Hydraulic Conductivity of Selected Sediments and Rocks

Material	Typical K [m/s]
Gravel	10^{-3} to 10^{0}
Clean sand	10^{-6} to 10^{-2}
Silty sand	10^{-7} to 10^{-3}
Peat on Thorne Moors	10^{-7} to 10^{-4}
Silt	10^{-9} to 10^{-5}
Clay	10^{-12} to 10^{-6}
Sandstone	10^{-10} to 10^{-6}
Mudstone / shale	10^{-13} to 10^{-9}
Data from Freeze and Cherry (1979) and Bromley *et al*. (2004)	

6.3.2 Hydraulic Conductivity of Peat

The success of peatland protection and restoration schemes depends on a good understanding of groundwater flow in the peat and this, in turn, depends on a good understanding of hydraulic conductivity (K) (Bromley *et al*., 2004). Estimates of K are an essential input to all groundwater flow models. Such models are used to predict the response of groundwater levels and flows to changes in the system resulting from management actions and/or climate change.

6.3.3 Controls on Hydraulic Conductivity in Peat

Peat is a complex organic sediment with unusual geotechnical properties, including a fibrous texture, low density and high compressibility (Evans and Warburton, 2007). Typically it is heterogeneous, with spatially-variable properties that reflect variations in vegetation type, compaction and degree of decomposition.

Generally the porosity and hydraulic conductivity of peat decrease with increasing compaction and decomposition (Egglesmann *et al.,* 1993; Evans and Warburton, 2007). The degree of decomposition can be expressed using the Von Post classification (Von Post and Granlund, 1926). Egglesmann *et al*. (1993) presented in graphical form showing hydraulic conductivity decreasing exponentially with increasing Von Post classification number.

Peat profiles are often divided into two layers: an upper, active, layer called the acrotelm and a lower, relatively inert, layer called the catotelm (Table 6-3). At the top of the acrotelm the hydraulic conductivity is high, but it tends to decrease rapidly with depth. The hydraulic conductivity of the catotelm can be three to five orders of magnitude lower than that of the acrotelm (Evans and Warburton, 2007). This two-layered model applies to undisturbed mires. In areas such as Thorne Moors, where peat has been cut, the acrotelm may be partly, or entirely, absent.

As well as layered heterogeneity related to decomposition, peat may display heterogeneity due to the presence of preferential flow paths such as peat pipes and artificial drains. Another potential cause of heterogeneity is the presence of localised woody material such as tree remains (Bromley *et al*., 2004).

The hydraulic conductivity of peat will generally vary with direction (anisotropy) as well as with position in space (heterogeneity). Typically, the horizontal or lateral hydraulic conductivity is higher than the vertical, reflecting the stratification of the deposits (Evans and Warburton, 2007). Beckwith *et al*. (2003) reported a mean anisotropy ratio (log_{10}[Kh/Kv], where K_h and K_v are the horizontal and vertical hydraulic conductivities) of 0.55 for raised bog samples. In other words, on average, the horizontal hydraulic conductivity was 3.5 times greater than the vertical.

Table 6-3 Properties of the Acrotelm and Catotelm

Property	Acrotelm (upper layer)	Catotelm (lower layer)
Thickness	10-40cm	Usually makes up the bulk of the peat deposit
Saturation	Fluctuating watertable giving both saturated and unsaturated conditions	Permanently saturated
Aerobic/anaerobic status	Fluctuating between aerobic and anaerobic	Anaerobic
Moisture content	Variable	Constant
Hydraulic conductivity	High, decreases rapidly with depth	Low
Water yield	High	Low
Exchange of energy and matter	Fast	Slow
Microbial activity	High numbers and activity (aerobic and anaerobic)	Low numbers and activity (anaerobic)
Based on Ingram (1978) and Bromley *et al*. (2004)		

6.3.4 Scale-dependence of Hydraulic Conductivity in Peat

As peat is heterogeneous, the hydraulic conductivity value measured for a small sample may not be representative of the effective hydraulic conductivity of a large volume of peat. One reason for this is that flow on a large scale may be influenced by macropores such as peat pipes and fractures; these are not present in small samples. Another reason is that a small sample may not reflect larger-scale variations in the texture of the peat matrix. The scale-dependence of hydraulic conductivity means that localised measurements (e.g. on peat samples or using slug tests – see below) may yield values that are inappropriate for modelling groundwater and representing flow on the scale of a peat bog.

A number of workers have found field measurements of peat hydraulic conductivity to be significantly lower than the “effective” hydraulic conductivity required for successful calibration of their groundwater models (see Bromley *et al*., 2004, for discussion).

6.3.5 Measurement of Hydraulic Conductivity in Peat

Peat is a very heterogeneous organic material with locally discrete features such as cracks, peat pipes, collapses, drains, variation in the degree of degradation etc. This means that different methods of measuring hydraulic conductivity in peat can produce variations in their results. Methods of measuring the hydraulic conductivity of peat include:

1. Laboratory measurements on small samples of peat using a permeameter;
2. Slug tests carried out on single boreholes/piezometers;
3. Tests carried out on ditches (double-ditch and single-ditch tests).

Laboratory measurements on small, undisturbed, samples of peat yield K values that may not be representative of the peat body on the scales considered in problems of regional groundwater flow and water level management.

A slug test involves making a rapid change to the water level in a borehole (e.g. by suddenly adding or removing a volume of water) and then monitoring the water level as it recovers. Given information about the construction of the borehole it is possible to estimate K using a standard formula. Slug tests are inexpensive and easy to carry out, but they suffer from the disadvantage that the resulting K value relates to a small volume of peat very close to the borehole. This volume may not be representative of the peat on a larger scale; in fact, its properties may reflect disturbance caused by borehole installation (e.g. Brassington, 2007).

Usually the results of slug tests are analysed using methods that assume a rigid soil. However, the high compressibility of peat means that this assumption may be unreasonable. Holden and Burt (2003) showed that compressible soil theory could give K values five times greater than those derived from rigid soil calculations.

Bromley *et al*. (2004) measured K over large volumes of peat using tests involving ditches on Thorne Moors. They developed a double-ditch test and a single-ditch test. The double-ditch test involved pumping so as to maintain a constant head difference between two parallel ditches that fully penetrate the peat; K was estimated using an equation developed by Barker (1986) for treating groundwater flow between two parallel fractures. The single-ditch test involved measuring the recovery of water levels following discrete pumping events and interpreting the results with the aid of a numerical groundwater model.

6.3.6 Peat Hydraulic Conductivity on Thorne Moors

Newson (1987) reported K values for peat on Thorne Moor of about 2 x 10^{-7} m/s for piezometers 1 to 1.5m deep. Heathwaite (1994) reported values of between 2 x 10^{-5} and 5 x 10^{-6} m/s for shallow peat on Thorne Moor. Bromley *et al*. (2004) measured peat hydraulic conductivity on Thorne Moor using four techniques: laboratory measurements, slug tests on auger holes, single-ditch tests and double-ditch tests. The results (Table 6-4) show that measured K values tend to increase as larger volumes of peat are “sampled” by the test. Measured values range from 1 x 10^{-7} m/s to 8 x 10^{-4} m/s.

It is useful to compare the peat K measurements to literature values for other sediments. The overall range from 10^{-7} to 10^{-4} m/s is equivalent to silt (at the lower end) and clean sand (at the higher end) (Freeze and Cherry, 1979).

Table 6-4 Measurements of Peat Hydraulic Conductivity on Thorne Moors made at Various Scales

Test	K [m/s]	Geometric mean K [m/s]	Comments
Laboratory measurements on peat cores	1.0 x 10^{-6} to 4.2 x 10^{-5}	2.4 x 10^{-6} (27 measurements)	Sample volume c.0.002m^3
Slug tests	1.3 x 10^{-7} to 8.0 x 10^{-6}	1.3 x 10^{-6} (93 tests on 35 auger holes)	Sample volume c.0.4m^3
Double-ditch test	1.1 x 10^{-4}	-	Ditch 15m long. One-third of the flow took place along a root hole
Single-ditch test	1.0 x 10^{-4} to 8.0 x 10^{-4}	-	Largest scale test – ditch 400m long
Data from Bromley *et al*. (2004)			

The results of this work suggests that on a larger scale a large proportion of groundwater movement within the peat mass on the site is likely to be along features such as cracks and pipes.

Work by Van Wirdum (2009) suggest that there, in places, might be a higher permeability layer on the interface between the peat and the underlying substrate caused by preferential flow paths along the lines of preserved tree roots. This would back the observations of Bromley *et al*. (2004)

6.4 Zone of influence of drains

Across large areas of Thorne Moors, notably in the milled area, the area drained by ditches and dykes can be quite small. Standing water in areas of cuttings, such as Unit 9, can be approximately 2 m higher than the water level in a ditch a few metres away (Figure 6-1).

Figure 6-1 Photograph showing the small area effectively drained by ditches

The influence of drain on the watertable is controlled by several factors. These include;

- The size of the drain (width, deep, rate of discharge through it);
- The degree of maintenance;
- The permeability of the material the drain cuts through;
- The difference in level between water level in the drain and in the surrounding peat (i.e. the hydraulic gradient).

The variability in the parameters of the drains on site means that there are some locations where drains are effective at lowering the watertable in the peat mass. An example of this is the boundary drain at Flower Garden (South Crowle) where the drain has lowered the watertable sufficiently for woodland to establish in this area. Most of this has now been cleared by the Lincolnshire Wildlife Trust, however, there is still extensive woodland around the edge of the site (Figure 6-2 and Figure 6-3).

Figure 6-2 Woodland Edge of Flower Garden (Natural England 2009)

Figure 6-3 Flower Garden Boundary Drain (NGR 475412, 413762 looking west)

6.5 Groundwater Levels and Fluctuations

Active growing *Sphagnum* maintains a high watertable through forming peat with a high specific yield[1] which reduces the fluctuations in the watertable. The peat also decreases in hydraulic conductivity with depth as it becomes more degraded, therefore as the watertable drops, it becomes harder to draw out the water for evapotranspiration. This system acts to conserve water by 'shutting off' evapotranspiration when the water levels drop and so maintains groundwater close to the surface with muted fluctuations. On degraded bogs this system is destroyed though drainage and the removal of the top layer of high specific yield peat.

On cut peat more of the degraded lower peat is exposed on the surface. Table 6-5 shows that a greater amount of degraded peat results in a lower specific yield overall which means that any fluctuations in the watertable are likely to be greater. Trying to maintain a permanently high watertable on degraded peat, therefore, poses greater problems for water level management.

Table 6-5: The relationship between specific yield and *Sphagnum* peat humification (after Schouwenaars 1993 in Price, Heathwaite and Baird 2003)

Peat Type	Degree of humification on Von Post scale	Depth (cm)	Specific yield
Young living *Sphagnum*	-	0-15	0.23-0.34
Slightly humified *Sphagnum* peat	H2-3	10-30	0.11-0.17
Moderately humified *Sphagnum* peat	H3-4	0-40	0.11-0.13
Strongly humified *Sphagnum* peat	H6-7	0-35	0.14-0.33 (sample with many living roots) 0.05-0.10 (sample without roots)

6.6 Groundwater Quality

On pristine raised mires the rate of organic degradation is low and, therefore, the dissolved and Particulate Organic Carbon (DOC and POC) content of the groundwater within and discharging from the peat unit is relatively low. On the site, the colour of the water in the ditches is dark, indicative of high DOC concentrations. The nutrient content of the water is likely to be low as the topography isolates the site from the surrounding area, so the site is predominately rainfall fed. There are a few locations where the nutrient content of the groundwater is likely to be higher, these are:

- Inkle Moor: the area is a groundwater basin and receives groundwater and surface run-off from the surrounding area;
- Areas of thin or completely removed peat, for example some of Will Pitts, the strips on Crowle Moors and at Elmhurst Cottage;
- Areas of warping, such as at Durham's Warping Drain.

[1] Specific yield (Sy) is a measure of the amount of water an aquifer will release when the watertable goes down. When the Sy is high for an aquifer, it will require more water to be released for the same given drop in groundwater level as will an aquifer with a lower Sy. Sy differs from porosity because not all water held in pores is released from the aquifer when the water level drops, as capillary forces act to hold onto the water molecules. The strength of the capillary forces is a function of the shape and size of the pores – large round pores have the ability to exert less capillary forces on water than small cylindrical ones. This means that an aquifer may have a large degree of porosity but a lower Sy than another aquifer with a smaller degree of porosity

In the early 1990s groundwater was pumped onto Thorne as part of initial restoration works. This water was likely to have a different composition to the water on site. This active has now ceased though the lasting impacts of this on on-site water quality are not known, but likely to be small.

6.7 Hydrogeological Conceptual Model of Thorne Moors

6.7.1 Introduction

Thorne and Crowle Moor SSSI covers a large area. Within these areas are sub-regions which have very different water mechanisms and hydraulic controls. In order to conceptualise the site, it has been necessary to divide it into a number of these sub-regions. There are, however, some over-arching principles which apply across the site, these are:

- The site is rainfall fed and receives no water from the surrounding area;
- The 25 Foot Drift means that there is only a limited amount of vertical seepage loss of water from the site;
- The thinner and more degraded the peat, the greater the fluctuations in the watertable;
- In general scrub invasion leads to greater evapotranspiration losses;
- Peat cutting works have changed the topography, drainage pattern and nature of the peat dramatically;
- The older the age of the peat cuttings, the wetter the area.

6.8 Hydraulic Boundary Conditions

This section outlines important hydraulic boundaries within the system.

6.8.1 Types of Hydraulic Boundaries

There are many types of hydraulic boundaries that can occur within a hydrogeological system. Outlined below are some of the boundary types which are most important to the conceptual understanding of the site (Bear 1979). The technical names for these boundary types are given below with a simplified explanation and examples of where they might be found.

Boundary of prescribed potential (i.e. constant head boundary or Drichlet boundary) – an hydraulic boundary between an aquifer and a body of open water. An example of a constant head boundary would be where a ditch cuts into and drains the peat (assuming the level in the ditch does not fluctuate). A groundwatershed can also be described as a constant head boundary.

Boundary of prescribed flux – a boundary where the flux is normal to the boundary surface and prescribed for all points. No-flow boundaries, such as that between the peat and the underlying 25 foot drift, are a type of boundary of prescribed flux.

The Unsteady Free (or Phreatic Surface) with Accretion - on Thorne Moors this boundary is the unconfined watertable within the peat which received recharge through infiltration of rainfall.

Seepage Faces

A line along a slope from which groundwater emerges, where the watertable intersects with the surface.

Abrupt Changes in Permeability – on site this is most notable in the impact of the tracks on the overall permeability of the peat body.

6.8.2 Vertical boundaries

Watertable

The peat on site is unconfined and the watertable forms the upper hydraulic boundary which receives input though rainfall recharge. Within topographic depressions, the watertable can lie above the ground surface with areas of open water. The watertable in general is a muted response to surface topography.

The depth to the watertable varies over the site. The areas where the watertable is deepest are often where there are rapid changes in topography or effective drainage.

Lacustrine Silt/Clay Aquitard

The lacustrine clay (Table 4-1) is expected to act as an effective aquitard isolating the peat above from units beneath. This barrier means that water in units beneath the lacustrine clay is likely to have insignificant interaction with the water within the peat on Thorne Moors and, therefore, these units are of limited importance in the conceptual model.

Bromley *et al.* (1997 in Birdsall 2000) installed a multiple borehole nest into the peat, clays and sandstone strata. This work estimated that the rate of leakage (i.e. recharge) to the Sherwood Sandstone aquifer beneath was 2.5 – 4 mm per year, which equates to 1% of annual rainfall.

Work by Van Wirdum (2009) concluded that there was likely to be limited interaction with the underlying aquifer, though the result of his work showed that upwelling and downwelling might be occurring at a local level.

This means the wetlands mechanism within Thorne and Crowle Moors are almost exclusively rainwater fed and regional groundwater movements have little impact on water levels on site. The only possible exception to this is Inkle Moor, as it was never part of the ombrotrophic peat mass (see Section 2.5). Due to the size of the site, it is impossible to rule out the possibility that there are some locations where vertical losses have a significant impact. However, the general principle, that across most of the site this is negligible, is still a useful one, until further site observations and conceptualisation occurs, which could inform better water level management.

Wind Blown Sands

In the Crowle Moor area, sands (likely aeolian (wind blown) sands) have been observed as the first layer of the underlying substrate. On some areas of Goole Moors the peat unit has been entirely removed leaving small exposures of this sand. In areas underlain by sand, the rate of vertical leakage has the potential to be higher if these are drained (either through pumping, cutting drainage ditches or altering the topography).

6.8.3 Internal Boundaries

Groundwatersheds

The groundwatersheds (i.e. the boundary between groundwater catchments) are likely to follow the surface water catchments described in Section 5.1 as the unconfined groundwater in the peat unit will follow a muted response to topography.

Discharge boundaries

Groundwater will discharge to any drain which cuts though the watertable and maintains a water level beneath the groundwater level. Blocking drains raises the watertable within the drain, reducing the hydraulic gradient from the surrounding land to the drains, reducing the discharge to the drains and raising the watertable within the surrounding ground.

Tracks

Tracks that run through the peat can create abrupt changes in permeability. Floated roads laid down upon peat have in some instances decreased the permeability of the ground in that area reducing lateral groundwater movement. The substantial limestone roads on the milled area of Thorne and Goole Moors will also create changes in permeability – it is currently not known whether the roads are of a higher or lower permeability than the surrounding peat.

Swinefleet Warping Drain

The Swinefleet Warping Drain is a high level water carrier which divides Thorne from Crowle Moors. It is lined with low permeability clay and forms a no-flow boundary between the water within the peat on the moors and the water carrier within the warping drain. There is likely to be some limited seepage through the drain. It is likely that the peat beneath the warping drain was entirely removed and the drain keyed into the underlying deposits to aid with its construction.

6.8.4 External Boundaries

In terms of water levels on the edge of the SSSI and the discharge of groundwater off site it is important to understand the nature of the external boundaries of the site and to what extent the peat is drained by them. This section combines knowledge gained through site walk overs, OS mapping, LIDAR and informed judgement to attempt to describe these external boundaries. Figure 6-4 shows the sections of the boundaries used in the descriptions in this section.

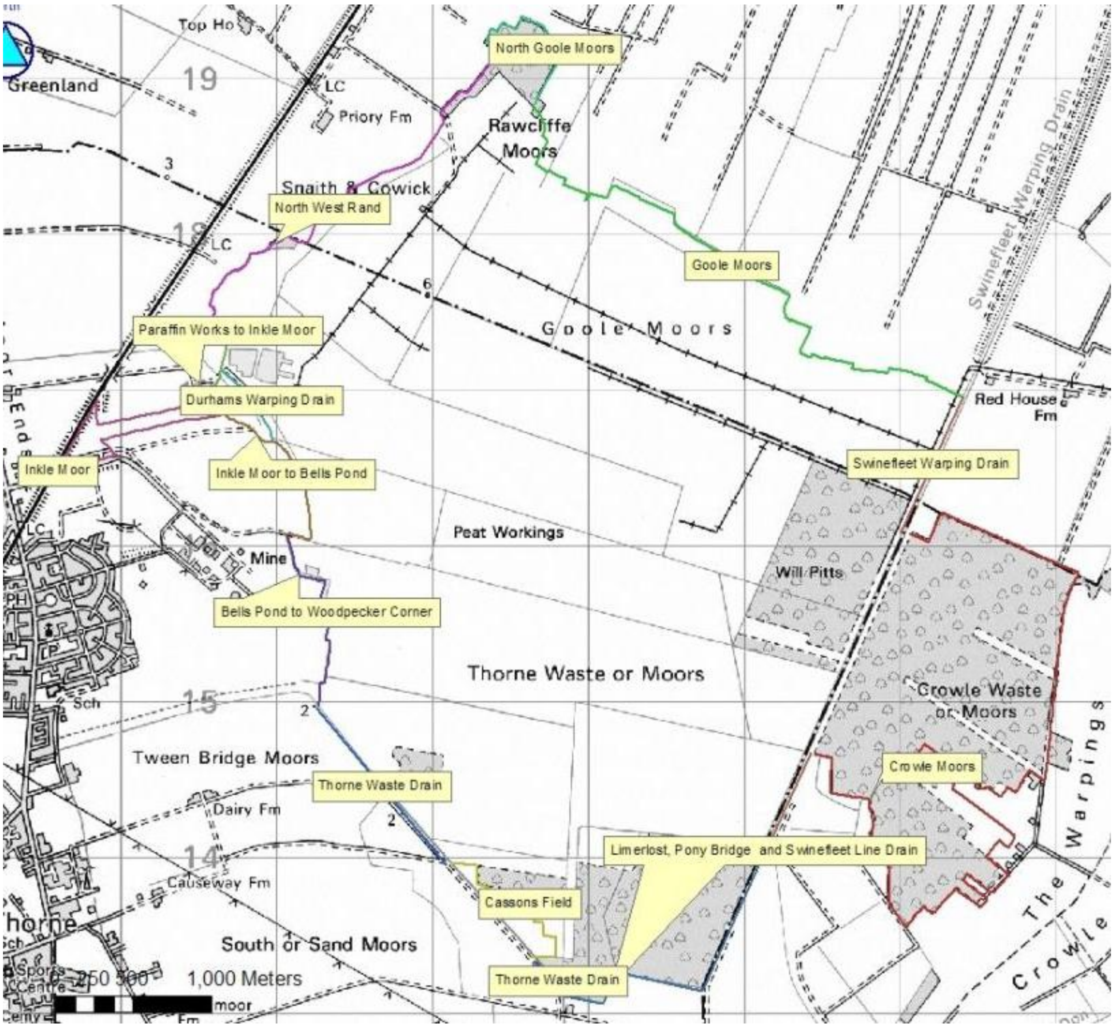

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Figure 6-4 External Boundary Sections

Thorne Waste Drain

Thorne Waste Drain is a major drain which forms the south western boundary of Thorne Moors. It is a deep drain which cuts into the 25 foot drift. The agricultural land to the west of it (and some areas to the east), was reclaimed though removing the peat, not through warping. These means that the drain rarely cuts through peat and, where it does, this peat is thin. This means that the drain has limited influence on the peat along it.

Cassons Field Minor Drain

Cassons Field is an agricultural strip of land to the east of Thorne Waste Drain. Around its eastern boundary with Thorne Moors lies a small drain (approximately 1 m deep). On the far side of this is a peat cliff approximately 1 to 3 m tall. The peat within this cliff is drained by the minor drain and because of its relief it is difficult for the watertable to mirror the topography (see section 6.9.2).

Limberlost, Pony Bridge Wood and Swinefleet

Along this boundary are minor drains. The SSSI lies lower than a dyke that has been built on the internal side of the site, possibly to stop surface run-off from discharging from the site. The land rises up from the SSSI to the external agricultural land along most of this boundary section. This means that the minor drains along the section act as a discharge boundary but will not drain much of the bog as the little of the bog lies higher than the drain in this location (see Figure 6-5). The agricultural land in this area consists of cut peat covered with a thin layer of warping. The topography of the peat cutting is still evident from aerial photography and the LIDAR data.

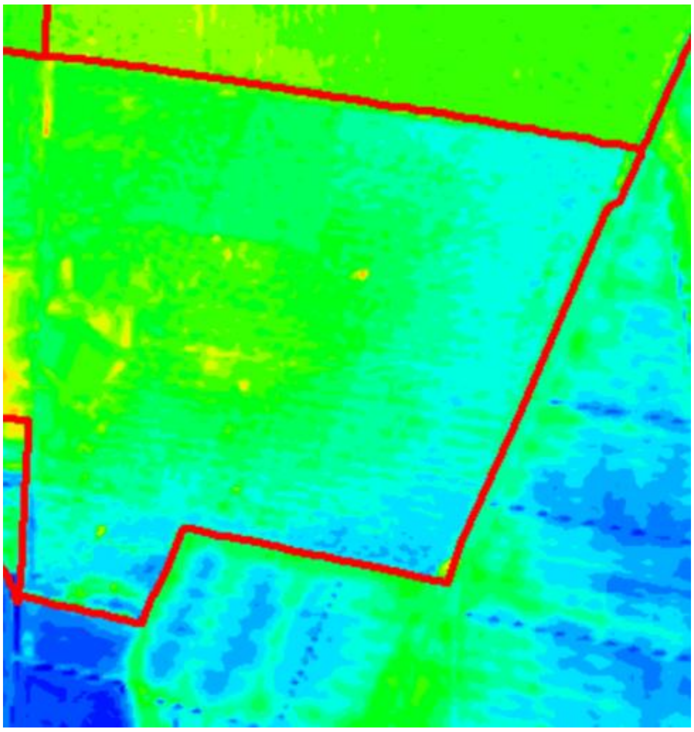

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Figure 6-5 A detail of the LIDAR topography map showing the depression of the southern boundary of Thorne Moors

Swinefleet Warping Drain, North of Pony Bridge Tram

As well as acting as an internal boundary, Swinefleet Warping Drain acts as an external boundary along some of its length and, in effect, the Swinefleet Warping Drain acts as a no-flow boundary.

Durham's Warping Drain

Between Inkle Moor and the Paraffin Works' cuttings, the land either side of Durham's Warping Drain has been warped and converted into grazed neutral grassland. This area of warp acts as a hydraulic boundary, isolating the small area of raised bog to the west (Management Unit 31) from the rest of the raised mire.

Goole Moors Boundary

From the Swinefleet Warping Drain to Rawcliffe Moors, along the northern boundary of Goole Moors, the majority of the drains run at right angles to the moor. Of the few drains that do run parallel to the site boundary most tend not to butt up right against the boundary, but lie slightly into the agricultural field network. This means that the drains in this area have limited effect on the water level within the peat mass.

Northern Goole Moors

Northern Goole Moors has minor ditches along the edge of the entire peat mass. These minor ditches cut into the peat mass and drain it and, therefore, are likely to lower the watertable on the site significantly. As the agricultural land in this area was produced via warping, it is likely that the minor drains cut through the peat, and drain it.

Snaith and Cowick Moor (NW Rand)

Along much of this section there is a minor drain on the edge of the moor. Towards the south there is a depression between the mire and the agricultural land, possibly denoting an area which is neither a raised mire nor agricultural land that has been warped.

Paraffin Works to Inkle Moor

The boundary in this area is complicated by the warping around Durham's Warping Drain. The site boundary ditch in this location is relatively minor and does not feed into the Warping Drain.

Inkle Moor

On the Northern boundary of the moor there is a bund which separates Inkle Moor from the farmland to the North. There is a shallow parallel ditch which, at the eastern end, bends and forms a boundary between Inkle and Thorne Moors. On the south side a minor ditch runs the length of the site. The old colliery railway and the main railway line embankments have created a topographical low in the arrow head formed by the old railway junction embankments. The low lying area has no direct outflow and water ponds here (NGR 469803, 416807).

Inkle Moor to Bell's Pond.

There is a relatively large drain which runs along the edge of the site in this area. This drain is located on the peat mass and drains southwards. At its southern edge is a steel pile dam weir (NGR 471312, 415408) which has raised the watertable in this area, however, the weir height is beneath the top of the drain.

Bell's Pond to Woodpecker Corner

The drains along this reach get progressively larger until they enter Thorne Waste Drain at Woodpecker Corner (NGR 471270, 414959). Along this section the peat within the site is at a similar height to the external land (mainly part of the old colliery).

Boundaries around Crowle

The boundaries around Crowle Moors are more complicated due to the ownership of the land being in strips. The southern boundary from the Swinefleet Warping Drain to Flowers Corner is formed by a series of minor drains. At points along this stretch the peat is higher than the surrounding agricultural land. Along the eastern edge of Crowle Moors are a series of minor drains which are too complex to describe here.

Along the northern edge is a small field drain, this lies on-site within the peat mass. This is the only drain on-site where running water was observed (Pers. Obs. December 2009). The agricultural land to the north is higher than the bog along most of this boundary.

6.9 Conceptual Models of Sub-Regions

Across the site there are distinct wetland areas which act together as a whole to form the site, but are subject to different hydraulic mechanisms. This section aims to provide a simple conceptualisation of these sub-regions. The areas referred to in this section are shown in Figure 6-6 and are:

- The milled area;
- South Thorne;
- Inkle Moor;
- Durham's Warping Drain and the Paraffin Works;
- North West Rand;
- Northern Goole Moors;
- Will Pitts Woodland;
- North, West and South Crowle Moors;
- Ribbon Row.

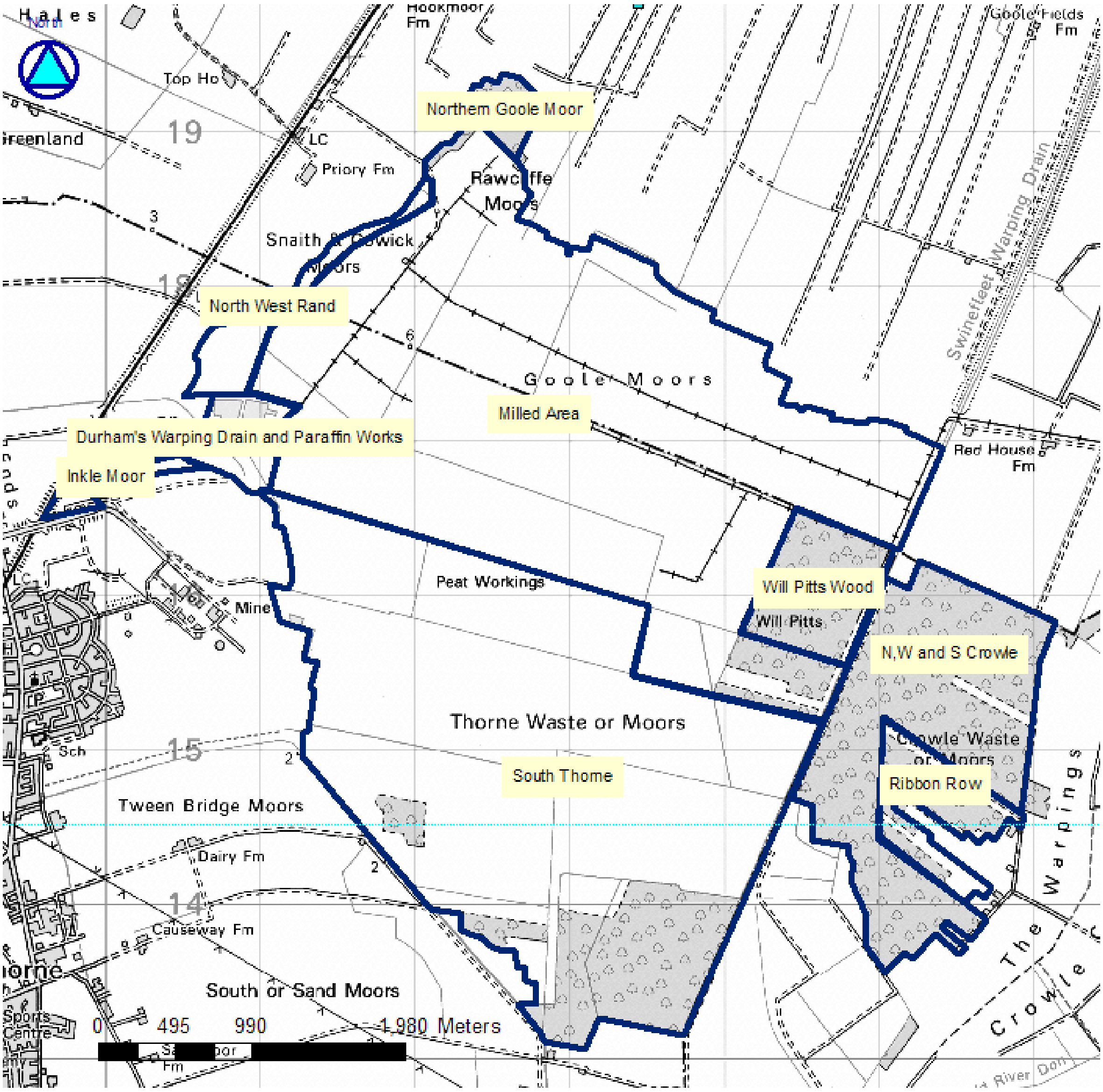

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Figure 6-6 Hydrogeological Conceptualisation Sub-Regions

6.9.1 The milled area

This area has been subject to 'milling' extraction leaving large flat areas with large drains spaced approximately 200-400 m apart. The peat in this area is relatively thin and some small areas are now completely devoid of peat. The degree of degradation of the peat ranges over the area but, in general, is quite high, with the upper layer of peat being the most degraded. Therefore, the peat no-longer has the ability to maintain high watertables with little fluctuation through-out the year. The upper peat is most degraded because this layer was dried out when it was drained for extraction, and has also been subject to the most disturbance during the milling operations.

Due to the degree of extraction of peat in the milled area, the sub-region forms a depression which is lower than the ground surrounding it. To the north and west lie rands on the boundary of the site which lie higher than the milled area. There are two notable breaks in this rand at NGR 437174, 418341 and between NGR 4744380, 417185 and 474807, 417108 (Points 5, 6 and 8 in Figure 5-8). The break in the rand at NGR 437174, 418341 is a drain which runs from the surrounding agricultural land into the milled area. It has been blocked by a corrugated plastic bund. Though, the agricultural land lies higher than the milled area, in winter water on site is higher than in the drain on the agricultural land so water discharges from this location. In summer, when water levels are lower, it is likely that flows would reverse if the bund was not present. The break between NGR 4744380, 417185 and 474807, 417108 represents an area where the rand is thin or absent and a number of drains allow water to discharge off site. The southern boundary of the area is the higher hand cut peat which forms South Thorne. Ditch blocking in this area has reduced the amount of run-off the milled area receives from this section. The Swinefleet Warping Drain bounds the milled area to the east: this is a high level carrier drain constructed from low permeability clay, which hydraulically isolates it from the milled area (Figure 6-7).

Much of the milled area has been subject to the installation of a series of bunds as part of restoration works (Figure 6-7) (English Nature 2005). These bunds lie on the milled peat surface and act to impound surface water within cells (see Figure 6-7). The water level within the bunded cells can be adjusted and controlled by pipes with adjustable angle outflows. In the winter, the cells are allowed to fill so that, on average, the depth of water within them is 30 cm above the peat surface. The aim is that this will stop the water level from falling beneath 20 cmbgl at the height of summer. The height of the water in the bunded cells is controlled by adjusting the height of the pipes which cross the bunds. The water from these cells discharges through adjacent cells and eventually to the large drainages which have remained unblocked in the area.

Figure 6-7 Bund Structure on a Milled Field (NGR 472049, 417797 looking West)

The drains in the milled area are large, linear features which often cut through the peat and into the underlying deposits. As the milled area is a depression, these ditches have remained unblocked to ensure that the area does not form a lake (Bull pers. comm.). Observations of water levels in the drains and on the adjacent land suggest that these drains only lower the watertable in a limited area surrounding the drains (see Section 6.4). This observation is backed up by the fact that surface water is often present within c.5 m of a drain with a substantially lower water level within it. This is due to the relatively low permeability of the peat and the low rate at which water can discharge from the drains, therefore, the water level in the drain remains higher, leading to a greater hydraulic gradient between the drain the surrounding ground.

The bunded cell system, the deep linear drains and the low hydraulic conductivity of the peat has formed small isolated cells of peat. The wider area exerts little control over the water level within these isolated cells. The main controls on the water levels in each cell are:

- The level of the bund outflow (if the area is bunded);
- The topography of the surface within a cell:
  - Are there depressions which collect the water?
  - Does the topography allow run-off to the surrounding drains?
  - What is the range of ground surface elevation within a bunded cell?
- Evaporation – controlled to some extent by the albedo – black peat has a higher albedo than vegetation;
- Transpiration - the type and extent of vegetation cover;
- The properties of the peat - cells with thicker, less degraded peat control fluctuations in the watertable better;
- Rainfall – the amount and intensity (this is likely to be fairly constant across the site).

The water levels within the drains have a limited effect on the water levels in the cells. The water levels in the drains are maintained at a lower level to ensure there is the capacity to receive water draining from the bunded cells.

The exception to this general conceptualisation of the milled area are the strips of woodland which are drier (Units 1 (eastern part), 2 and 3). These are drier than the surrounding milled areas. Only Unit 1 (eastern part) is noticeable higher on the LIDAR (Figure 3-1) than its surroundings, however, the woodland in Units 2 and 3 are not. It is likely that the reason these areas are drier is the result of greater evapotranspiration.

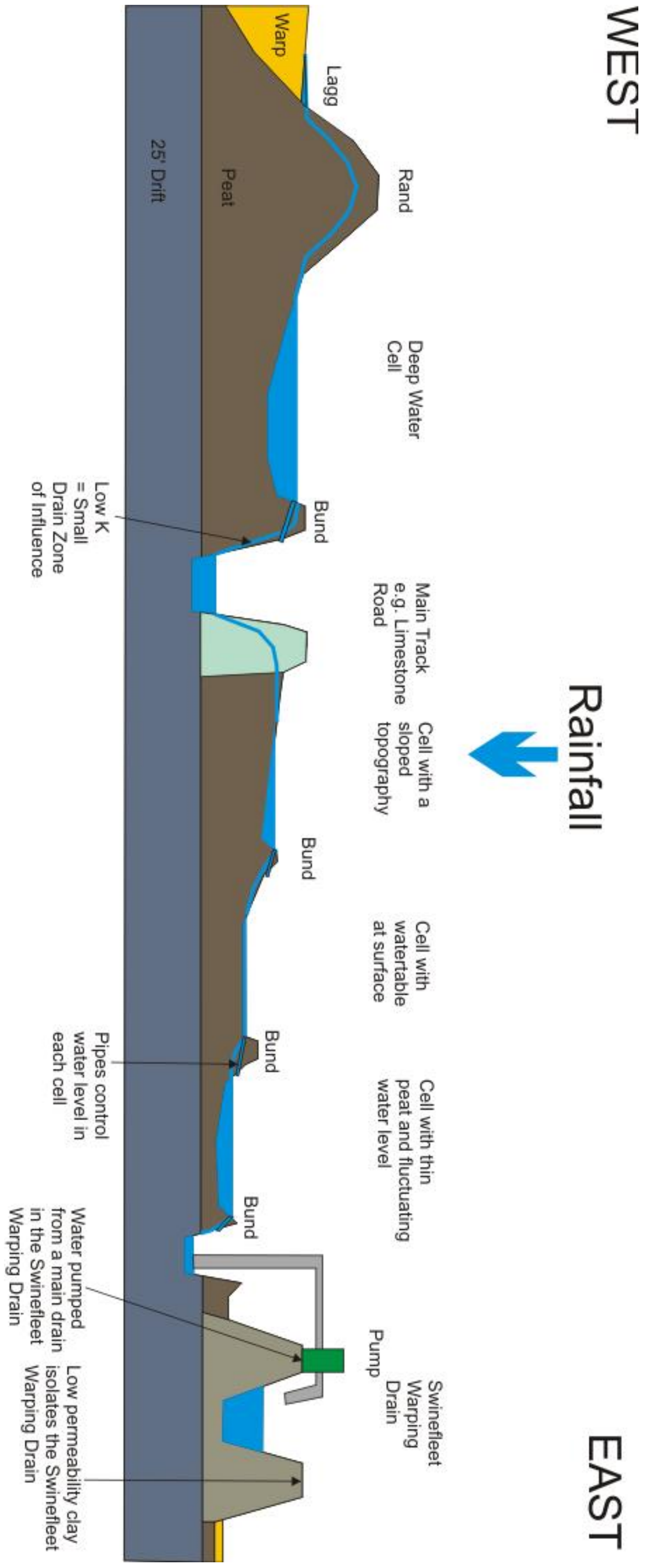


Figure 6-8 Conceptual Model of the milled area

6.9.2 South Thorne

The topography of the south of Thorne Moors is a consequence of the peat cutting works over this area. The topography takes four forms:

- The canals topography: series of slightly raised mounds surrounded on three sides by a shallow wet canal formed through the Dutch Hand Graving extraction technique;
- English Hand Graving ridge and furrow cut pattern (as seen on the north of Crowle Moors);
- Mechanical Baulk Cutting – which produces a similar but more pronounced topography than the English Hand Graving;
- Areas of uncut peat (e.g. Unit 16);
- *Ad hoc* edge cutting.

These areas are divided from each other by a series of floated roads made from logs, peat and imported clay that act as boundaries, isolating areas of peat cutting from each other (Figure 6-10). These roads can act as an effective boundary to lateral groundwater movement. For example, within the Canals, north of the track along Colli's Tram, the watertable is at or near the ground surface However, the land to the south is up to a metre lower than in the north and the watertable appears to lie a significant depth below the surface given the density of tree growth in this area (see Figure 6-9).

Figure 6-9: Colli's Tram looking eastwards (NGR 471607, 414900)

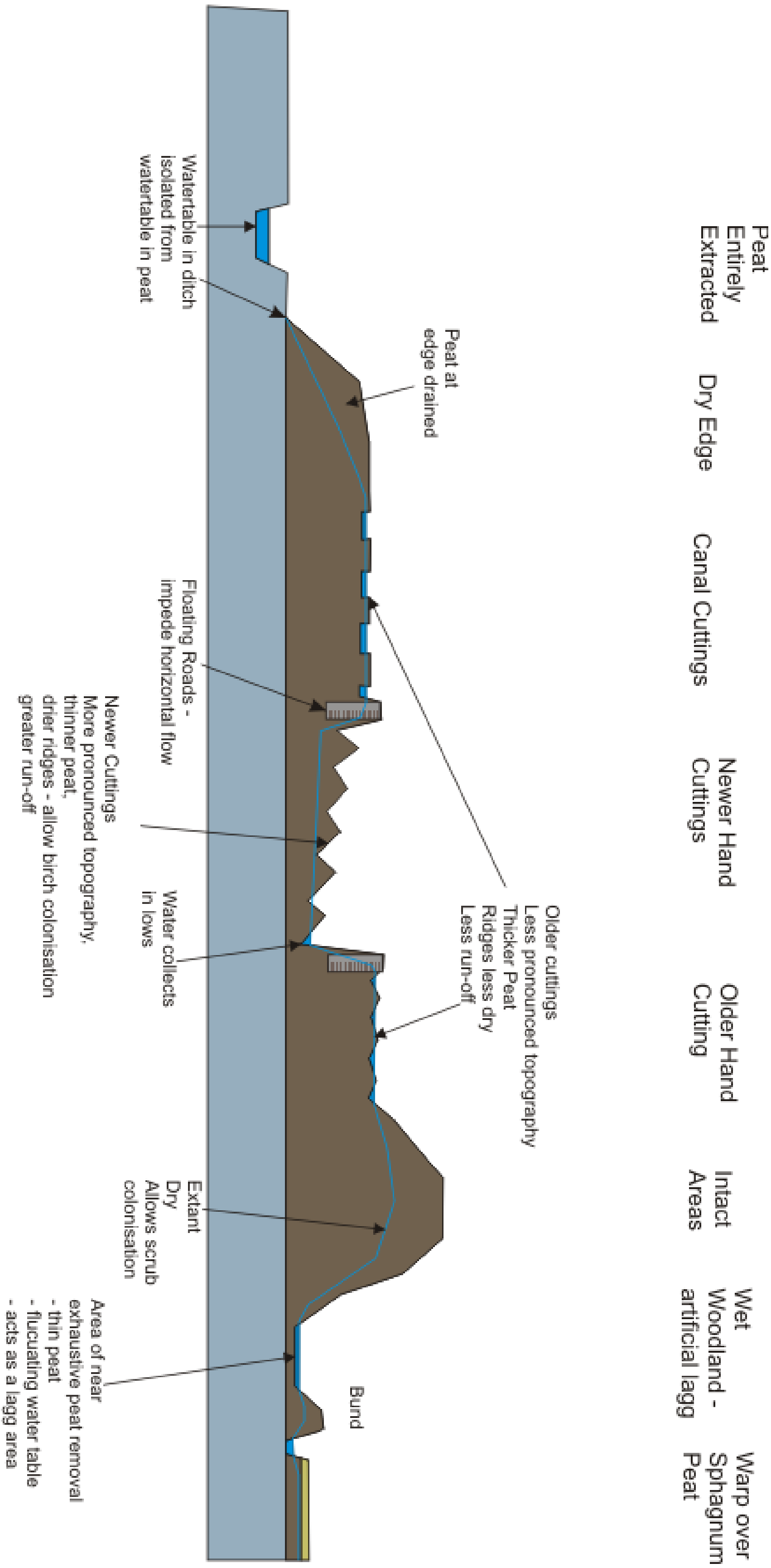


Figure 6-10 Conceptual Model of South Thorne (Note – the line of cross section is normally east-west but is not strictly adhered to)

There are several factors which appear to control the degree of wetness in different parts of the South Thorne Sub-region (Figure 6-10). Due to the nature of the topography, the same factor can lead to an area being too dry in one area or too wet in another:

- Topography
  - Micro-topography – in areas of more recent cuttings, the ridges between tend to be drier. The topography is too varied on a small scale to allow the watertable to follow it, so the ridges remain dry and the furrows act as effective drains.
  - Macro–topography (hills and depressions) – some large depressions can be wetter (e.g. NGR 472780, 413950) and some higher areas can be drier (e.g. NGR 472780, 413950).
- Run-off – the ArcGIS catchment analysis (Figure 5-1) (Section 5.1) highlights closed depressions in which water will collect. These correlate well with existing areas of standing water.
- Peat thickness – this is related to the topography. Low lying areas tend to have thinner peat. This means that the peat in these areas tends to be more degraded (as older peat is exposed) and so groundwater levels are more prone to fluctuations and the peat is more prone to drying out.
- Degree of degradation – this is often related to peat thickness which affects the storativity and hydraulic conductivity of the peat. It can also be related to the degree of drainage an area has suffered from. Areas of baulk cutting can and were more effectively drained than the Dutch hand graving areas; therefore, the peat has suffered from a greater degree of degradation.
- Vegetation – birch scrubland occupies the drier areas, poor fen the wetter areas. Wet woodland covers the areas of thinnest/absent peat, with grassland covering the highest areas of uncut peat, sometimes giving way to rhododendron or bracken. Birch scrubland establishes itself on drier areas where it forms a feedback loop, increasing evapotranspiration, making it drier and thus more suitable to birch colonisation.
- Floating Roads - these can limit lateral groundwater movement. This, in some cases, allows areas with a higher elevation to keep their water and deny a supply of this water to the lower areas (see Section 6.4)

There are two key control structures in the South Thorne Sub-Region which maintain high water levels within important main drains. These are:

- The Angle Drain Weir (NGR 474405, 414669);
- New Mill Drain (Blue Bridge) Weir (NGR 473515, 415639).

The Angle Drain Weir maintains a high water level within the drain and maintains high water levels within Pony Bridge Marsh and Will Pitts Scrape. The New Mill Drain Weir maintains a high water level in the New Mill Drain. The New Mill Drain forms the boundary between the milled area to the north and the Canal Area to the south. Without the weir, a large area of the Canals would be drained by the New Mill Drain. In addition to these formal structures there is an earth bund on the Southern Boundary Drain, where it joins the Western Boundary Drain. This bund maintains a high water level in the drain, reducing the rate of drainage from the canals area. This bund regularly overtops, allowing water to spread across the boundary track, into the Western Boundary Drain.

Even though South Thorne Moors has been placed in one hydrogeological Sub-Region for the purposes of this report, there are areas within it which require individual comment.

Pony Bridge and Limberlost Wood

This area forms the eastern and south eastern boundary of South of Thorne Moors. This area has been subjected to *ad hoc* edge peat cutting in the past so the peat is thin or completely absent and there is no regular ridge and furrow pattern.

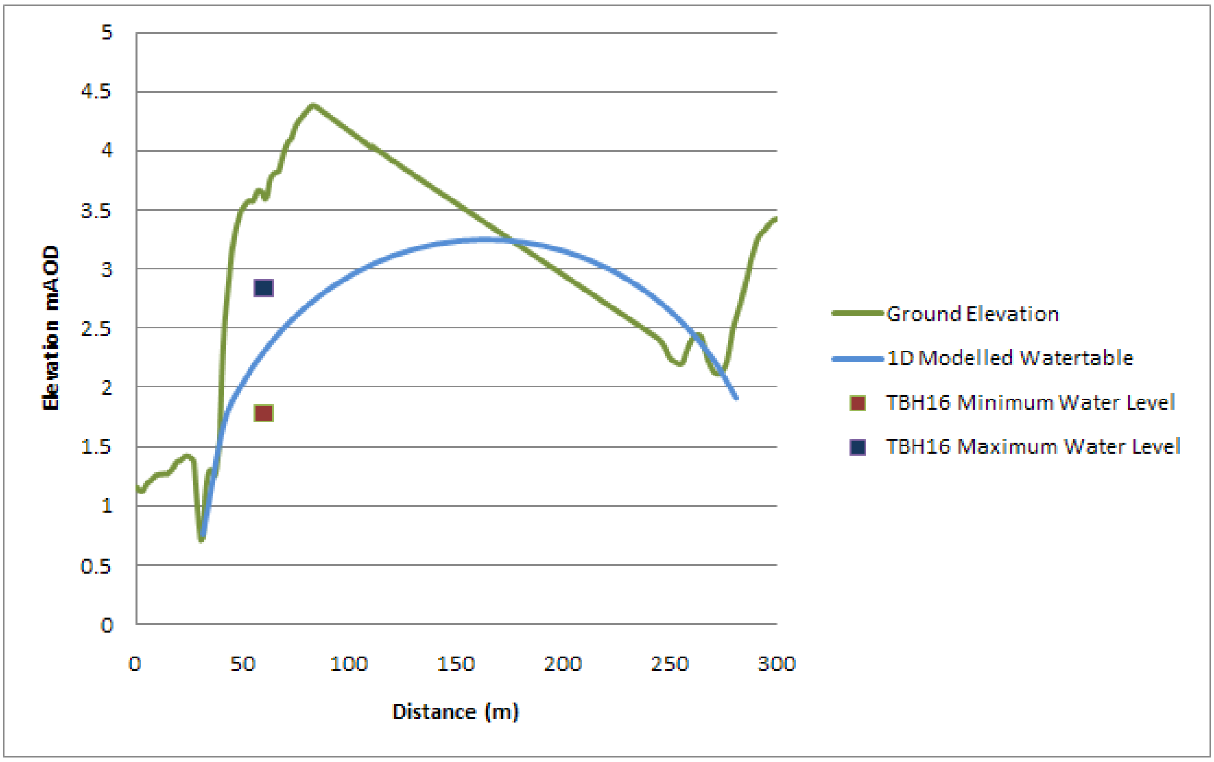
The area forms a depression with higher peat to the west and a road/bund on the eastern boundary separating the peat from the warped arable fields. The area is covered by wet woodland and the watertable is prone to fluctuations.

The area approximates an area of lagg fen with its location, thin peat, topography and mineral input. The latter could be from the surrounding agricultural land, underlying drift or limited, unsuccessful warping attempts (Eversham 1991).

Uncut area of Unit 18

On the south western boundary lies an area of intact peat, where no peat cutting has occurred. A tall 2-3 m cliff of peat with a small drain at the base forms the boundary of this intact area (Figure 6-13). The combination of the boundary ditches and the narrow width of the high ground means that the watertable is unable to match the ground surface and so the watertable can be a significant depth below ground level (Figure 6-11 and Figure 6-12).

On the high ground of this area, thick rhododendron vegetation has colonised. This vegetation is expected to increase the rate of evapotranspiration and interception in the area, exacerbating the suppression of the watertable.



Note- the cross section is from LIDAR information which has poorly removed the thick rhododendron vegetation in the middle section.

Figure 6-11: Cross Section across Unit 18, 1D groundwater model and the range of water levels in TBH16

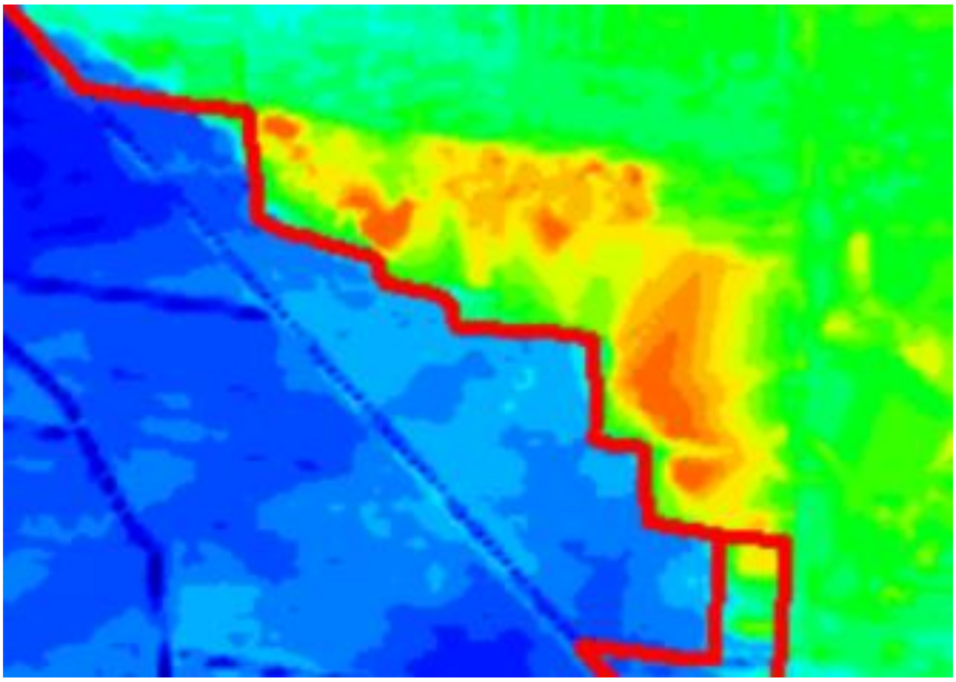


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Figure 6-12 Detail of LIDAR Topography map showing Unit 18

Figure 6-13 Photograph of the edge of the peat mass at Cassons Garden

Western Unit 16 (near Elmhurst Pumping Station)

Along the boundary of Unit 16, it appears that the peat has been removed in certain areas (Figure 6-14). This could represent areas of abandoned land that was improved for agriculture and may once have represented an extension of Cassons Field.

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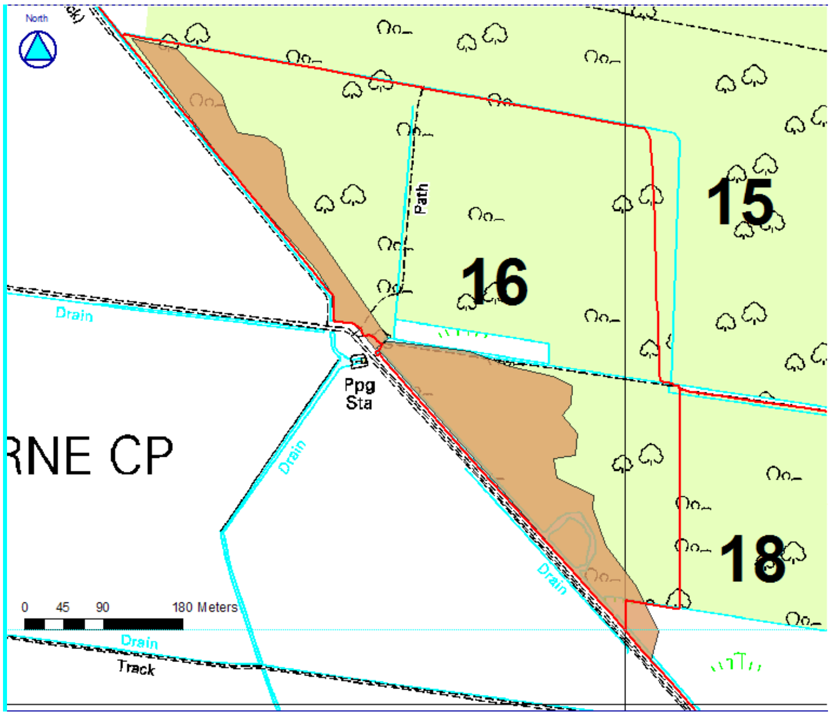

Figure 6-14 Map of the Extent of Mineral Soils Over Unit 16

The extent of mineral soils in Figure 6-14 is the result of combining information about augering in the area, with LIDAR and aerial photograph data to create a map of the extent of mineral soils in the this part of the SSSI.

6.9.3 Inkle Moor

Inkle Moor represents an area which has undergone strip reclamation from the edge of the raised mire. A summary from historic maps on the development of Inkle Moor is laid out in Section 2.5. This is the key to understanding Inkle Moor.

Within the arrow head of Inkle Moor, there are four rank grassland fields which are likely to be underlain by warping and then the 25 Foot Drift. At the western end of the arrow shaft, strip reclamation has removed most of the peat but, at the eastern end, some peat remains and here a lagg type habitat has formed.

The area is contained within a topographic depression. The low permeability of the 25 Foot Drift suggests that groundwater input into Inkle Moor is likely to be small. The wetland is maintained by run-off from fields to the south (there is a ridge on the northern boundary which stops run-off) collecting in the depression (Figure 6-15).

Ditches run along the length of the strip (a consequence of the strip reclamation) and these divide the rand from Inkle Moor.

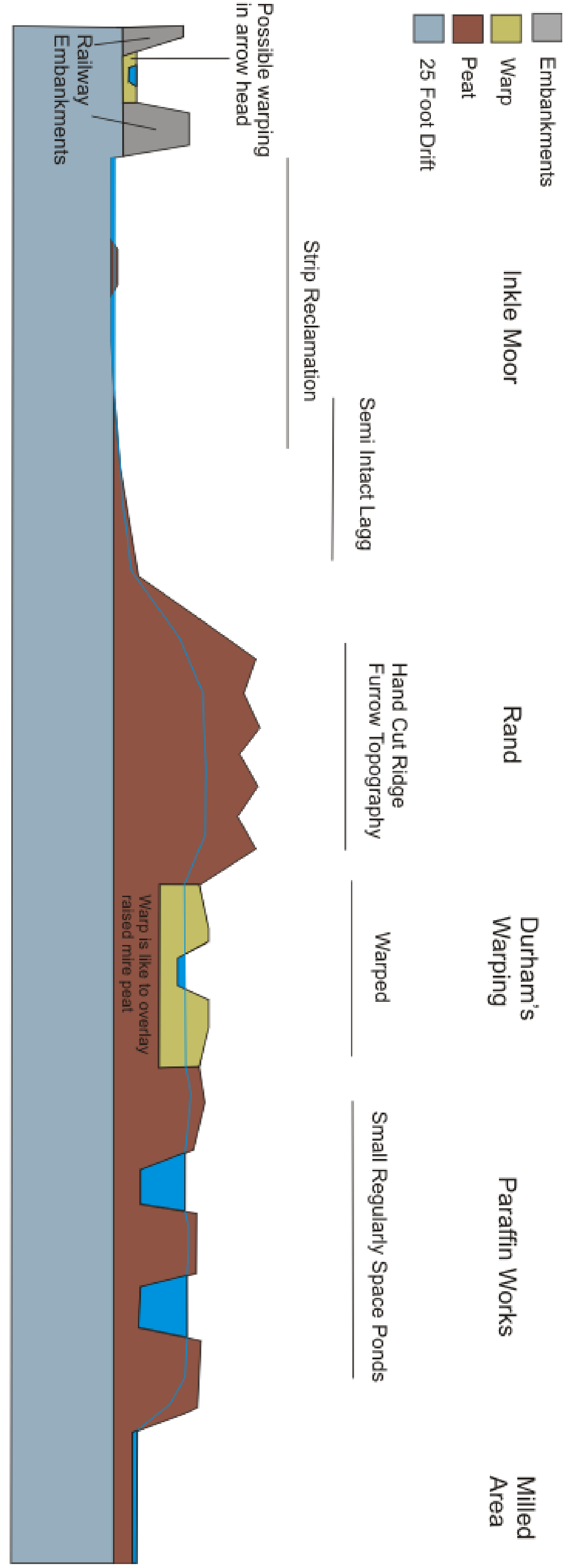

Figure 6-15 Inkle Moor, Durham's Warping Drain and Paraffin Works (NTS)

6.9.4 Durham's Warping Drain and the Paraffin Works

Durham's Warping Drain and the Paraffin Works lie on the western boundary of the site. Within this small area there is a great deal of variation in geology, topography and vegetation (Figure 6-15). It can be split into three main sections;

1. The rand area – a small isolated area of peat. This has been subject to hand cutting and is covered by deep, regular drains which have lowered the watertable. A lowered watertable has allowed bracken and birch scrubland to dominate this area;
2. Durham's Warping Drain – An area approximately 20 metres in width either side of the line of Durham's Warping Drain has been warped, and a clay deposit now lies over the peat. The area is covered in grassland which is grazed by a herd of Hebridean sheep;
3. The Paraffin Works - this area is dominated by small, isolated regular pools. This area is unique on Thorne Moors due to its topography. Around the edge of the pools the vegetation is dominated by cotton-grass. The area is dangerous to access so information on the nature of the peat in this area is not well known.

6.9.5 North West Rand

This area forms a raised margin between the agricultural land to the west and the lower 'milled' interior of the mire. The topography suggests that the area has been subjected to some hand cutting, leaving a series of shallow drains running east-west spaced approximately 22 m apart (a chain).

The area is covered with scrub vegetation (mainly heather), with alder and birch (*Betula pubescens* and *B. pendula*) woodland along the western margin. Within the ditches on the edges of the area (*i.e.* not on top), the ground is wet and vegetation is dominated by cotton-grasses (*Eriophorum vaginatum* and *E. angustifolium*). The ditches become drier towards the interior, as the natural topography removes water from the area.

On the inner edge of the rand, near the paraffin Works, there is a steep slope of peat (c.1.5m tall) which borders the 'milled' interior. There is a ditch running along the top of this within the rand which is full of water. The rate of groundwater movement through the peat to the lower milled surface is insufficient to drain this ditch of water. At the southern end of the ditch there is a control structure which maintains a high water level by only allowing water to pass through a pipe to the interior of the mire once the water level reaches a certain height.

Figure 6-16 shows the rand on the left, the interior milled surface on the right and the cliff separating them. It also clearly shows the full ditch on the rand (showed by the line of cotton-grass), perched higher than the milled interior surface.

Figure 6-16 The North West Rand on Thorne Moors (NGR 470941, 417324)

The watershed of the rand, in most cases, is towards the western margin, so the majority of any water falling on it will flow eastwards towards the interior of the mire. Where the watershed is found further east, most of drainage ditches have plastic sheet pile dams across them. This combination of sheet pile dams and the positioning of the watershed means that only a small proportion of the run-off generated on the area will discharge off site.

Along the western margins of the site there is a drain in a depression that runs north-south between the raised rand and the raised, warped agricultural land. More particularly, in the southern and middle half of this depression, there are pools of water. These are likely to be the location of topographic lows where water can pool.

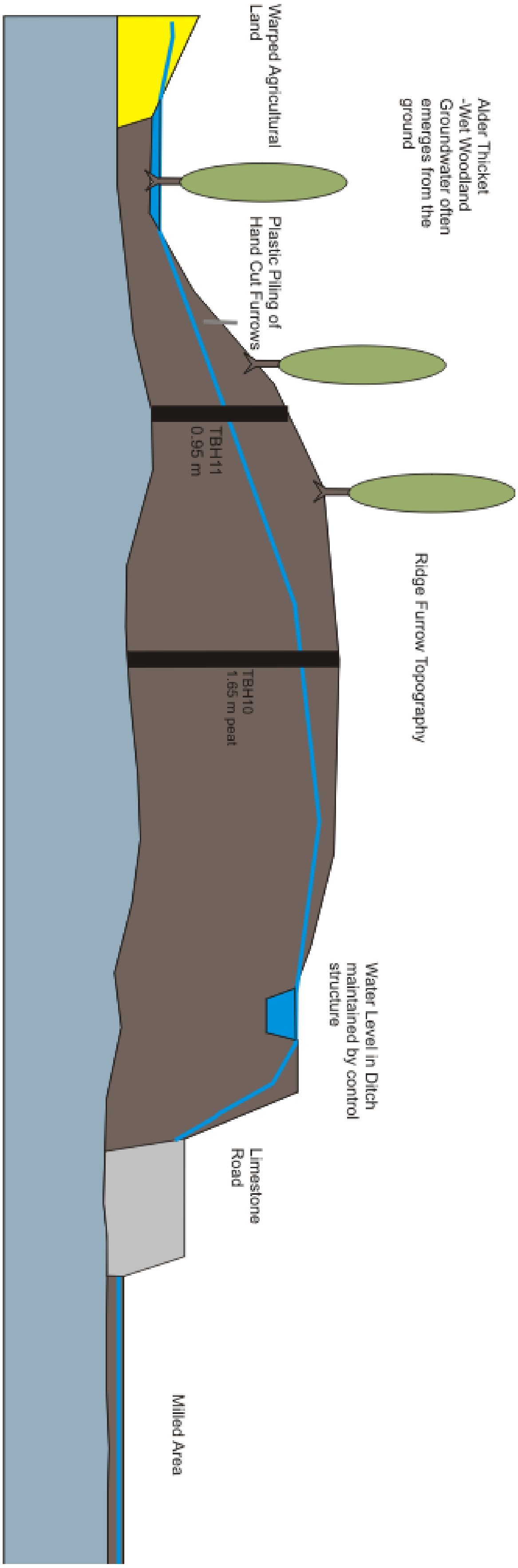

Figure 6-17 North West Rand Conceptual Model

6.9.6 Northern Goole Moors

Northern Goole Moors represents an isolated raised mire on the edge of the SSSI. The centre of the mire is intact; however, limited cuttings have occurred around its edge. A deep drain cuts through the area and there are drains which bound it on all sides. The peat cutting and external drains have lowered the watertable enough to allow bracken and birch woodland to establish around the edges. In the centre, the watertable is near or at the surface during the winter and some *Sphagnum* is present. The creeping scrub invasion has increased evapotranspiration from the mire, lowering the watertable further.

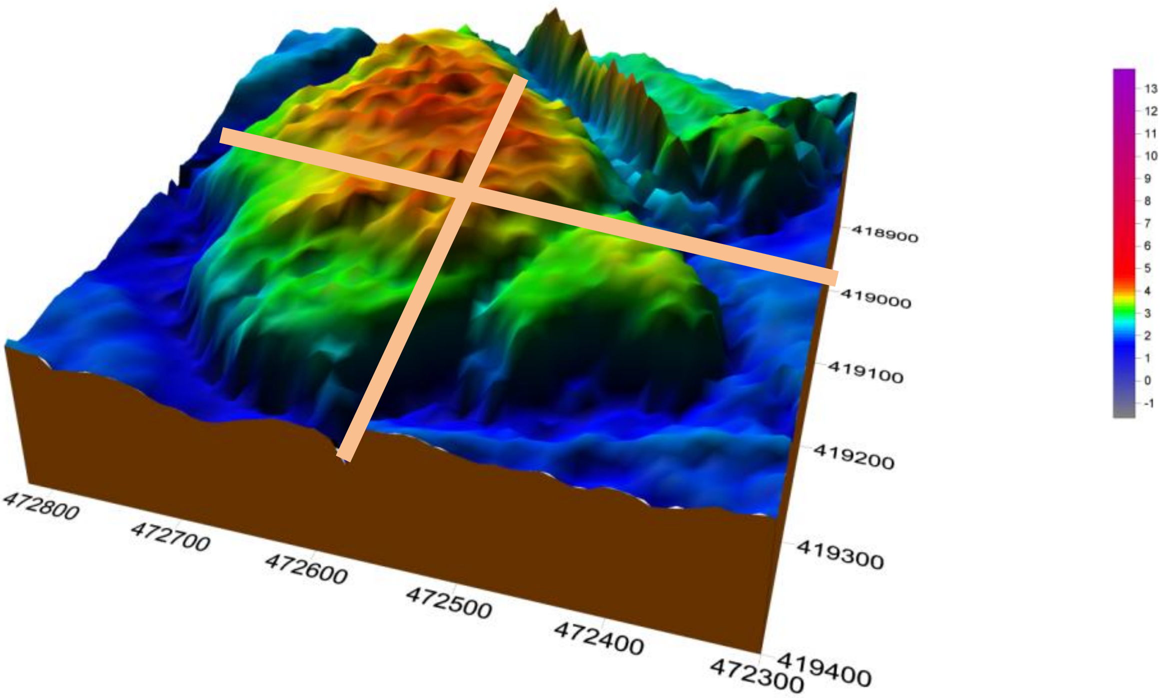

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Figure 6-18 DTM of Northern Goole Moors viewed from the North (Note the areas in green approximate to the areas of cuttings and the red areas the intact raised mire) (Orange lines = lines of cross sections)

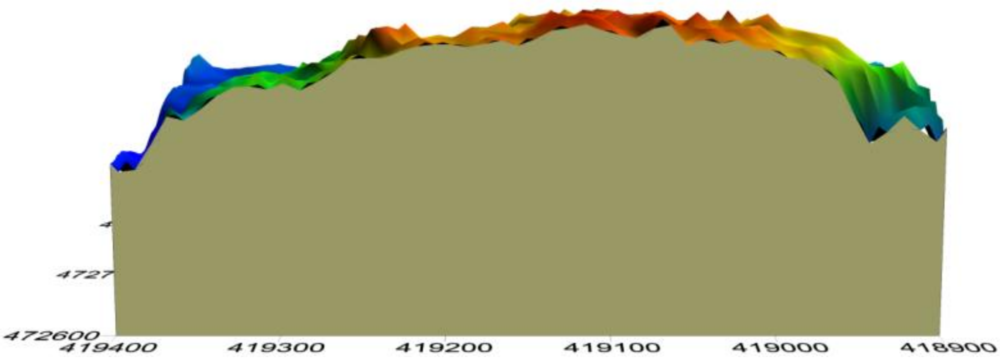

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Figure 6-19 Cross Section North South through Northern Goole Moors

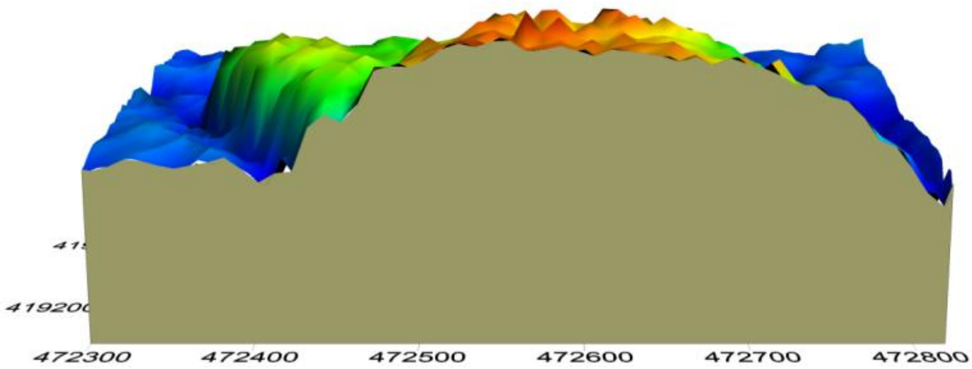

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Figure 6-20 Cross Section East West through Northern Goole Moors

6.9.7 Will Pitts Woodland

This is a low lying area next to the milled area and is dominated by mature wet woodland. Across the area the water level appears to be relatively high with ephemeral standing water being present throughout.

Much of Will Pitts Wood is an abandoned area of warped fields which have been colonised by wet woodland species (Bull, K. pers comm.). In the north and north-west the warp is more apparent, but in the south (which may have been an old decoy pond) it is less so.

A number of drains dissect the area; these may originally have been the field boundary drains. The relationship between the drains, substrate and the groundwater level within the peat in this area is not well understood. On its eastern boundary, Swinefleet Warping Drain lies a significant height above Will Pitts Wood. As this drain is clay lined, it is in hydraulic isolation from the water in Will Pitts.

6.9.8 North, West and South Crowle Moor

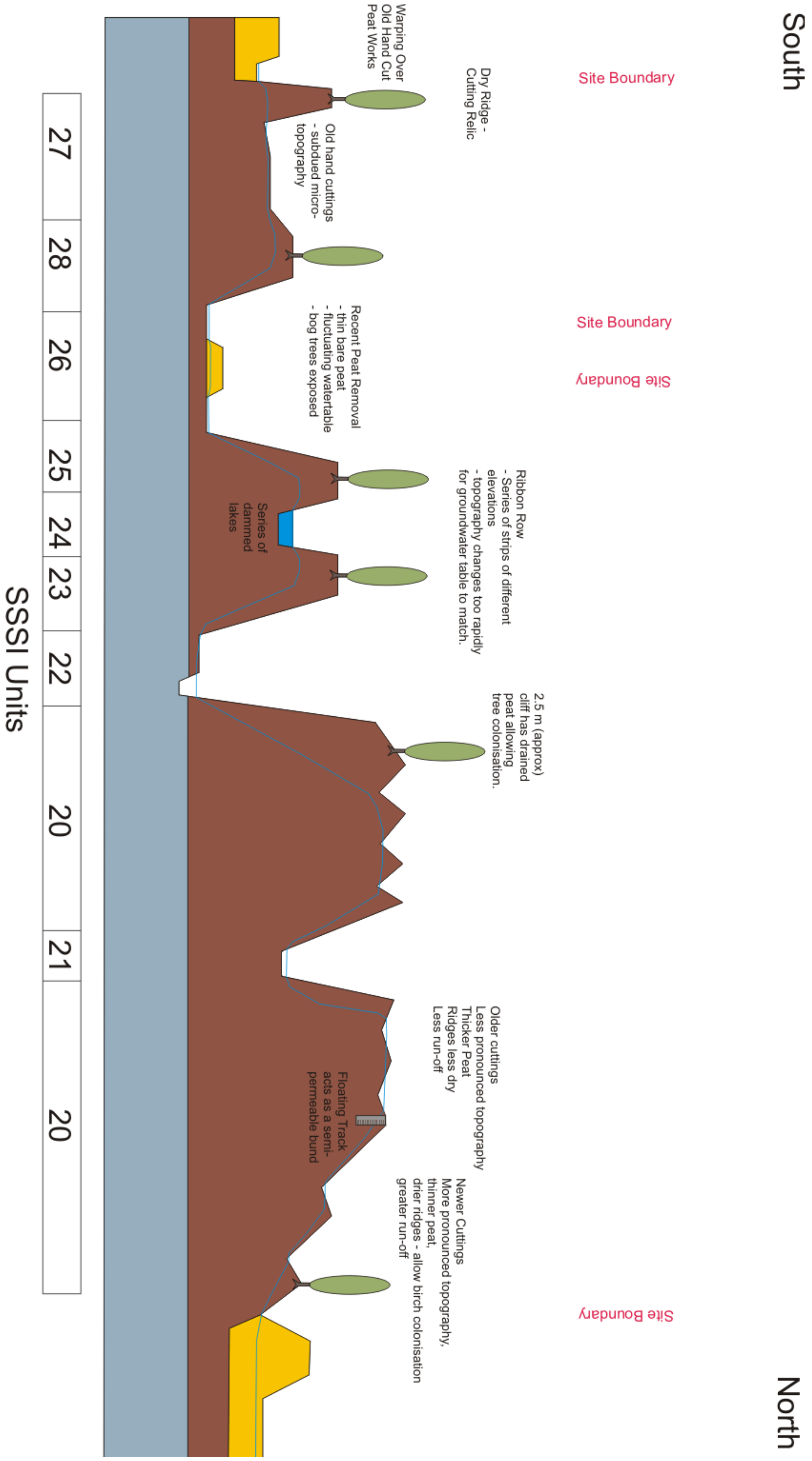

Figure 6-21 Conceptual Model of Crowle Moor

Although included together in one hydrogeological sub-region, a further level of sub-division is required to describe the conceptual model of this part of the moor. There are three main areas which require separate description:

- North Crowle (Units 20 and 21);
- The Yorkshire Triangle (Unit 19);
- Flower Garden and Yorkshire Moors (Unit 27 and 28).

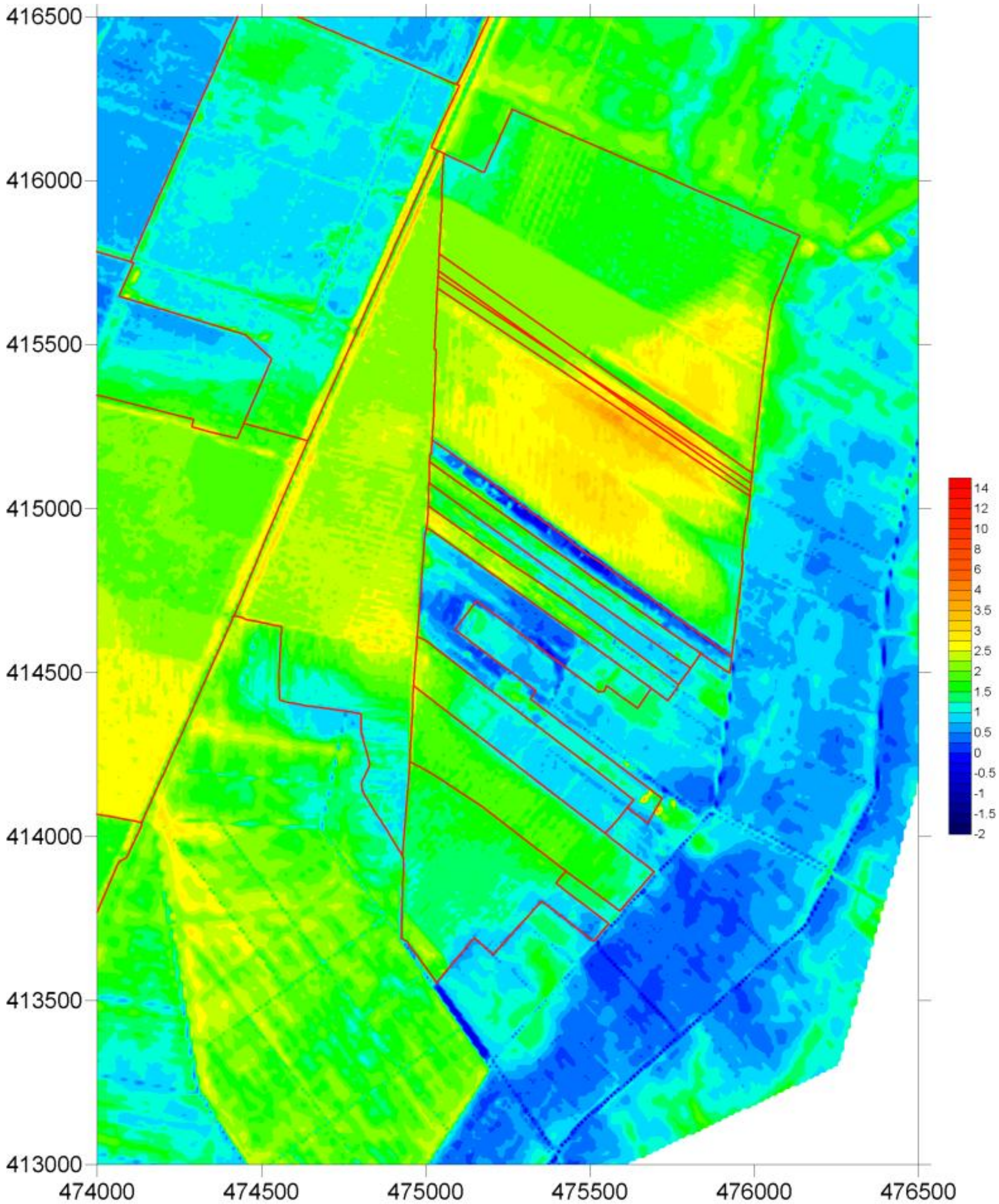

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Figure 6-22 LIDAR topography map of Crowle Moors

North Crowle

North Crowle is in many ways very similar to the hand cut ridge and furrow parts of parts of South Thorne Moors (section 6.9.2). Areas of older cuttings (i.e. less pronounced micro-topography) tend to be wetter and newer cuttings tend to be drier.

The southern part of North Crowle is bounded by a 3 m tall cliff of peat produced through peat abstraction in the strip to the south (see Figure 6-23). This cliff drains the peat mass to the north. An approximate 25m wide strip along the cliff edge has been colonised by thick silver birch scrub, indicating the extent lowered watertable caused by the peat cliff. A borehole installed on top this peat cliff (CBH9 in Appendix B.1.1) shows a metre plus range in groundwater levels between the end of the summer low and the winter high level. In Figure 6-24, these levels have been plotted on a cross section of the peat cliff with a 1D model analytical model representation of the watertable. The model has been keyed into a level just above the summer low. This model indicates that the watertable begins to be within 25cm of the ground surface approximately 30m north from the cliff edge. This distance ties in with the colonised strip of birch along the cliff edge.

Figure 6-23 Peat Cliff on Ribbon Row, Crowle Moors.

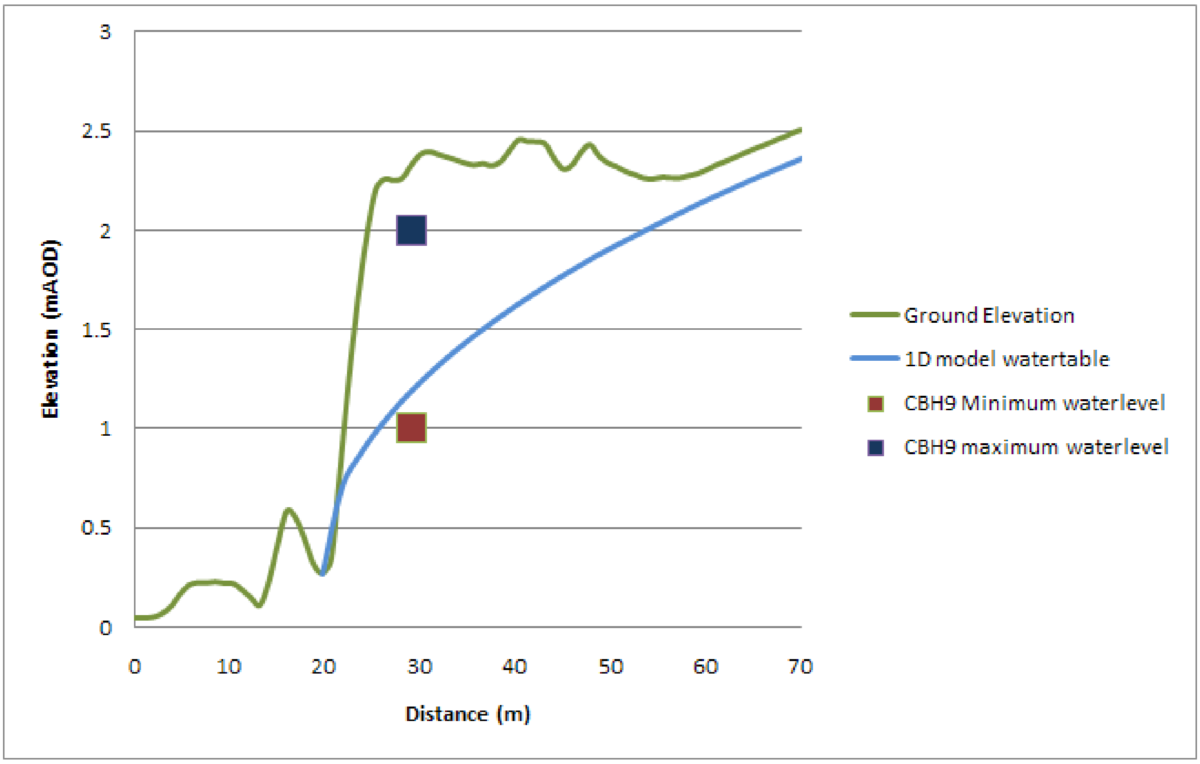

Figure 6-24: Peat Cliff on Crowle Moors and its effect on the watertable

To the west the area is bounded by the Yorkshire Triangle which is an area of similar hand cut ridge and furrow topography. To the north and west, the area is bounded by warped agricultural land (augering has shown this warp to be 60 cm thick and overlying H4 sphagnum peat. The agricultural land to the north, and in the small field in the west, lies between approximately 0.5 – 2 m above the level of the peat. The boundary drain is within the site boundary at a lower level than the agricultural fields and cuts through the peat. Some small scale damming has occurred on this drain. It is unlikely, therefore, that any run-off could occur off the site on the northern boundary to inundate the agricultural fields. The fields to the east are lower than the site, but a boundary road, which may act as a bund, and a large agricultural ditch on this boundary will limit run-off.

A track runs from NGR 476012, 415460 to 475024, 415965. This divides an area of slightly higher older cuttings to the south from newer cuttings (wet in the furrows, dry on the ridges) to the north. The track is an old floating road constructed from tree logs. These have sunk over time and the logs have been replenished. This has formed an effective bund between the older and newer cuttings which has been made more effective by plastic corrugated sheeting at certain points along the track, impeding lateral groundwater movement.

In the northwest of Church Piece, the boundary ditch water is flowing off-site (observed to be approximately 3 ls^{-1}). This is one of the only places on the site that running water was observed.

Yorkshire Triangle

The majority of the Yorkshire Triangle is like the hand cut ridge and furrow topography seen over North Crowle and South Thorne. The north of the area is slightly wetter than the south and this may be as a result of topography (it is slightly higher in the south).

An old tramway runs east-west across Unit 19 from the Bailey Bridge. This tramway acts as an effective bund between the higher ground to the north and the lower ground to the south, keeping the higher ground wetter. The tramway impedes groundwater movement and cuts of the supply of water to the lower ground, leaving it drier.

The south of Unit 19 is covered in established woodland with large trees, suggesting that the area has been dry for a significant period of time. This area is at a similar elevation to the agricultural land which bounds it to the south and is effectively drained by the agricultural boundary ditch.

Flower Garden and Yorkshire Moors (Compartments 84 and 85)

The Flower Garden and Yorkshire Moors make up the southern part of Crowle Moors. The boundary ditch to the south is large and forms a peat cliff between 1 and 3 m tall. Peat pipes have been observed in the peat cliff and the drain effectively lowers the watertable around the edge of the Flower Garden and has allowed a border of birch woodland to establish.

The microtopography of the Flower Garden is indicative of old English Hand Graving. The microtopography is muted and the watertable is at or near the surface within the old furrows, where cotton-grass has established. However, the area currently has a heathland feel about it. This is supported by the presence of typical heathland species, such as heather and bilberry *Vaccinnium myrtillus*. Lowland heath is an uncommon habitat this far North, however, there are examples within the region on the Coversands and elsewhere in the Vale of York, at Allerthorpe Common. Heathland is generally a floristically poor habitat but it is home to numerous rare species of fauna, including numerous invertebrates, reptiles and birds.

A marked change in vegetation occurs between the Flower Garden and Yorkshire Moors. In the latter, the trees are more established (which is likely to mean that the rates of evapotranspiration in this compartment are higher) and the ground is much drier under foot. Hand-cut ridge and furrow topography is evident but there is little floristic difference between the vegetation in the ridges and the furrows, suggesting that the watertable is sufficiently below the ground surface to make the comparable depths of groundwater sufficiently similar so as not to affect the vegetation cover. The strip to the north of the Yorkshire Moors has been warped. There is a small boundary ditch which will drain the peat mass to a degree.

6.9.9 Ribbon Row

This area is divided into long (approximately 1000m) chain or double chain width plots (i.e. 22 or 44 yard wide strips) which have a complex history of land ownership and peat extraction. The degree of peat extraction often varies greatly between the different strips due to each strip being individually managed. This has led to large variations in surface topography; with cliffs of peat up to 3 m tall between the strips, which have been extensively cut, and those which have had seen little or no extraction.

The lower strips form large drains through the peat, leaving the higher strips dry and extensively covered in birch woodland.

In some of the most extensively cut strips, the deeper wood peat and large ancient bog timbers are exposed (notably in Units 22 and 26). In places, all the peat has been milled and the underlying substrate is exposed.

Unit 26 is one of the units which has been extensively milled. This unit lies in a topographic depression with higher peat (areas subject to less extraction) to the north, south and west and warped agricultural land to the east. This also forms a strip through the centre of the Unit (outside the SSSI boundary). This depression is drained by two drains which flow from the unit to the road. Without these drains, this unit would form a lake. The unit is prone to extensive ephemeral flooding with areas of standing water forming after periods of rainfall. The depression drains the extant peat mass to the north, south and west during the summer but water level tend to recover in the winter (see Figure 6-23).

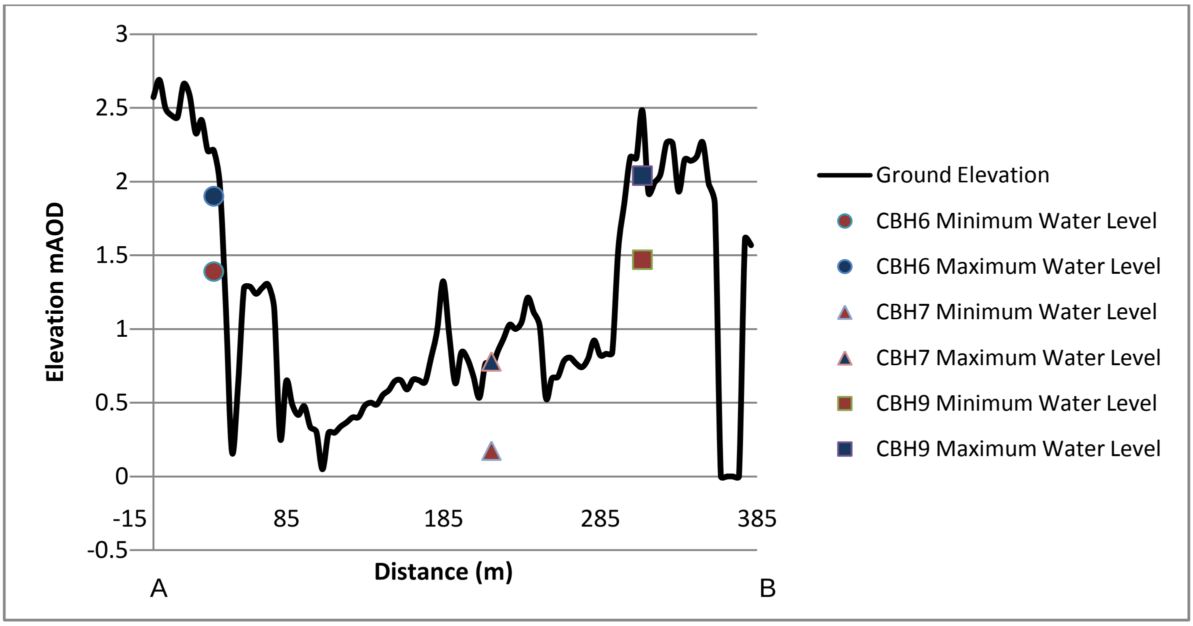

Figure 6-25: Cross section across Unit 26 with measured water level ranges

Figure 6-26: Aerial Photograph of Ribbon Row (with line of Figure 6-23 cross section in Black) (Natural England (C))

Between Units 22 and 26 there are three units have not been subject to the same degree of extraction and these form a raised area. The centre strip (Unit 24) has been subject to the greatest degree of extraction and forms a depression. A number of dams cross this depression, forming a series of deep linear ponds. These ponds form areas of high water and, without their presence, this strip would form an effective drain. Due to the rapid change in topography between the strips (approximately 2 m difference in elevation in 5 m), the dammed ponds are not high enough to raise the watertable in the surrounding strips to a level which would inhibit birch scrub invasion (Figure 6-21).

Unit 22 is similar to Unit 26 but more effectively drained so it is drier and does not have large areas of standing water. A drain runs along its length at the base of a 3 m (approx) cliff of peat. This excavated strip effectively drains the peat to the north and has led to birch scrub invading these areas (See Figure 6-23).

7 MONITORING PROGRAMME

7.1 Pre-existing Monitoring Programme

Natural England use an array of dipwells and collect other data to monitor the water regime on site, these include:

- 6 dipwells in the canal area;
- 13 dipwells in a cross pattern within SSSI unit 17, across the southern half of Thorne Moors.

7.1.1 Analysis of existing data

Temporal Variation

Natural England has collected dipwell readings from 22 boreholes across the south of Thorne Moors for over three years. This data is presented in Figure 7-1 and Figure 7-2.

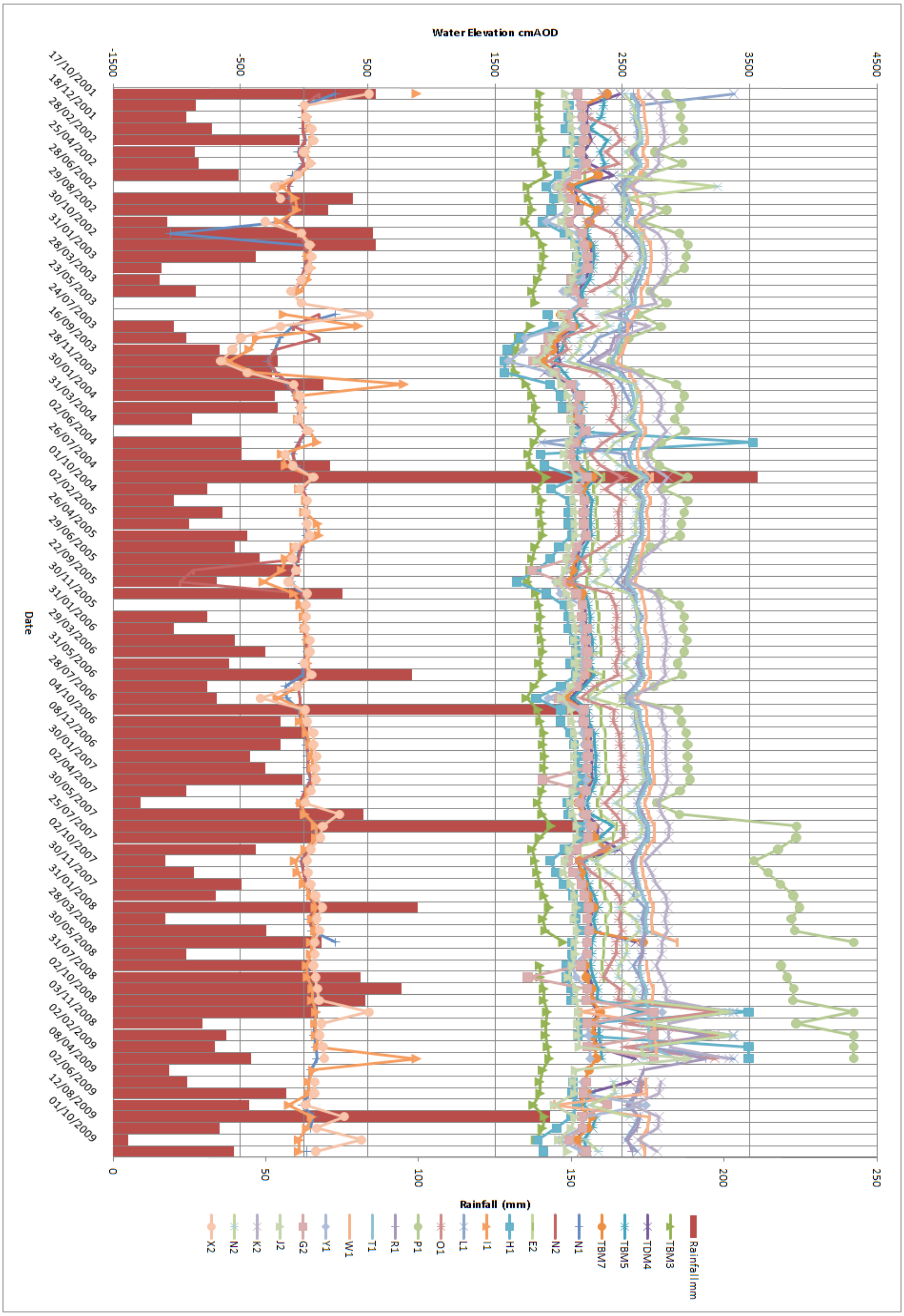

Figure 7-1 Water Elevation (cmAOD) for Twenty Two Natural England Boreholes between October 2005 and March 2009 against monthly rainfall data

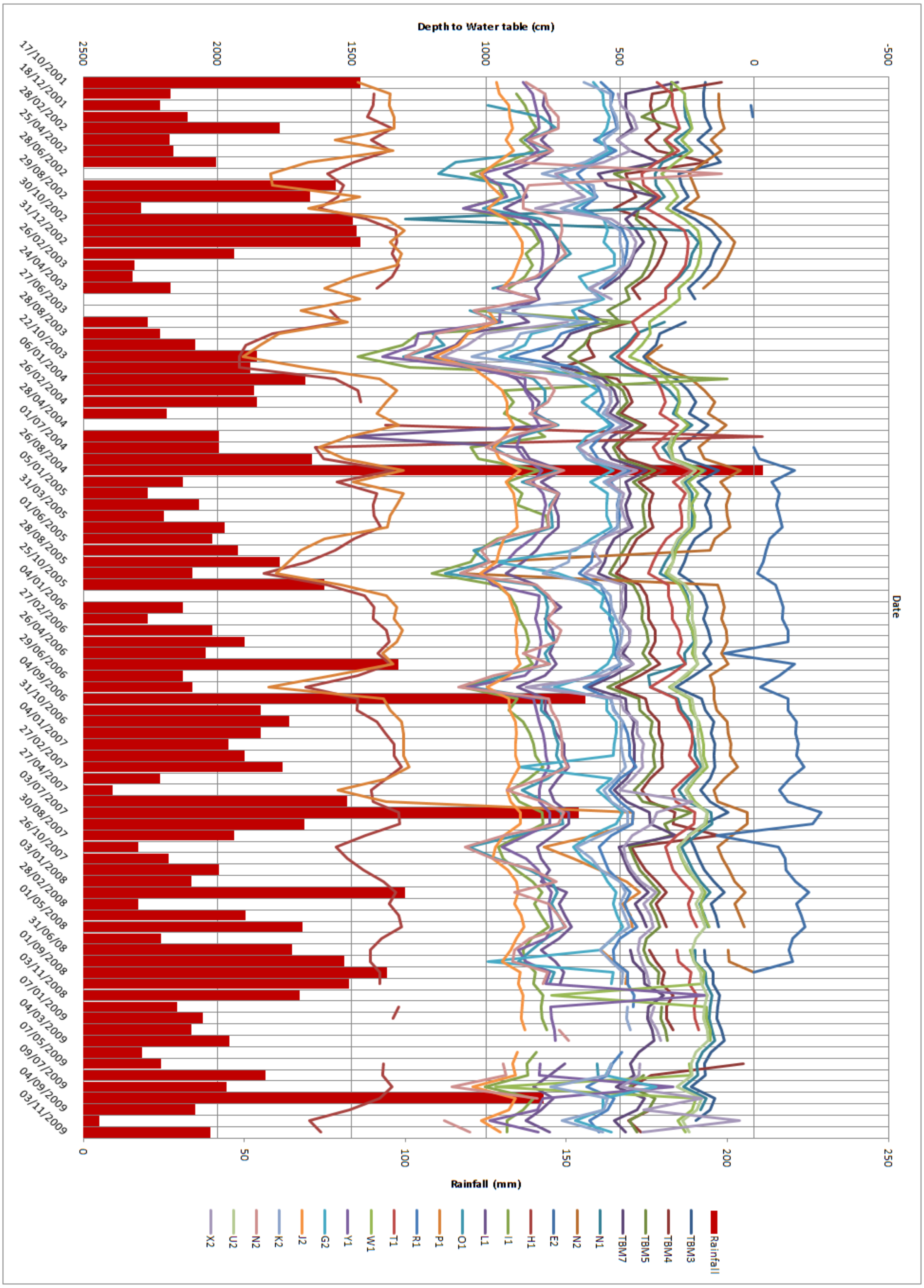

Figure 7-2 Depth to Watertable from the Surface for Twenty Two Natural England Boreholes between October 2005 and March 2009 monthly rainfall data

Between 2001 and the Spring of 2007, all boreholes showed a seasonal fluctuation pattern with the lowest water levels most often seen in September. The lowest level could be earlier when September was wetter, notably in the late Summer of 2006 where a particularly wet month allowed the recovery of groundwater levels earlier in the autumn. Water levels rise in the autumn and winter and are maintained at this level till early to mid Summer.

After May 2007 this strong seasonal trend is less pronounced; this could be as a result of restoration works or changes to the climate during this period. The drop in water levels in the late summer, seen before 2007 would have been the result of evapotranspiration from deciduous woodland. Therefore, tree cutting, which has occurred in recent years, would have made this late summer loss less pronounced. The 70 cm rise in water level at borehole TBM3 (located within the relatively wet Canal's region) after March 2007 could be the result of restoration works causing a dramatic change in water levels or damage after this date.

Spatial Variation in Groundwater Levels

Figure 7-3 and Figure 7-5 have been produced through interpolation of the groundwater levels between each Natural England borehole and generating groundwater contour maps and cross sections. This method has limitations as it does not take into account the effects of drains and changes in topography between boreholes, therefore the maps produced are not accurate predictions of groundwater levels at partially locations. This is especially apparent in the winter cross section (Figure 7-6) where the groundwater is predicted to emerge above the ground surface by several tens of centimetres; which is impossible. However, in spite of these limitations, the figures can be used to describe spatial trends in groundwater during the summer and winter.

Figure 7-5 and Figure 7-6 show that the groundwater levels in the Canals and the area south of the Angle Drain and west of the Swinefleet Warping Drain stay near or close to the WLMP targets (groundwater level within 100 mm of the surface) during winter and summer. This shows that the ditch blocking south of Angle Drain has been effective, however, across the dome of south Thorne (Figure 7-7), the groundwater level in summer and winter is much deeper.

The groundwater levels on the western site of the dome (Borehole H1 and I1) are much lower than the eastern side (boreholes R1, T1 and W1). There are two possible contributing reasons to this; ditch blocking is less effective in this area, and/or the density of tree vegetation which appears denser in this area has increased the rate of evapotranspiration.

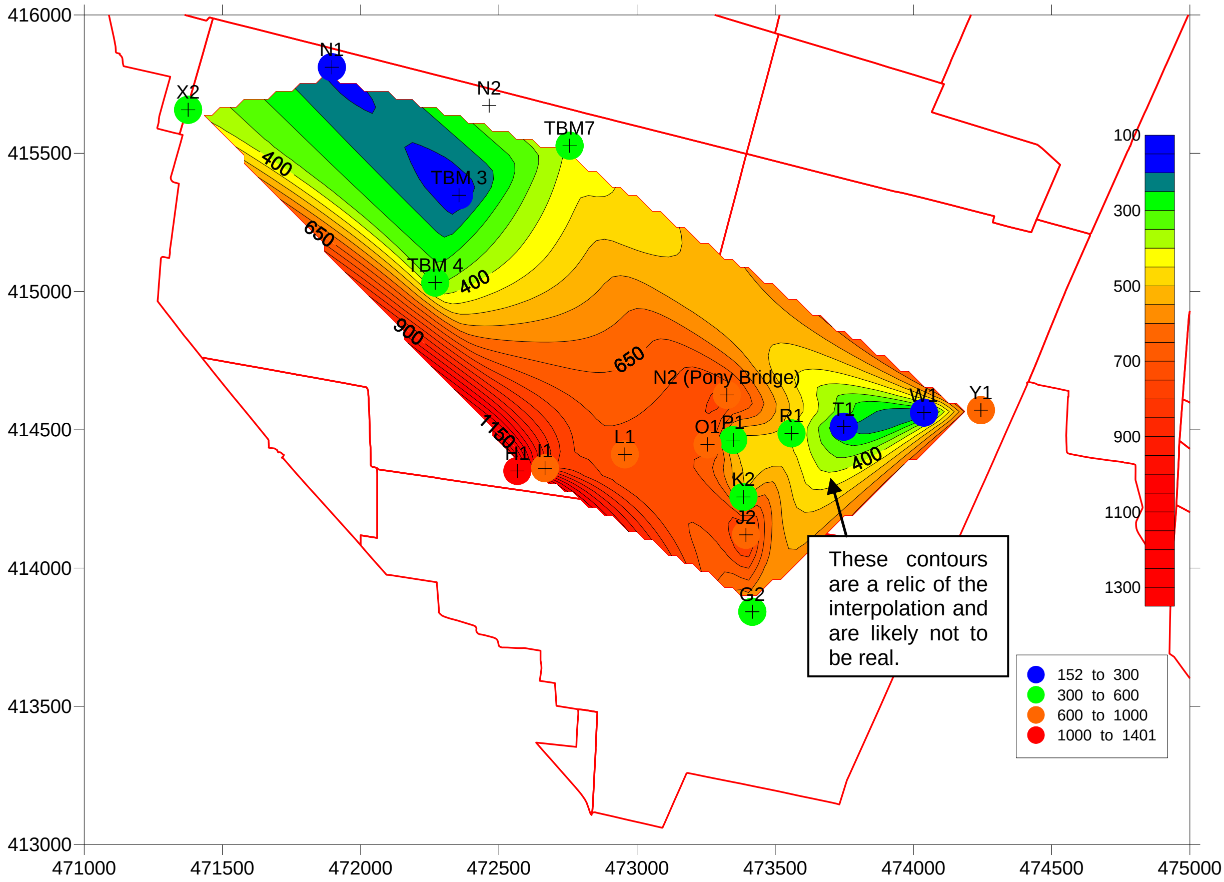

Figure 7-3 Depth to Groundwater in summer across South Thorne on 28/7/08

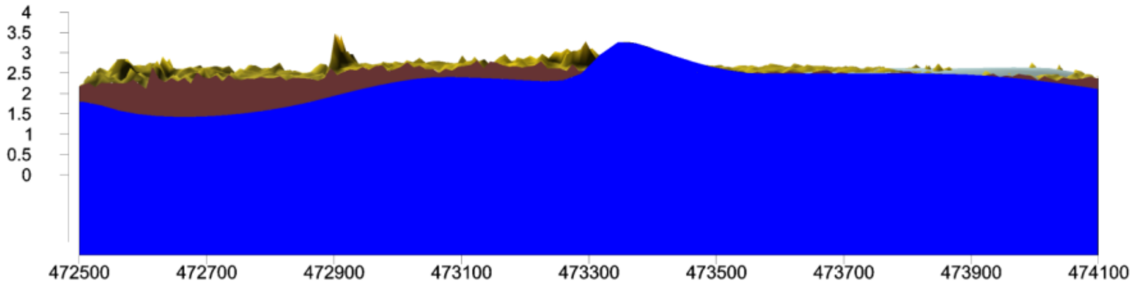

Figure 7-4 Summer Groundwater Cross Section

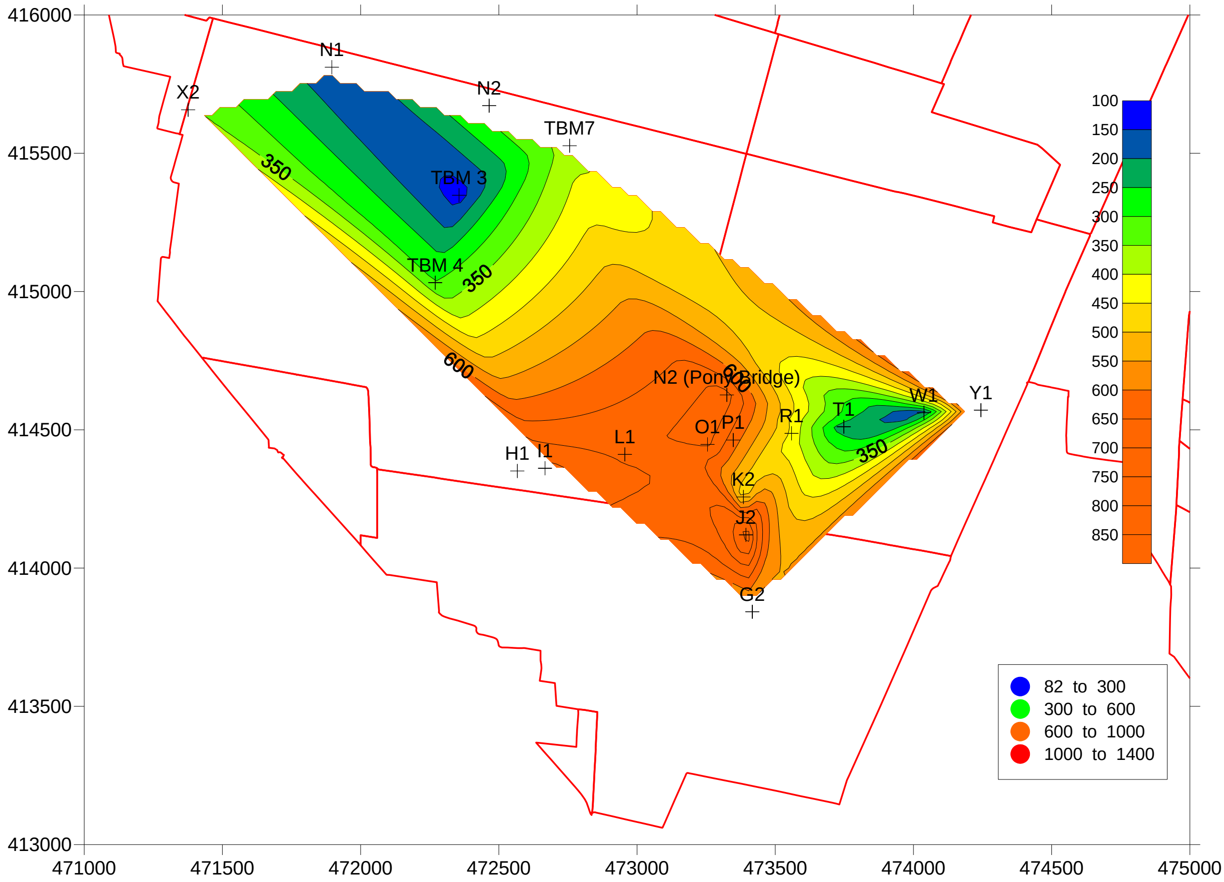

Figure 7-5 Depth to Groundwater in Winter across South Thorne on 7/1/09

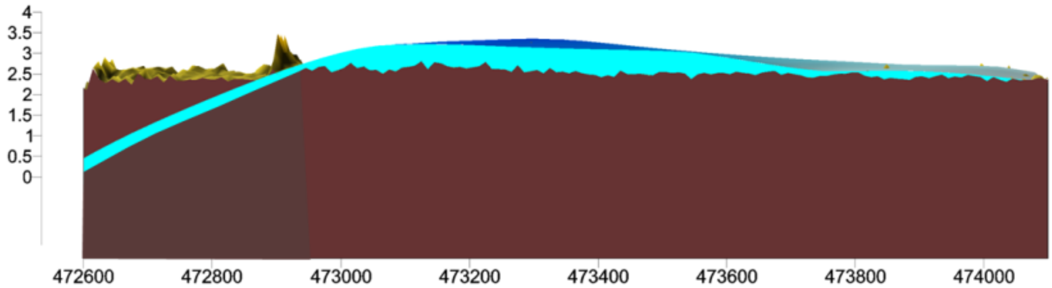

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Figure 7-6 Winter Groundwater Cross Section 1/7/08 (note where groundwater is shown to be above ground surface, the ground is fully saturated).

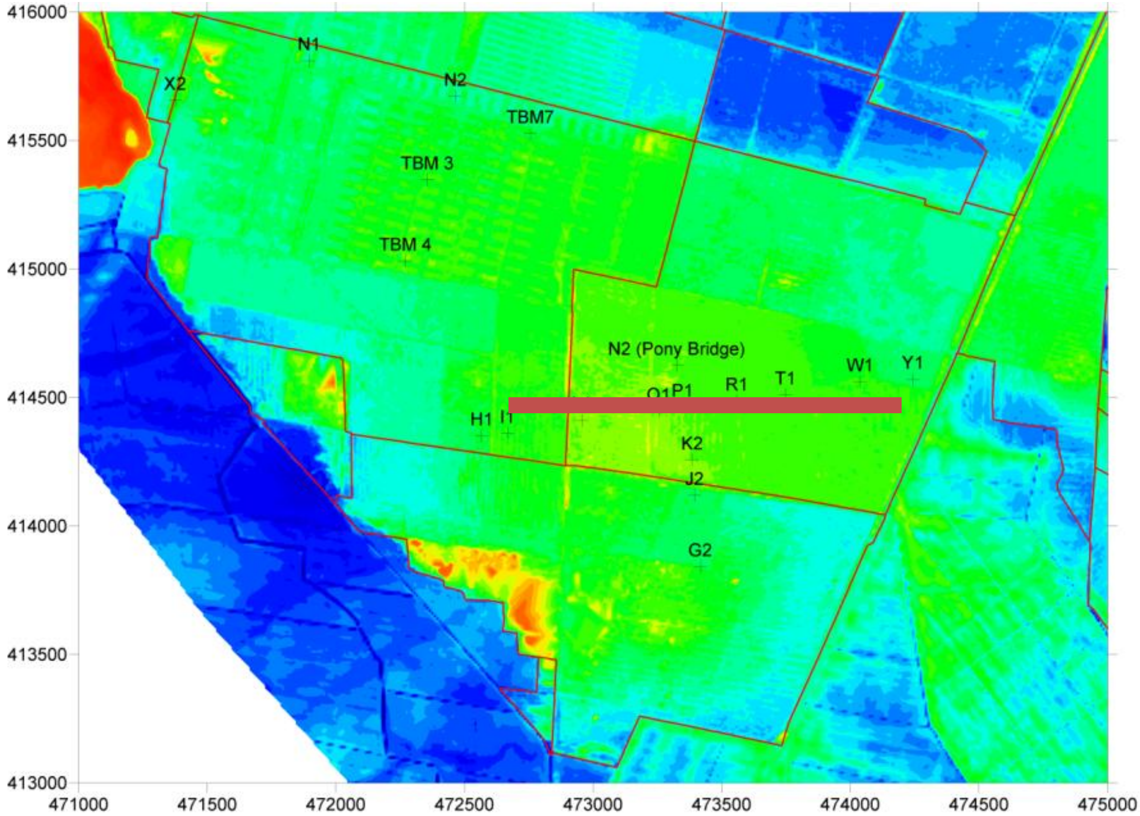

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Figure 7-7 LIDAR Contour Map of South Thorne showing line of cross section

7.1.2 JBA Monitoring

JBA has installed an extensive monitoring array (25 boreholes and 26 gauge boards) to fill in the gaps in the monitoring array installed by Natural England. This new monitoring has focused on areas away from south Thorne and on gauge boards in major drains. All boreholes were installed with pressure transducers (trolls) to give a continuous record of water levels during the monitoring period. The location of the boreholes and gauge boards are shown in Figure A 10 and the water level graphs and discussion is given in Appendix B.1.1.

7.1.3 Extending the Interpretation of Monitoring

Monitoring through gauge boards and boreholes by themselves can only provide information about that exact location. Thorne and Crowle Moors is a very large site and, even with an extensive monitoring array, the distance between monitoring points can be very large. A method is therefore required to fill-in the knowledge gaps between the monitoring points, assess the areas for which the monitoring points are representative and utilise other sources of information to make inferences about the watertable depth across the entire site. This is required to assess where the water level targets are currently being met and where they are not, to identify areas where restoration works can be targeted. Figure 7-8 is the result of this exercise. It splits the site into a number of areas, based on seven water level categories:

- Sufficiently Wet – i.e. roughly meets the target water level all year round to allow lowland raised mire habitats to form;
- Slightly too dry –the groundwater level lies approximately 30 to 60 cm below the ground surface;
- Fluctuates - Wet – the water level in the area fluctuates too much to meet the target water level but overall the watertable is above or near the surface;
- Fluctuates – Dry – Water levels in the area fluctuate too much and the area is regularly too dry;
- Too Dry – Watertable is approximately more than 60 cm below the target water level;

- Too Wet – The area is almost permanently covered with standing water;
- Not Applicable – Usually areas which have been subject to warping or the peat is absent so should not be subject to the same water level targets.

The information used to create Figure 7-8 is derived from a range of data sources, these include:

- Natural England boreholes;
- JBA monitoring array;
- Site walk-over;
- LIDAR;
- Aerial photographs;
- ArcGIS catchment analysis;
- Vegetation survey;
- Inference.

In the main, the process can be described in the following stages. The data from a borehole is analysed to assess the average water level and the annual range in watertable to categorise the changes in the water level. Then LIDAR, aerial photography, vegetation survey and maps of the drainage pattern are used to assess the extent of the area for which the borehole is representative. A representative area will have:

- similar topography – i.e. of a similar elevation and peat cutting type and age;
- similar vegetation type so that the rate of evapotranspiration is likely to be similar across the area;
- major drainage ditches defining its area.

Sometimes an area will not be covered by a representative borehole, (e.g. some topographic depressions with semi-permanent surface water in South Thorne). In that case aerial photography and site walk-overs, and LIDAR are used to categorise an area and define its extent. A number of aerial photographs were used (Natural England, Google Earth, Bing Maps) to give an indication of whether the features seen on the aerial photography were representative of an area or of an ephemeral nature captured by the photography.

Numerical groundwater modelling was mooted as an alternative to this method, however, any such modelling would be unable to take into account all the secondary sources of information fully and could not represent all the varied hydrogeological conditions accurately enough to provide the information required to assess the water level targets.

The boundaries of the categories in Figure 7-8 were deliberately chosen to aid the use of the secondary sources of data. Above 30 cmbgl is used as the definition for 'sufficiently wet' and below 30 – 60 is used for slightly dry for several reasons:

- Roughly, a watertable at or just above 60 cmbgl means that water is visible in the deeper ditches and furrows but the majority of the land is dry under foot. At 60 cmbgl, it is evident from a site walk-over that the watertable is at a level such that the area is quite wet but not wet enough for a lowland raised bog habitat;
- At 60 cm or above the control on the rate of evapotranspiration on Thorne is dominated by the type of vegetation rather than water supply (Birdsall 2000), therefore, scrub removal becomes an effective tool for raising the watertable;
- In addition to borehole data, there are several pieces of evidence suggesting areas where the watertable is at or above 30 cmbgl, . these include;
    - The vegetation type – there are no birch trees or growth is stunted or drowned out.
    - Surface water is often present within small depressions and between hummocks.

Fluctuating areas tend to be located where the peat is thinner and more degraded, which allows the groundwater level to fluctuate to a greater extent than on other areas on the site. Areas where the water levels fluctuate above and below the ground surface are often dominated by wet woodland vegetation (e.g. Pony Bridge Wood).

The definition of 'Sufficiently Wet' in this process is not as strict as the water level restoration aims laid out in Section 8.2.

Watertable close to ground level (within approximately 10cm of the surface) and indicative of anaerobic conditions. The mean free groundwater level over the mire expanse should not fall more than 25cm below the surface in more than one year in five

This is because within the areas defined as 'Sufficiently Wet' much of the it will achieve the stricter target, however, due to micro-topography difficulties it would be impossible to achieve this aim across the whole area. A good example of this is the Canals Area in South Thorne, where the comb like pattern of higher and lower ground means that the higher ground does not achieve the strict restoration aim but, over the wider area, the Canals can be considered as sufficiently wet.

As explained above, Figure 7-8 (and Figure A 12) is produced through several lines of interpretation and underwent several revisions as more evidence was forthcoming. This means that the figure is dynamic in nature and can be refined further. It has been impossible to 'ground-truth' the whole map due to access difficulties. With these caveats in mind, this figure has been used as a tool with which to focus restoration plans.

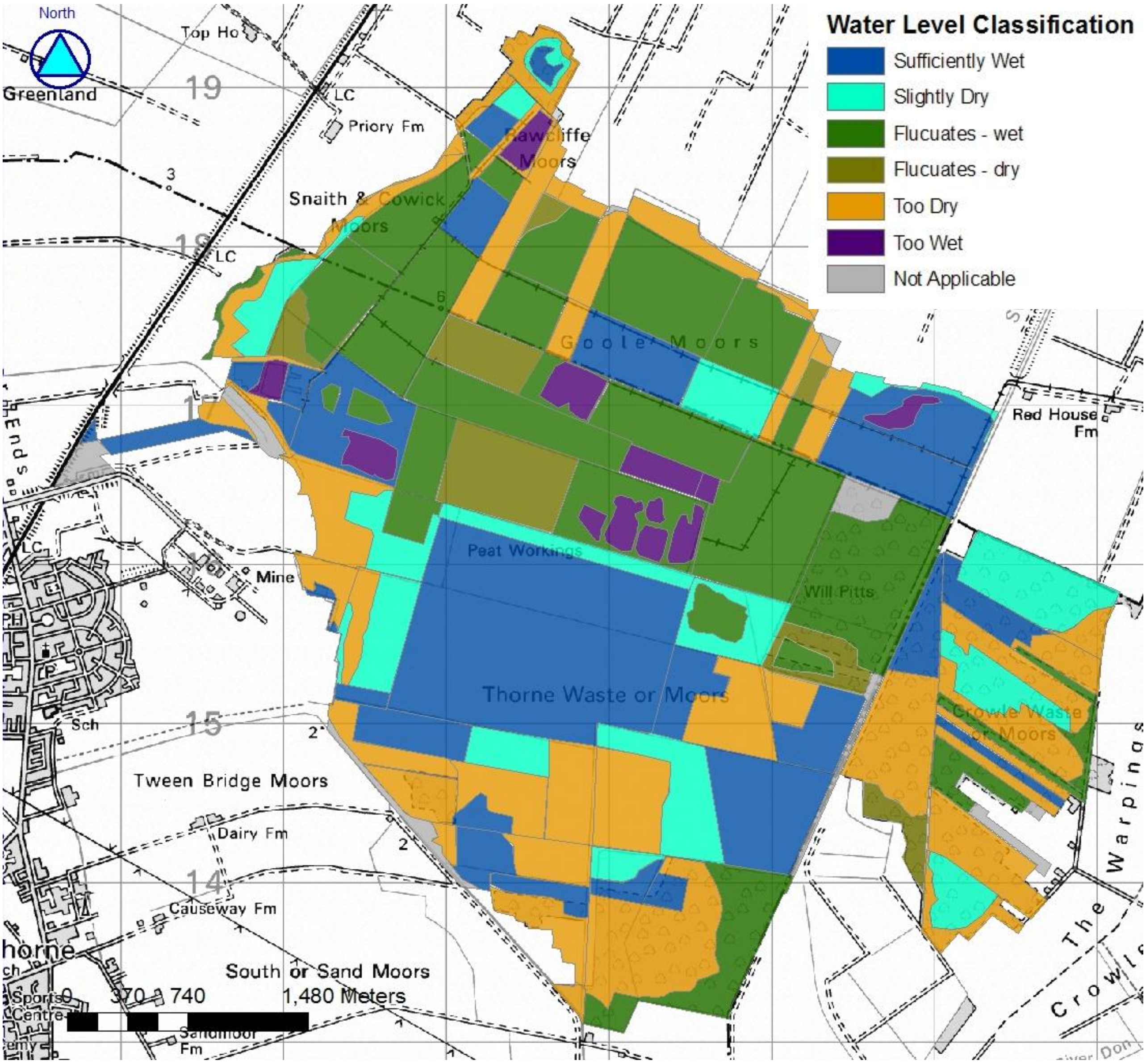

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Figure 7-8 Water Level Categorisation across Thorne and Crowle Moors

8 WATER LEVEL MANAGEMENT PLAN

8.1 Current Management Strategy

Formal management to improve the conservation status of the Thorne, Crowle and Goole Moors SSSI only occurs on Natural England and Lincolnshire Wildlife Trust owned land and in areas subject to management agreements with Natural England. This covers most of the site, but excludes some areas which are in 'Unfavourable Declining' condition such as Northern Goole Moors, strips of land on Goole Moors and parts of Ribbon Row on Crowle Moor.

Natural England manages the land in Lincolnshire (land east of Swinefleet Warping Drain) and the land in Yorkshire separately.

There are two main strategies for managing the Natural England land in Yorkshire (Bull, K. pers. comm.). These have been developed in response to the different topography and drainage schemes that occur on site.

8.1.1 Milled area Management Strategy

This section relates to areas that have been mechanically milled for peat, producing flat bare areas, isolated by raised roads and linear drains on Thorne, Goole and Rawcliffe Moors. Due to the degraded nature of the peat and the lack of vegetation covering the area, the management plan for these areas aims to revegetate the peat, stop it from drying out and reduce, possibly reverse, the degradation process without producing areas of deep water, which would prohibit the establishment of bog vegetation.

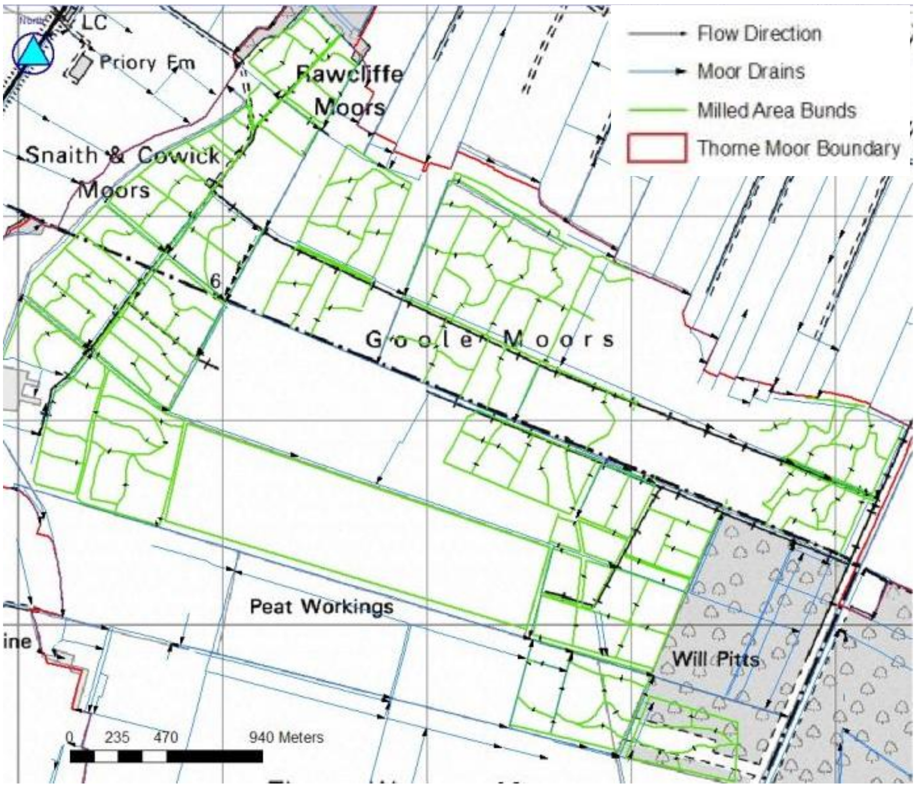

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Figure 8-1 Location of Natural England's Bunds on the milled area (as planned) (English Nature 2005)

Since 2006 a series of bunded cells have been created across the area. In the winter, these are allowed to fill so that, on average, the depth of water within them is 30 cm above the surface (Bull, K. pers. comm.). The aim is that this will stop the groundwater level from falling beneath 20 cmbgl during the summer. The height of the water in the isolated, bunded cells is controlled by adjusting the height of the pipes which cross the bunds. The water from each of these cells discharges into the next cell and so on (like contoured paddy-fields) until eventually it reaches one of the large drains, which have remained unblocked in the area. The milled area forms a depression so the water, once it has entered the main drains, is pumped out of the area from the Blackwater Dyke up into the Swinefleet Warping Drain.

The ability to control the fall in the watertable is limited by the unpredictable nature of the climate, (i.e. whether the summer is very dry or wet), although, to date, it has been quite successful. The present conditions have been designed to allow cotton-grass stands to develop initially and produce areas where *Sphagnum* mosses might grow in the future.

In spite of the qualified success of this strategy, there are a few difficulties. Firstly, some of the bunds are large and spaced too far apart, resulting in large parts of the bunded areas being covered in water which is too deep for the establishment of cotton-grass. In these areas soft rush has become established. Secondly, there is only one discharge pumping point for the system, on the eastern half of the site, which limits the fine control on the system that the site manager requires. Thirdly, there are strips of land currently outside Natural England's ownership on Goole Moors which would benefit from the same system of bunding works undertaken elsewhere.

8.1.2 South Thorne Management Strategy

The topography of the Canals Area and south Thorne is very different from the areas where milling has occurred, due to the hand cutting and baulk cutting methods used in this area. Before management measures were started, the site was too dry and much of the area was covered in birch scrubland. The management strategy in this area has been to block the ditches with dams to reduce run-off and to remove large areas of scrubland vegetation. The aim of this to reduce run-off and evapotranspiration.

The strategy has been quite successful so far but an understanding of the water budget and groundwater movement in the area, in combination with improved monitoring to characterise the nature of the watertable and how it fluctuates, would be valuable in assessing where further work might be required in the area.

8.1.3 Management Strategy for Lincolnshire Wildlife Trust Land on Crowle Moors

Lincolnshire Wildlife Trust owns a large proportion of Crowle Moors. The current management plan looks to manage the area in three different ways depending on the water level. The wettest areas are managed as bog, slightly drier areas as heathland and the driest as woodland (Ken Green pers. comm.).

The aim is to re-wet as much of the site as possible to establish bog vegetation. The techniques used to achieve this include: sheet pile bunding, vegetation removal and sheep grazing (which can stop scrub encroachment which would lead to increased evapotranspiration and, therefore, a lowering of the watertable). These techniques are used to keep as much water on site as is possible.

8.1.4 Hydrological Protection Zone

A proposed Hydrological Protection Zone (HPZ) was developed by JNCC (Morgan-Jones *et al*. 2005) for Thorne Moors (Figure 8-2). This is based upon a simple conceptualisation of Thorne Moors and its boundary conditions.

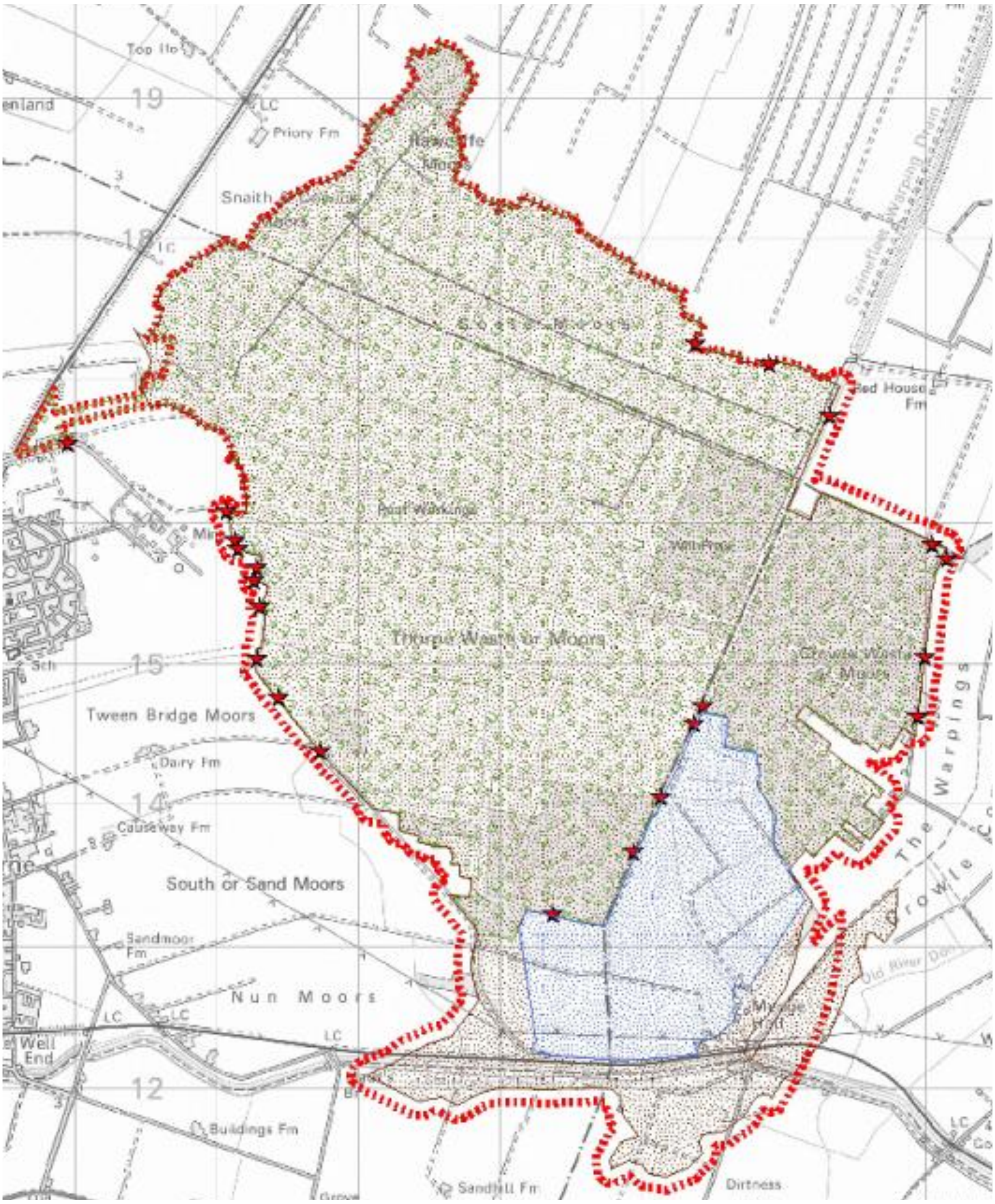

Figure 8-2 Proposed Hydrological Protection Zone for Thorne Moors (JNCC, 2005)

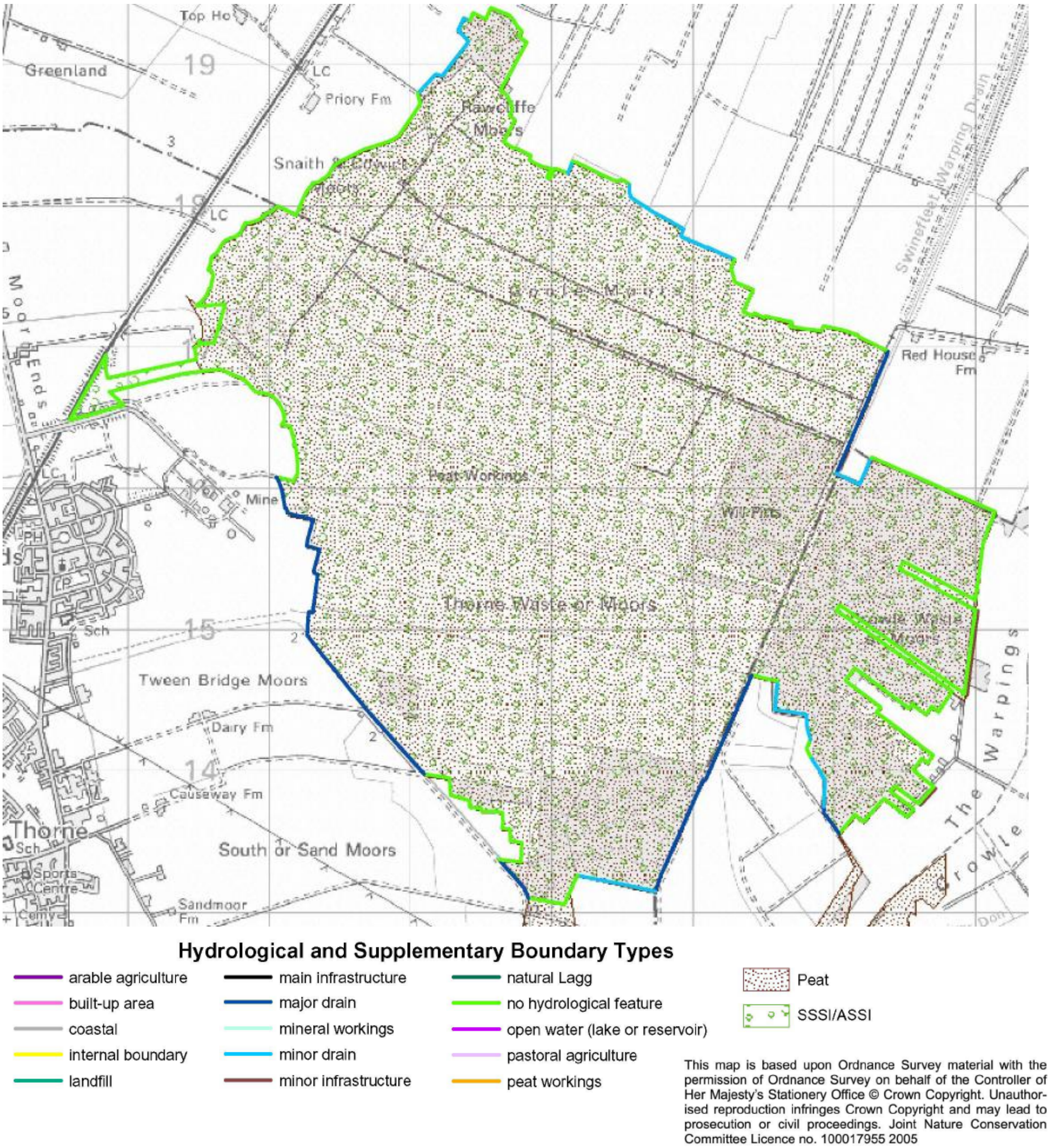

Figure 8-3 JNCC Boundary Classification of Thorne Moors (JNCC, 2005)

Additional conceptualisation work completed as part of this study may be able to help refine parts of the JNCC conceptualisation and the extent of the proposed HPZ. These include:

- The Swine Fleet Warping Drain is likely to act as a no flow boundary rather than a constant head boundary. Therefore, where the Warping Drain forms a boundary between the SSSI and arable fields, no HPZ is required;
- The area to the south of Thorne and Crowle (outside the SSSI) marked as peat by the JNCC report (JNCC, 2005) is in fact warped agricultural land and, therefore, is not required to be within the HPZ zone. The warp in this area overlays what appears to be abandoned hand-cut peat workings - the topography is still shown in the LIDAR and aerial photography. Limited auguring (at one location) in this area has shown that there is 1 m of warp overlying peat. Given these facts it seems reasonable to debate whether this area should be protected within the HPZ for the lowland raised mire;

- The warping around Durham's Warping Drain (NGR 470662,417110) and the area of peat absence near Elmshurst pumping station and Cassons Garden will not require protection (though they could form part of the protection zone);
- Reviewing the LIDAR and identifying where the SSSI is lower than the surrounding agricultural land and there are no significant drainage ditches should allow the pinpointing of areas where the buffer zone could be minimal;
- A number of the definitions of the site boundary defined by the JNCC work (2005) now appear to be inaccurate (Figure 8-3). A number of boundaries have been defined as having no hydrological features whereas currently they have minor or major drains along the edge. These include:
    - Northern Goole Moors;
    - Sections of the North West Rand Boundary;
    - Cassons Garden;
    - South Eastern Boundary of Flower's Garden.

The original boundary conceptualisation did not likely take into account that the boundary ditches often do not dissect the peat. For example, on the internal side of Thorne Waste Drain, the peat is often very thin or absent (Figure 8-4). The drain cuts into very low permeability clays, rather than peat, therefore, it will not drain the peat to the extent that the original assumptions suggested. The far lower values of hydraulic conductivity for the 25 Foot Drift should be used over higher peat range hydraulic conductivities to calculate the HPZ. This means that the width of the proposed hydrological buffer zone can be reduce significantly around much of the site.

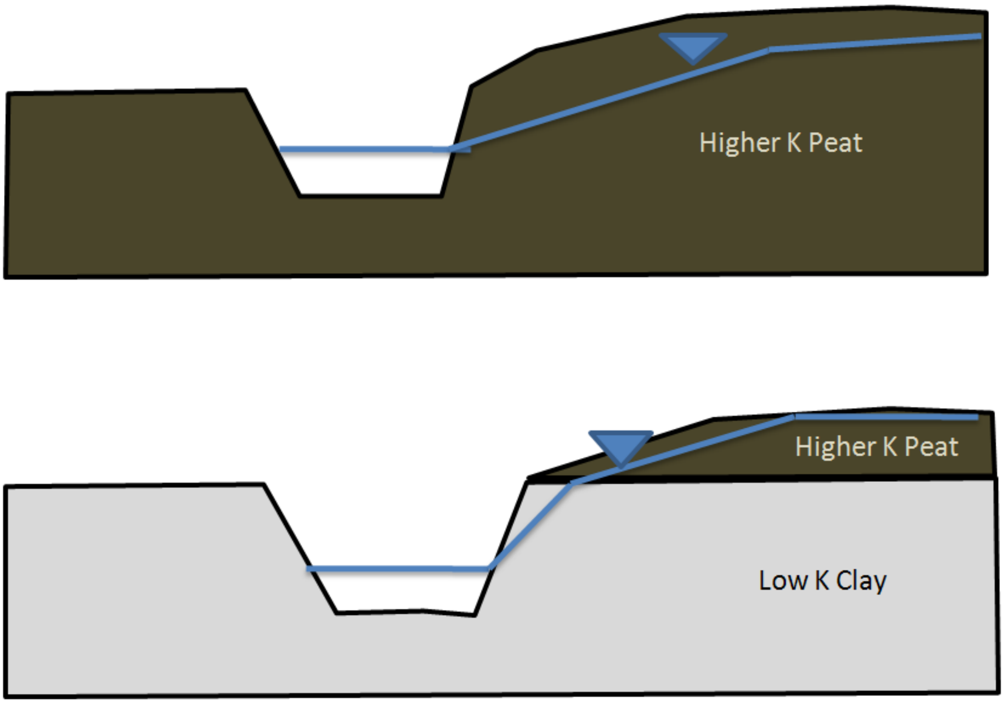

Figure 8-4 Likely initial conceptualisation of major drain boundaries for the HPZs (above) and the updated conceptualisation (below)

Thorne Waste Drain, and other similar drains, are likely to have a far smaller impact on the water levels within the peat on Thorne Moors than was originally envisaged. There has been work on Thorne Moors (Van Wirdum, 2004) which suggests that there is often a unit of higher permeability at the interface between the peat and the clay which should be taken into account. However, it is still likely that the initial conceptualisation of many of the drains leads to a too conservative outcome.

Suggested adjustments to the proposed HPZ

Section 8.1.4 reviewed the proposed HPZ (JNCC, 2005) around Thorne, Crowle and Goole Moors and identified a number of inaccuracies which could require adjustments to be made. This section identifies these adjustments, however, it should be noted that this assessment is based solely on conceptualisation and no attempt has been made to create any analytical or numerical models to aid in defining the spatial extent of the HPZ.

The following adjustments to the HPZ are suggested (Figure 8-5):

- Removing the area of warped agricultural land to the south of Crowle Moors and Thorne Moors from the area required to be protected by the HPZ;
- Minimising the HPZ along the Swinefleet Warping Drain (but maintaining a HPZ on the Swinefleet Line Drain;
- Minimising the HPZ along the Thorne Waste Drain where the peat is absent or of minimal thickness;
- Around Bell's Pond limiting the lateral extent of the HPZ up to the edge of Thorne Colliery Tip;
- Creating a HPZ at the Green Belt as there is a boundary ditch at this location;
- On the North West Rand and Northern Goole Moors boundary there are some minor ditches along the boundary and a topographical depression on the edge of the agricultural land. The HPZ could be extended to the edge of this topographic low;
- Along the northern boundary of Crowle Moors, the agricultural land lies above the level of the SSSI, this would allow the area of the HPZ to be minimal;
- The track running along the northern half of the eastern boundary of Crowle Moors is likely to act as a less permeable bund reducing the influence of the external drain. This means that it may be possible to reduce the HPZ in this area;
- Along Ribbon Row much of the eastern end of it is warped and the peat is often lower than the surrounding land. In this area the HPZ can be made much smaller;
- A relatively large HPZ is likely to be required for the south of Crowle Moors as there are large boundary ditches and the topography is such that the bordering agricultural land and the edge of the site lie within a topographical depression. The drainage of the agricultural land here also drains the edge of the site, therefore, a HPZ is required.

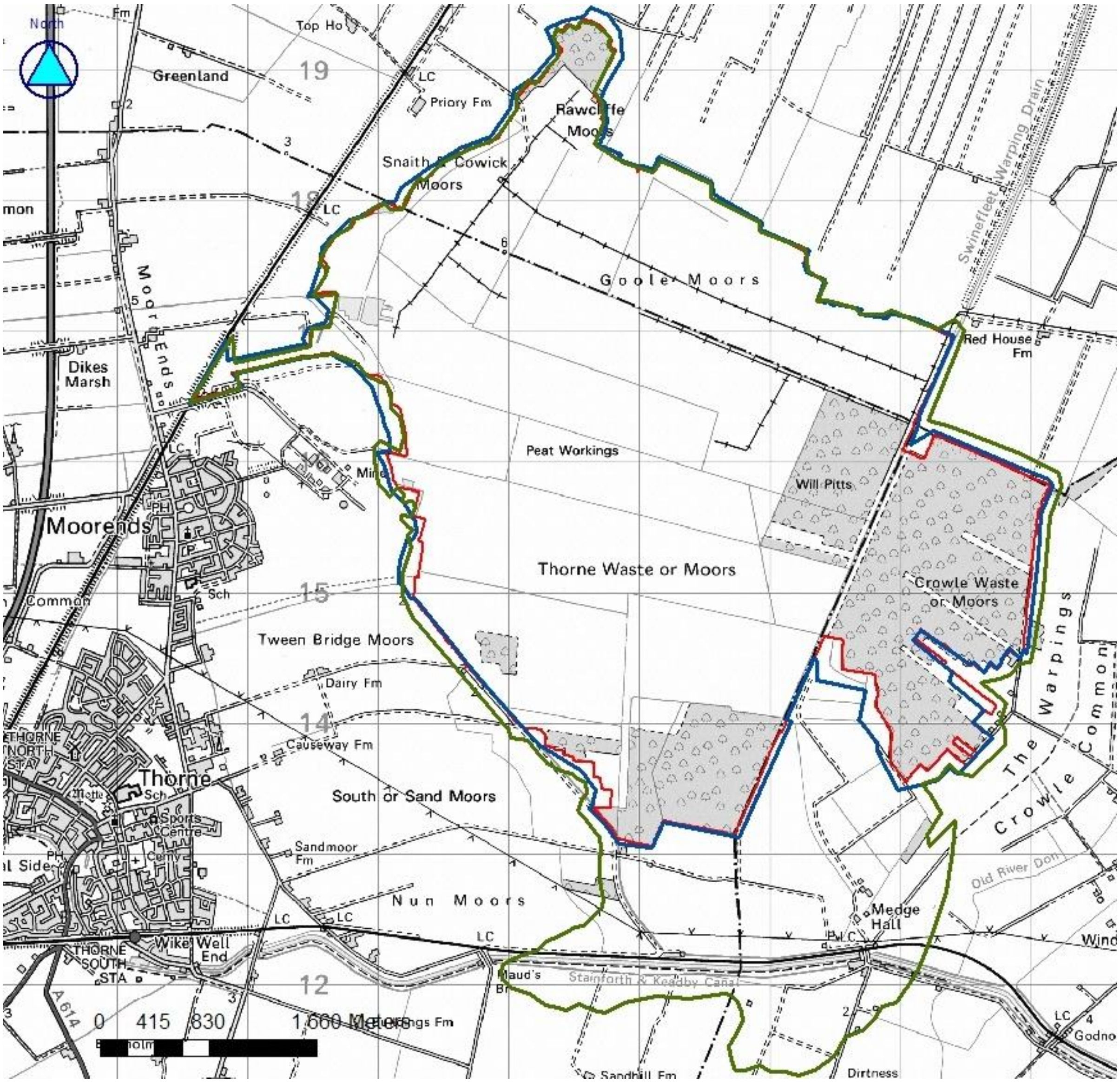

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Figure 8-5: JNCC Proposed HPZ and the Adjusted Proposed HPZ (Green = JNCC Proposed HPZ, Blue = proposed adjustments and Red = SSSI site boundary)

The suggested modifications of the HPZ have not been subjected to a full review using the HPZ methodology (Morgan-Jones *et al*., 2005). Given that this review has suggested extensions to the HPZ in some locations and reductions in others in order to create an effective HPZ, it is recommended that a full review using the JNCC (Morgan-Jones *et al*., 2005) methodology be conducted as part of the WLMP implementation process.

8.2 Restoration Aims

The following water level targets have been set for the SSSI by the previous WLMP (JBA 2008);

> *There is a single objective for the Thorne, Crowle and Goole SSSI WLMP which is:*
>
> ***to provide water levels to bring the site into favourable condition (or unfavourable recovering condition) by 2010****.*
>
> *To achieve this objective, a series of specific targets are outlined below.*

Within the favourable condition table it is considered that the water level requirements of the degraded lowland raised bog habitat are:

- *Watertable close to ground level (within approximately 10cm of the surface) and indicative of anaerobic conditions. The mean free groundwater level over the mire expanse should not fall more than 25cm below the surface in more than one year in five.*
- *Stable water levels close to ground level around the edges of the raised bog. Water levels in ditches are not to fall more than 50cm below ground level in more than one year in five.*
- *Appropriate habitat such as lagg fen should surround the bog for such a distance as hydrological studies recommend.*

The desired distribution of designated habitats, and their water level requirements, will determine the targets for water level management for the SSSI. From the review of existing information to date, key targets have been identified for the SSSI in order to achieve the overall objective. Key targets and actions for water level management are outlined in Table 8-1.

Table 8-1: Actions and Targets for Water Management

	Target	Action	Responsibility
1	**CONSERVATION – bog habitat**		
1a	Watertable within approximately 10cm of surface.	• Develop a robust understanding of the hydrological regime by: ○ Reviewing previous studies undertaken on the Moor ○ Collaborate with current studies ○ Collecting and analysing new data as appropriate • Develop options to manage hydrological inputs and outputs to provide the water levels required for favourable condition • Apply the Hydrological Protection Zone approach to the site	IDB Group Natural England
1b	Stable water levels close to ground level around the edges of raised bog		
1c	Water levels in internal ditches not to fall more than 50cm below ground level in more than one year in five.		
2	**FLOOD DEFENCE**		
2a	No increase in flood risk to people or property.	• Undertake flood risk assessments of the current and future management scenarios as part of the options development • Investigate alterations to the drainage network to allow greater flexibility in management	IDB Group
3	**AGRICULTURAL LAND**		
3a	Appropriate water levels for land use	Undertake review of the current pumped drainage operating regime to assess its capacity to accommodate increased surface water runoff	IDB Group
3b	Alter water management practices	• Investigate appropriate agri-environment support to allow altered water levels	Natural England IDB Group
4	**WATER RESOURCES**		
4a	Sufficient ditch water levels retained in summer for use by licensed abstractors.	• Discuss collaboration with Environment Agency on abstraction modelling	IDB Group Environment Agency
5	**CLIMATE CHANGE**		
5a	Climate change accommodated within water level management	• Investigate impact of climate change on the water management of the Moor	IDB Group
6	**WATER QUALITY**		
6a	Limit pollution of watercourses from land drainage associated with water level management.	• Investigate water quality as part of options development.	IDB Group

	Target	Action	Responsibility
7	***NIGHTJAR***		
7a	*No significant adverse effect on Nightjar populations as a result of implementing the WLMP.*	• *Undertake assessment of any construction works and changes in water levels on Nightjar habitat as part of the Plan.*	*English Nature/ Environment Agency*

The question should be asked whether, as a result of the conceptualising work conducted as part of this study, the aims set out in Table 8-1 are still achievable. The degree of degradation of the peat and the change in topography as a result of peat cutting works means that intermediate restoration aims should be defined to stop further degradation and encourage peat formation. However, the water level targets should be seen as the final aim of any restoration works. The second point to emphasise is that other restoration aims may be more desirable for areas of the site, such as in areas of ancient or wet woodland and these should be reflected in this report.

The degree to which the water level targets are feasible is controlled by the amount of degradation an area has incurred. Table 8-2 (Schumann and Joosten 2008) classifies the degree of degradation wetlands have been subject to. It classifies degradation on the basis of changes to plant, water and peat. Plants are most sensitive to degradation (e.g. overgrazing) and changes in the floristic composition are the first to respond to modifications of the system. At the other end of the degradation scale are changes to the structure of the peat (e.g. intensive drainage and cutting). These changes represent large scale modification of the system: changes to the peat of a wetland require the greatest degree of modification. Once these changes have taken effect, they are the hardest to restore.

Table 8-2: Scale of Degradation State of Wetlands (Schumann and Joosten 2008) (Green = not affected, yellow = slightly affected and brown = severely affected)

Degradation State	Peatland Components						Site Characteristics	Peat Accumulation
	Plants		Water		Peat			
	Fauna / Flora	Vegetation	Hydrology	Soil Hydraulics	Form and relief	Peat deposits		
0 – Minimal	green / yellow	green	green	green	green	green	Natural spontaneous vegetation: undrained human impact restricted to hunting/gathering; possibly some changes in flora and fauna	> 0 (≤ 0)
1 – Minor	yellow	yellow	green	green	green	green	Change in vegetation because of low-intensity grazing/mowing or forestry: not/slightly drained; no pedogenesis yet	> 0 (≤ 0)
2 – Modest	yellow	yellow	yellow	green	green	green	Freshly deeply drained; spontaneous vegetation changed through recent drainage or regular harvesting.	≤ 0
3 – Moderate	yellow	yellow	yellow	yellow	green	green	Low-term very shallow drainage; some pedogenesis; spontaneous vegetation changed by long-term use.	≤ 0 (> 0)
5 – Major	brown	brown	brown	yellow	yellow	green	Long-term deeply drained or inundated, strong pedogenesis; peatland form modified by subsidence and oxidation	<0
6 - Maximal	brown	brown	brown	brown	brown	brown	Intensively drained; strong pedogenesis or compact peat surfaces; peat body severely affected by peat erosion, oxidation or extraction.	<<0

On Thorne Moors the degree of degradation ranges from five to six on the above scale. Such degrees of degradation will affect the restoration aims for much of the designation. This means that, over much of the site, the ideal of creating an almost pristine lowland raise mire will not be possible within a human life time. Practical interim restoration aims should be sought and these should be based on the following guiding principals:

- Stopping further degradation of the peat mass by raising the watertable to near or at the ground surface throughout the year;
- Removal of scrub in areas where it is inappropriate and ensuring it does not re-establish through raising the watertable;
- The establishment of peat forming vegetation;
- Given the timescales involved in the creation of raised mire peat, restoration measures should have a long life span or lead to the creation of a self-sustaining system;
- The interim restoration aims decided upon should be stepping stones towards the creation of a self-sustaining lowland raised mire system.

Table 8-3 summarises the restoration aims and the actions required across the site to achieve these aims. Currently the final restoration aim for the whole site is to restore it to a functioning lowland raised mire, however, due to the time scale required to achieve such an aim, this report instead focuses on producing achievable interim restoration aims for each hydrogeological sub-region, based on the current conditions of these areas. All the restoration aims are based firmly on the mantra of not allowing any further degradation of the peat mass where this is avoidable and encouraging peat formation. The options appraisal summarised in Table 8-5 sets out various methods by which the aims and actions required can be achieved.

Table 8-3: Restoration Aims and Actions Required for Thorne and Crowle Moors SSSI

Hydrogeological Sub-Region	Management Compartments	Restoration Aims	Actions Required
Northern Goole Moors	1 and 4	Creation of a sustainable isolated lowland raised mire within decades	Scrub clearance and raising the watertable around the edge of the site.
Will Pitts Wood	28 and 36	Maintain this as an area of wet woodland.	Watching brief
North West Rand	4 and 5	Long term creation of a rand habitat, with a high watertable across the area and low scrub density.	Initial scrub removal and maintenance of a high watertable through appropriate means.
Milled area	2,6,7,8,9,10,11, 13,14,15,16,18, 19,20,21,26,27, 34,35,40 and 43	Initial creation of a poor fen habitat colonised by cotton grass and *Sphagnum* with a high, stable watertable in which peat accumulation can occur.	Creation of an effective drainage system which can ensure that the area is not overwhelmed by standing water. Creation of high, stable watertables through appropriate means. Encourage the colonisation of peat forming flora. Ensuring that areas of permanent standing water are removed to allow colonisation by appropriate vegetation.
Ribbon Row		The creation of sustainable habitats in an area where the degree of degradation	Maintain high, stable watertables in the strips of thin peat to create poor fen habitat.

Hydrogeological Sub-Region	Management Compartments	Restoration Aims	Actions Required
		and the variation in topography is such as to limit the ability of any scheme to produce high, stable watertables across the whole of the area. Reduce the ability of the low lying areas in Ribbon Row to drain the rest of the Crowle Moors peat mass.	Abandon attempts to create a watertable which can match the topography in the higher areas.
North, South and West Crowle.		Long term creation of a raised mire habitat, with a high watertable across the area and low scrub density Creation of lagg habitat on the edge of the raised mire.	Initial scrub removal and maintenance of a high watertable through appropriate means.
Inkle Moor, Durham's Warping Drain and Paraffin Works	32 (Inkle Moor)	The creation of a lagg habitat.	Stop drainage of the area. Allow appropriate vegetation colonisation.
	33	Improving the neutral grasslands. Maintaining the Inkle Moor Ponds.	Removal of encroaching scrub and maintain the grasslands. Watching brief to ensure the ponds are not filling-in.
	31 and 29	Long term creation of a rand habitat, with a high watertable across the area and low scrub density. Maintaining grassland on the area of warping.	Initial scrub removal and a maintenance of a high watertable through appropriate means. Maintain area of grassland.
	30 (Paraffin Works)	Long term creation of a raised mire habitat, with a high watertable across the area and low scrub density.	Initial scrub removal and maintenance of a high watertable through appropriate means.
South Thorne	68 (Pony Bridge Wood)	Maintain and manage the area of wet woodland. Scrub removal and raising of the watertable on the area of hand cut peat. Allow for a natural lateral progression from the raised mire to the wet woodland area.	Watching brief on the area of wet woodland. Initial scrub removal and maintenance of a high watertable through appropriate means on the raised mire section.
	63	Halting the spread of rhododendron and eventual eradication. Create a sustainable topography (i.e. one where the watertable can be maintained at a high level) which can maintain a raised mire habitat.	Removal of rhododendron. Adjusting the topography and installing structures which can raise the water level.
	51	Maintaining this area of	Watching Brief on woodland.

Hydrogeological Sub-Region	Management Compartments	Restoration Aims	Actions Required
	(Woodpecker corner)	woodland. Reduce scrub and raise the watertable on the rand.	Scrub removal and possibly control structures to increase the water level on the rand.
	37,38,39,44,45, 49,50,51,52,53, 54,55,56,60,61, 63,66,68	Long term creation of a raised mire habitat, with a high watertable across the area and low scrub density. Creation of lagg habitat on the edge of the raised mire.	Initial scrub removal and maintenance of a high watertable through appropriate means.

8.3 Proposed Water Level Management Plan

As the site is hydraulically isolated from its surroundings, the proposed WLMP for the site will consists of four option types:

1. Decrease evapotranspiration;
2. Reduce run-off;
3. Increase water storage on site;
4. Lagg creation.

In the most basic terms, this means vegetation clearance, ditch blocking, bunding and damming of water.

8.4 Summary of Options

Table 8-5 below summarises the management options available for the hydrogeological sub-regions and the individual management compartments within them. Over the whole site similar restoration techniques are recommended to aid restoration:

- Scrub clearance;
- Bund systems, including contour bunding of hand-cut areas;
- Ditch blocking;
- Piling and re-profiling;
- Lagg creation;
- New ditches outside of the mire;
- Levees;
- Pumping and modification of the drainage regime.

The following section describes the nature of these restoration techniques and Table 8-5 and Figure A 13 outline where these techniques should be implemented.

Scrub Clearance

Scrub clearance is likely to be an effective method of reducing evapotranspiration over much of the site. There are some notable areas where the woodland is of higher ecological value and these would not be cleared. These include:

- Will Pitts Wood;
- Pony Bridge Wood and Limberlost Wood;
- The Alder Thicket on the edge of the North West Rand;
- Some oak woodland at Woodpecker Corner;

- Woodland at the bottom of the Yorkshire Triangle.

Scrub clearance would focus on birch scrub and woodland in areas that Figure A 14 shows to be either too dry or slightly too dry. In areas which are sufficiently wet it is likely that the high water levels are causing a die-back of the scrub, meaning that manual scrub clearance is not required.

In areas of scattered trees, the tree spacing may be deemed appropriate, especially in light of the need for Nightjar habitat. It is important that these areas of scattered trees are not allowed to form more dense woodland and a monitoring plan for this is recommended.

There are currently dense rhododendron stands in Compartments 37, 63 especially and some others. These should be considered for removal. However, the costs of rhododendron removal are likely to be very high.

Restoration Techniques for English Hand Graving and Mechanical Baulk Cutting Areas

The ridge and furrow topography created by English hand graving and mechanical baulk cutting methods across much of the site has led to the development of a micro-topography which does not allow the watertable to follow the ground surface, leading to dry ridges and wet furrows. The ridge and furrow topography also encourages drainage and increased run-off, leading to a general lowering of the watertable.

Depending on the age and the technique of abstraction used to form the micro-topography, three different restoration techniques are recommended (Figure 8-6). The exact nature of the micro-topography can vary over a small area, therefore, it is recommended that the choice of the exact method employed be reviewed on a field-by-field basis once scrub clearance has taken place. The three techniques are:

- Small Ridges with Drains within a Wide Furrows Restoration - the topography is such in these areas that blocking the small drains at regular intervals with peat bunds (similar to grip blocking techniques) is likely to raise the water level in the wider furrows, bringing them up to a suitable level at or near the surface;
- Subdued Ridge and Furrows on a Sloping Field – on some of the older English hand graving fields the topography is more subdued but the slope on the field is such that the higher ends of the field are drained. In these fields it is recommended that a contour bund similar to those installed on the milled areas be placed across the fields;
- Wide Ridges, No Drains – where the micro-topography is such that there are wide ridges with small peat cliffs down to a narrow furrow. It is recommended that a peat bund be placed across the furrow to a height slightly proud of the ridges (to allow for settlement).

Due to the micro-topography, the techniques recommended will only allow the watertable to be at the required height for parts of the field (ridges or furrows). The micro-topography is such that there appears to be no sustainable solutions for accounting for this.

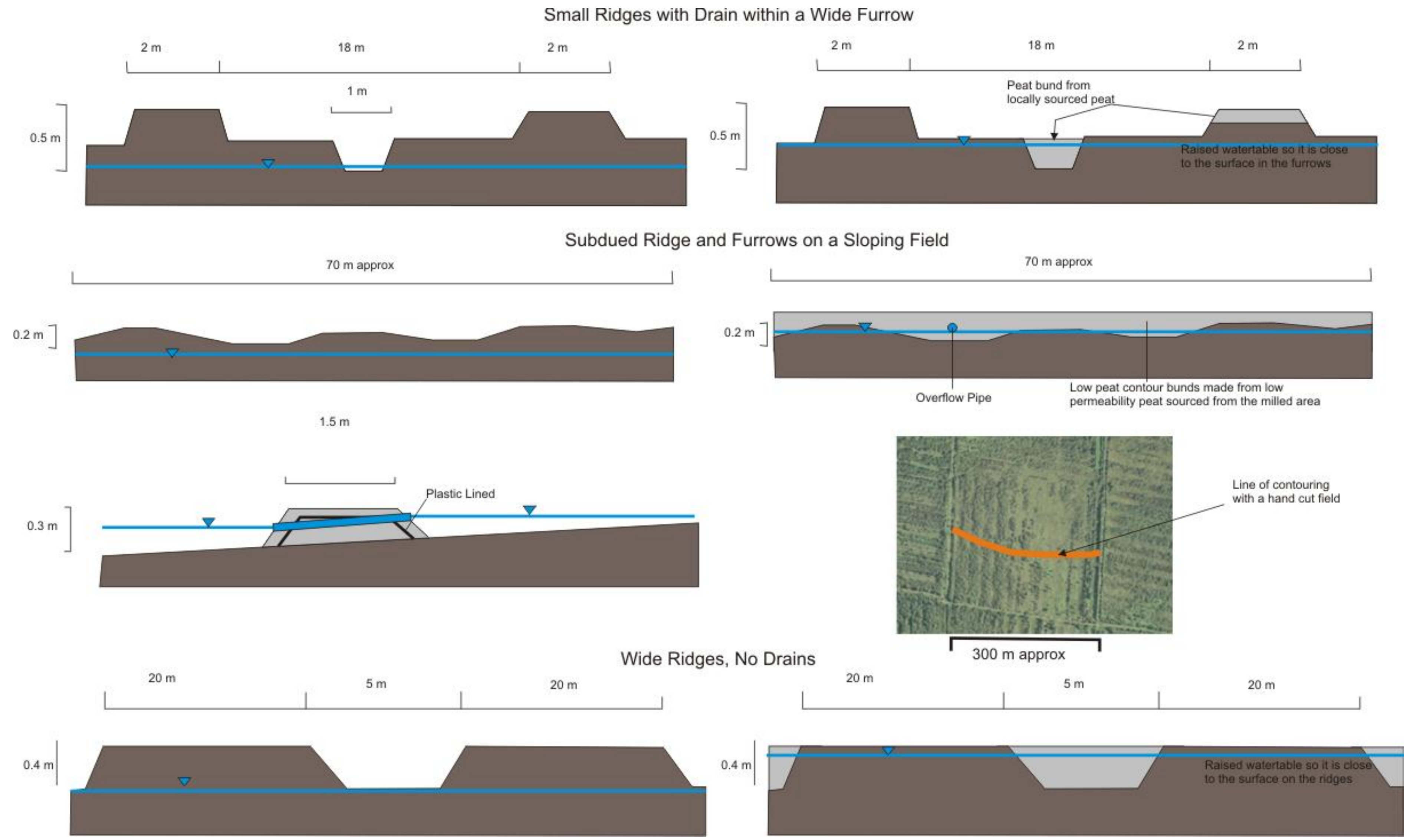

Figure 8-6 Schematic of Ridge Furrow Topography Restoration Techniques (NTS)

Bund Systems

Bund systems have been employed successfully over much of the milled area. They consist of low bunds (approx 0.3 m high) with adjustable outlets that discharge through bunded cells to the main drains. It is recommended that these be extended over most of the areas that have been milled.

Ditch Blocking

This encompasses a range of methods for ditch blocking, including peat bunds, plastic sheet piling and larger structures. Within minor drains on the peat mass, peat bunds and plastic sheet piling, which have already been employed on site, should produce satisfactory results. The larger agricultural drains which surround the site will require larger-scale engineering works in order to block them.

Piling and re-profiling

The history of peat working on site has left some areas with rapid lateral changes in topography and in some locations there are 'peat cliffs'. In some areas the topography is such that it would be impossible to raise the watertable to within 25 cmbgl without re-profiling or sheet piling.

Rapid changes in topography are not naturally sustainable features and are prone to erosion and peat degradation, leading to the topography naturally flattening out given enough time; however, these areas are also prone to colonisation by scrub and woodland. Without piling or re-profiling, scrub could become established and difficult to remove. 'Peat cliffs' have a lower watertable because of the topography. Woodland and scrub colonisation results in more water loss via evapotranspiration, potentially exacerbating the problem of a lowered watertable and causing the area of watertable drawdown to extend further from the 'cliffs'. As scrub encroaches further from the 'cliff' edge it could make the situation worse. A good example of a 'peat cliff' is the one separating Compartments 76 and 77.

Re-profiling involves carrying out earthworks to create a new profile for a peat 'cliff' face, so that the topography is gentler. The watertable can more closely match this new topography, so that the watertable can be at or near the surface.

Sheet piling involves placing a vertical impermeable barrier along the edges of 'cliffs' and smaller breaks in slope in order to impound the groundwater within the peat mass. This prevents the water from draining away and thereby raises the watertable. An area of open water may be created adjacent to the piling. It is important that the piling retains water.

Re-profiling is likely to be the preferred option for longer, higher, peat 'cliffs'. Sheet piling is more suitable for smaller stretches where there is a break in slope, in areas that are difficult to access with larger moving plant and, potentially, at the edge of the site where there is insufficient land for re-profiling.

Shape of Reprofiling

The following section aims to assess the shape of the reprofiled proposed slopes based on site data, monitoring and 1D analytical groundwater models. The reprofiled slopes should be shaped so that the watertable can closely match the profile of the slope.

In order to find the shape of the watertable along the slopes which require reprofiling a 1D analytical model was used (Figure 8-7). A range of hydraulic conductivity values were tried (1.0×10^{-4} to 8.0×10^{-4} m/s Bromley *et al*. (2004)) and a estimate of recharge based on the MORECs 100 square was used (74 mm per year).

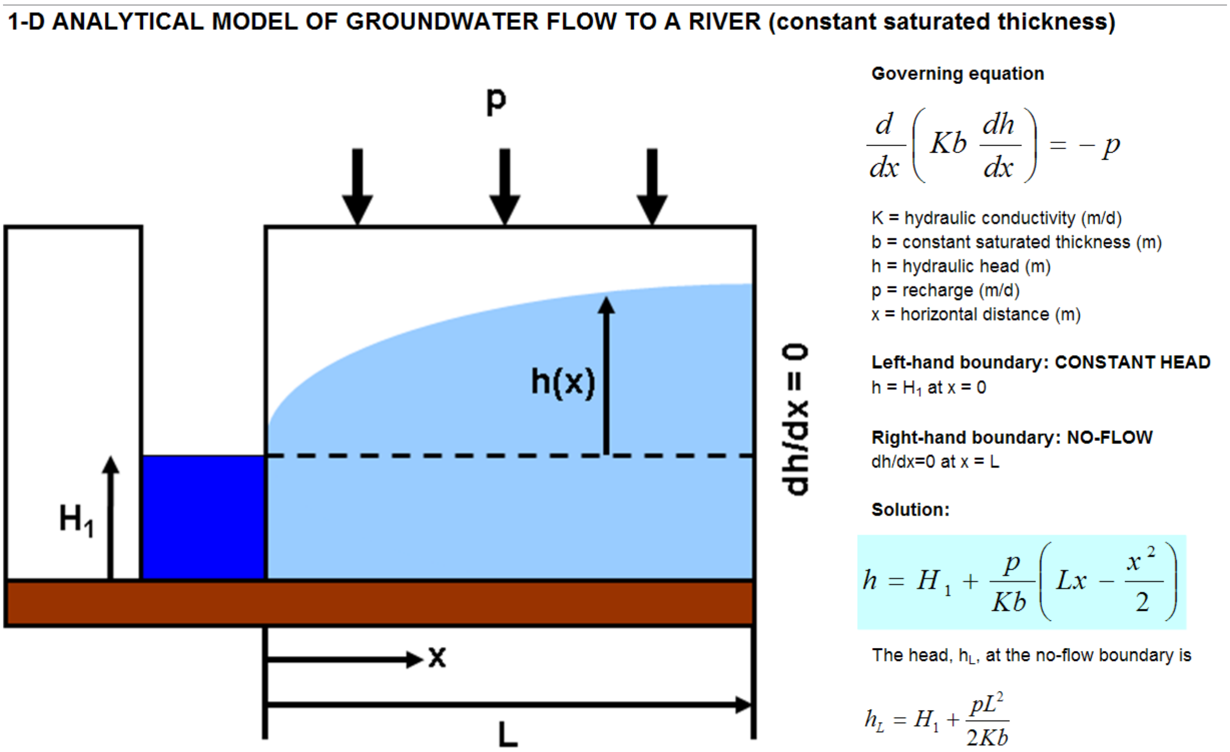

Figure 8-7 Systematic of the 1-D Analytical Model Used in the Reprofiling Design

Borehole CRBH9 which lies above the peat cliff in the centre of Crowle was used to provide information on the actual drawdown caused by the cliff. This information was used to assess the most appropriate value of hydraulic conductivity to use in the calculations of 4 x 10^{-4} m/s (i.e. one that showed a similar degree of drawdown at the same distance from the cliff edge).

The distance from the edge of the cliff that requires reprofiling was estimated as being the distance that the analytical model showed the groundwater emerging above the surface. Table 8-4 estimates the distance from the edge that will require reprofiling on several of the peat cliffs across the site.

Table 8-4 Estimates of the Distances Required for Reprofiling

Name	Grid Reference	Distance (m)
Middle Crowle (Compartment 76/77 Boundary)	475432, 414934	35
Cassons Garden (Compartment 63)	472648, 413701	The topography of the peat mass in this area is likely to be too narrow and the boundary ditch too deep to allow effective reprofiling.
Ribbon Row (Compartment 81)	478988, 414680	20
Goole Fields (Compartment 10 and 13)	472280, 417710	20

The estimates stated in Table 8-4 are provisional to aid in quantifying the scales of work required. A number of assumptions have been made in the calculations and, before implementation works begin, it is recommended that these calculations be reviewed when more on-site evidence has been gathered. In certain areas reprofiling may be done in conjunction with other restoration techniques. This may raise the watertable at the base of the peat cliffs and reduce the degree of reprofiling required.

Lagg creation

Where an HPZ is likely to be required, it is recommended that, in most cases, lagg habitat formation be encouraged through a range of techniques. Creating a lagg is likely to improve the water levels around the edge of the site through creating a buffer area with near-surface water levels. The techniques which could be used to create lagg areas include:

- Ditch blocking;
- Ditch infilling – around Northern Goole Moors simply blocking the ditches will not stop the peat mass from being drained as the land outside the SSSI is significantly lower than the peat at the edge of the SSSI (Figure 8-8 and Figure 8-9). This is because ditch blocking creates an open water body from which water can evaporate and/or escape as runoff so that, in effect, the peat is constantly (but slowly) being drained. Infilling the ditch with a low permeability material (likely to be warp sourced from the new drain created to bound the lagg) would act as a seal, reducing drainage from the base of the peat mass and raising the watertable. This would have a similar affect to piling. Infilling ditches would allow the volume of water that would have been contained within the ditches to spread out over the lagg area.
- Levees – in some locations the natural topography surrounding the site is not currently suitable for lagg creation as the agricultural fields fall away from the site. In these areas, small levees approximately 0.4 m tall with designed overspills would impound surface water within the lagg (Figure 8-10 and Figure 8-11).
- New ditches – on the edge of the lagg creation areas, new agricultural drainage ditches will be required. These will be placed on the outside of levees or on the edges of the topographical depressions used as boundaries to the lagg creation areas.

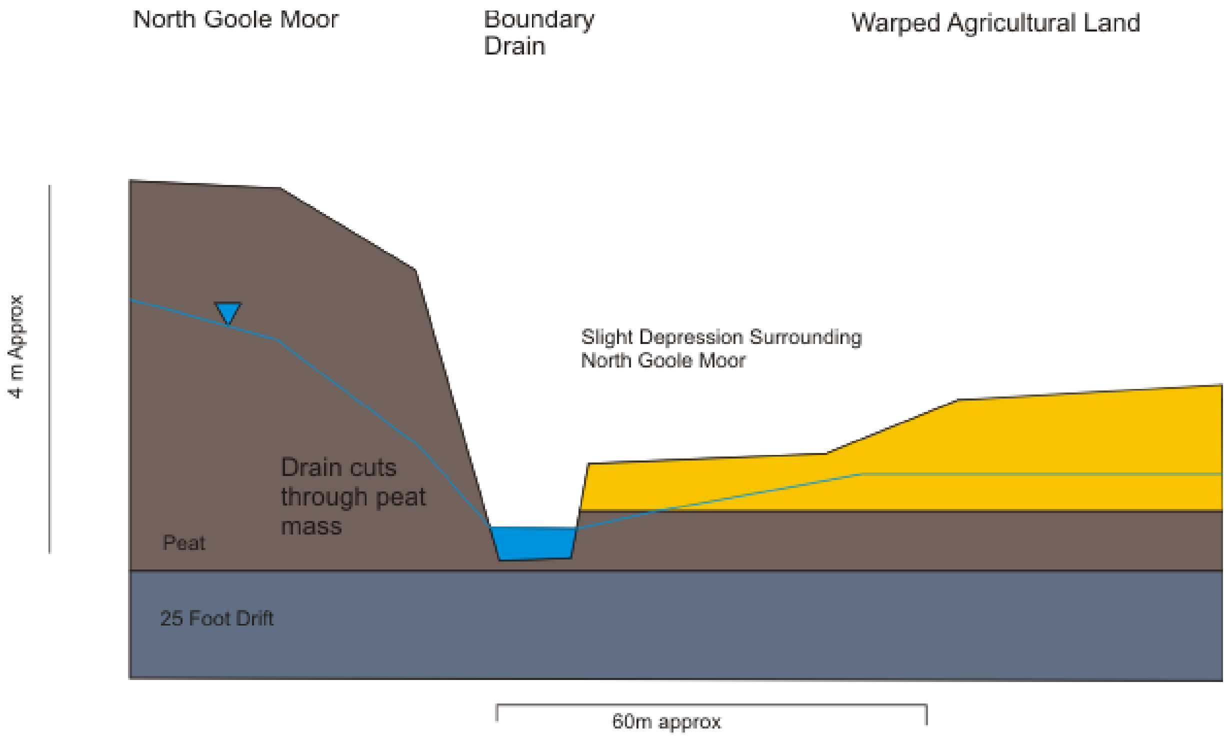

Figure 8-8 Conceptualised Model of Northern Goole Moors Before Lagg Creation

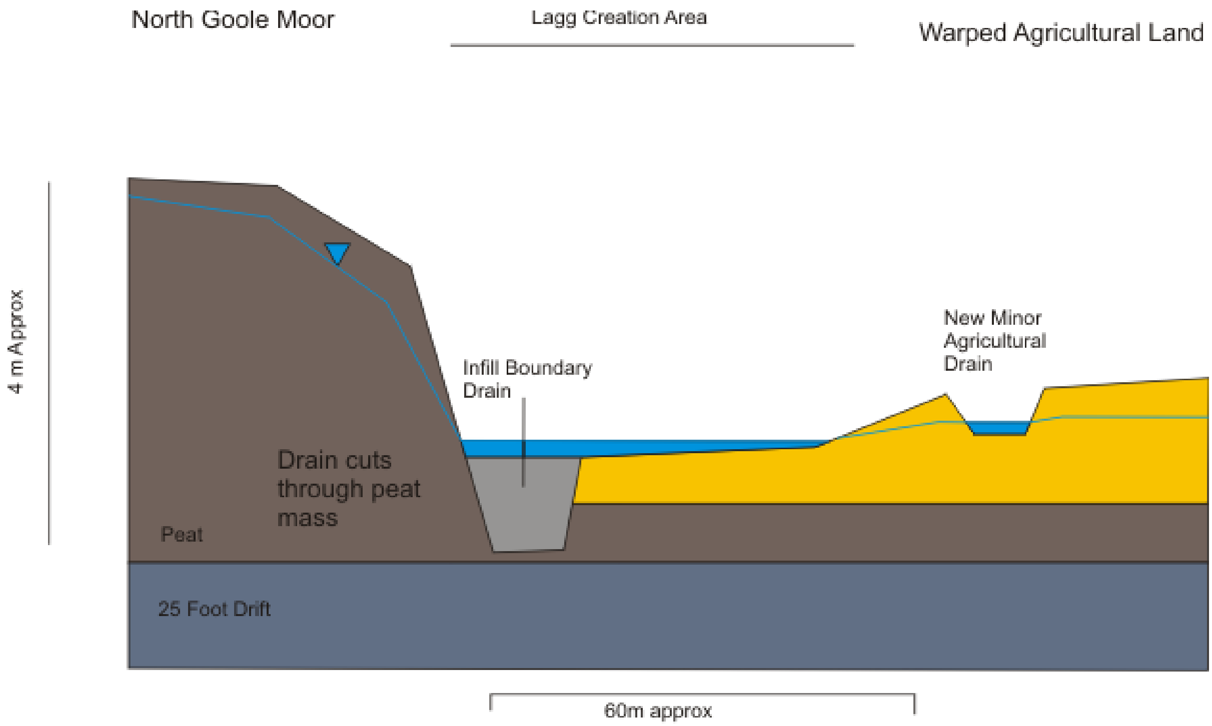

Figure 8-9 Conceptualised Model of Northern Goole Moors After Lagg Creation

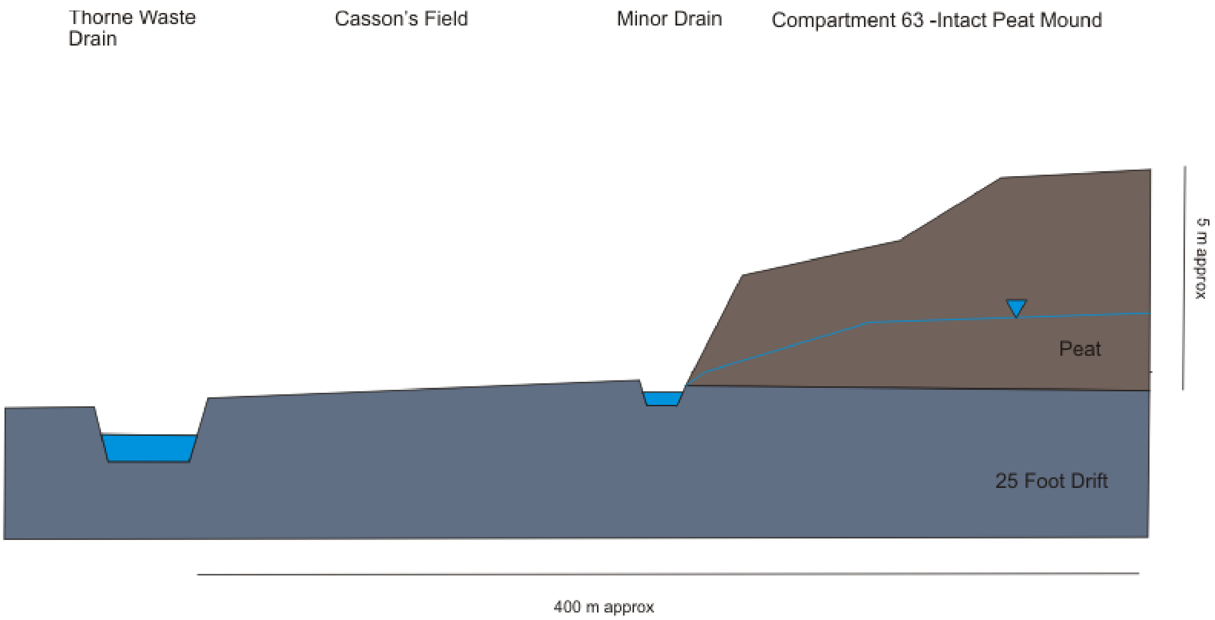

Figure 8-10 Conceptualised Model of Cassons Field Before Lagg Creation

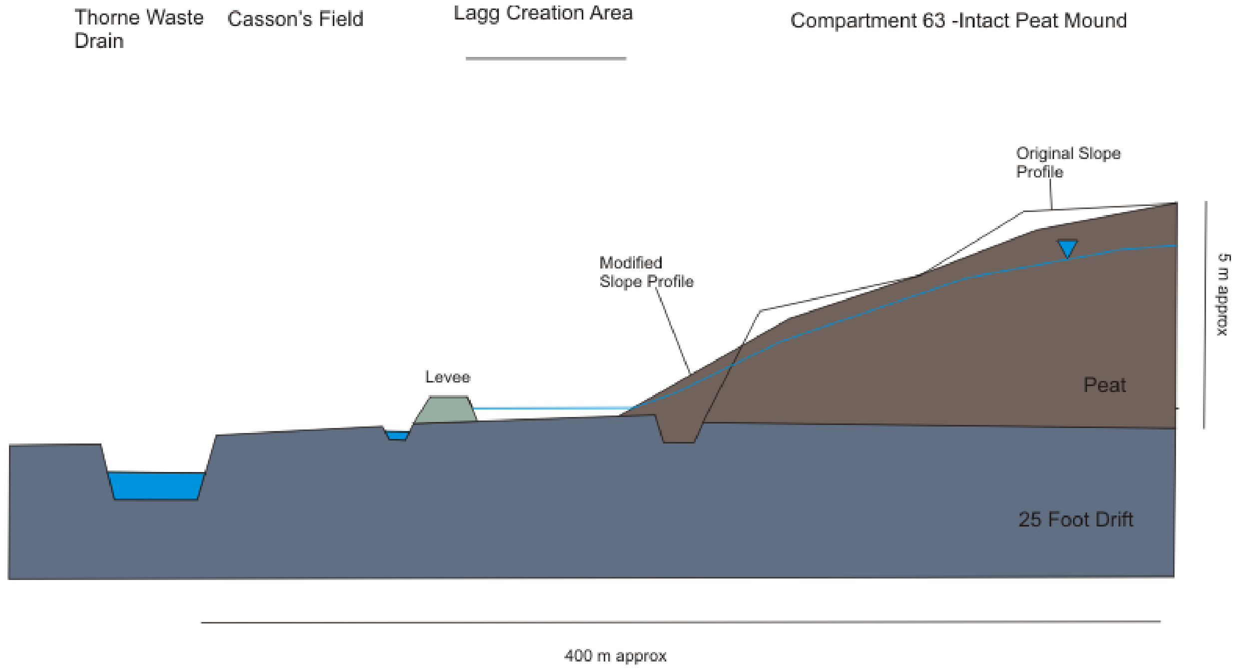

Figure 8-11 Conceptualised Model of Cassons Field After Lagg Creation and Reprofiling

Modifications to the Drainage Regime in the milled area

The main aim of the pumping and drainage regime within the milled area should be to maintain sufficient storage capacity within the main drains to allow the cells to drain freely into them, so that the water within the cells does not become too deep and so that the bunds are not overtopped. Given the relatively isolated nature of each cell and the small zone of influence of the main drains over the milled areas (due to the low permeability of the peat in these areas), the water levels within the main drains are likely to have only a limited effect on groundwater levels across the area. However, the ideal scenario would be to maintain water levels in the main drains at just below the outflows from the cells for as much of the year possible. This would limit the degree of degradation in the peat that forms the banks of the main drains in the milled area.

The current system has several features that make it difficult to maintain sufficient storage capacity and to maintain high water levels within the main drains:

- There is one outlet to the system and this discharges to the Swinefleet Warping Drain in the east. This means that water within the drainage network on Rawcliffe Moors and Snaith and Cowick Moors has to travel over 3 km before it reaches an outlet. In order to lower the water level in the main drains in these more distant areas, it is necessary to begin pumping quite far in advance of a storm event;
- The maximum discharge rate from the system means that pumping is often required to start far in advance of forecasted rainfall events;
- There is no formal system for regulating the rate of discharge based on the capacity of the system (the capacity within the main drain and the bunded cells) and the forecast intensity of the rainfall;
- Pumping is controlled manually, and this requires Natural England staff to be on-site. Rainfall events that are not forecasted accurately, or that occur at times when personnel are not on site, are less likely to be responded to effectively.

As a result of these problems the pumping and drainage system is slow, inflexible and prone to draining the system too much and sometimes unnecessarily. There is also a risk of unforeseen rainfall events resulting in widespread flooding on site and bund overtopping. The following modifications to the system are recommended to improve this:

- Increasing the number of discharge points from the system. This would reduce the path length of water discharging from the system, so pumping could occur closer to rainfall events. It would also allow the main drains in parts of Rawcliffe Moor and Snaith and Cowick Moors to be lowered independently from the rest of the system. The two proposed new discharge points are shown in Figure A 13:
  - The drain at NGR 470695, 417280 which runs along the northern boundary of the Paraffin Works;
  - The drain on Rawcliffe Moor at NGR 472085, 418710 at the Priory Farm Entrance.

  It is likely that both of these discharge points could consist of adjustable weirs. Works to open these discharge points would include increasing the capacity of the drains upstream and downstream, surveying the gradients of the main drains and determining which parts of the altered drainage system the new discharge points could drain;
- Assess the capacity of the current pump, in order to assess whether a larger pump would allow pumping to commence later. It would also be necessary to consider the capacity of the drainage network downstream to accept the pumped input;
- Creating an automated telemetry pumping system. This system would automatically control the rate of discharge from three discharge points based on stage levels in the drains. This system would be able to react quicker and later to rainfall events, reducing the incidences of over-pumping;
- Control structures within the main drains in the milled area to allow for more flexible control of which direction the drains flow.

8.4.2 Summary of Management Options

Table 8-5 outlines the management options for the site by management compartment. Up to three options have been given for each area. Option 1 is currently the preferred option as it is believed that this is most likely to achieve the water level targets for the site.

Table 8-5: Summary of Management Options

Hydro-geological Sub-region	Management Compartments	Options 1 – Preferred Option	Option 2	Option 3
Milled area	2,6,7,9,11,14,15,21,27,34,43 (Bunded Mill Area)	Adjusting the heights of the outflows from the bunded cells to produce a mean watertable elevation at, or just below, the ground surface. These adjustments should be informed by survey work on species colonisation in each bunded cell and through analysing data from a monitoring array.		
	2,6,7,8,9,10,11,13, 14,15,16,18,19,20,21,26,27,34,35,40,43 (The whole milled area)	Creating a pumping system based on automated telemetry to maintain relatively high water levels within the main ditches all year round whilst still maintaining the capacity to deal with large rainfall events. Increasing the number of discharge points from the system by reopening ditches that breach the North West Rand at NGR 472057, 418769 (Creykes Gate) and 470476, 417290 (Durham's Warping Drain). At the detailed design stage the impact of the downstream catchment and pumping stations will be assessed. This will include an	Increase the number of discharge points from the system (as option 1).	Maintain the current system of weirs and pump.

Hydro-geological Sub-region	Management Compartments	Options 1 – Preferred Option	Option 2	Option 3
		assessment of suitable maximum consented discharge rates.		
	8,16,18,19, 20,21,26,35 (The milled area without bunding)	Extending the bunding system across the whole of the milled area, to include Natural England land not included in the original plans, and also land not currently owned by Natural England.	Delay extending the bund system and give time for vegetation communities to develop before assessing the need to extend the bund system further (i.e. allow time to see whether desirable communities develop naturally without intervention.	
	10, 12, 13, 18, 20 (The Wooded Strips)	Removing scrub and blocking the minor drains that surround these compartments.	Scrub removal.	
	10, 12 and the northern halves of 13 and 14	Bunding or re-profiling the edges of these units where higher ground is surrounded by main drains or lower milled ground, e.g. the boundary between units 10 and 11. Options for the type of bunding (sheet piling, etc.) or re-profiling have not been appraised.	Scrub removal and raising the water level in the surrounding drains through control structures.	
	12	Blocking of the hand cut ridge-and-furrow topography with peat bunds. Scrub removal. Bunding boundary ditch.	Scrub removal. Bunding boundary ditch.	Scrub removal and watching brief.
Northern Goole Moors	1 and 3	Removing scrub – possibly using an 'aerial runway' method in areas of intact raised mire hummock topography. Creating an HPZ – infilling the current boundary drain and instating a new drain 60 m away from the current one so as to create a lagg habitat in the natural topographical depression that surrounds the compartment. Blocking internal drains that run through the peat.	Scrub removal and control structures within the internal and surrounding boundary drains.	Scrub removal and block internal ditches.
Inkle Moor, Durham's Warping Drain and Paraffin Works	33	Removing scrub and instating a regular grazing management program.	Remove scrub and instate a mowing regime.	
	32	Lagg creation – blocking the ditches that drain the edge of the raised mire (Unit 31), thereby encouraging the wet woodland and lagg fen habitat which already occurs over much of the site.	Watching brief.	
	31	Removing scrub.	Scrub removal and review effectiveness	

Hydro-geological Sub-region	Management Compartments	Options 1 – Preferred Option	Option 2	Option 3
		Blocking of the hand cut ridge-and-furrow topography with peat bunds. Maintaining grazing of the warped area.	of ditch blocking in the area. Maintaining grazing of the warped area.	
	29, 30	Removing scrub in areas where it is apparent that the raised water levels are not causing the scrub to die back.	Watching brief.	
North West Rand	4 and 5	Removing the birch scrubland, leaving the established alder wet woodland on the edge of Compartment 5. Defining an HPZ in the northern part of the area by blocking the external ditches and creating a habitat like the Alder Thicket found in the southern part of the North West Rand.	Removing the birch scrubland, leaving the established alder wet woodland on the edge of Compartment 5.	
Will Pitts Wood	28, 36	Watching brief		
South Thorne	37,38,39,44,45, 49,50,51,52,53, 54,55,56,60,61, 63,66,68	Removing scrub in areas where it is apparent that the raised water levels are not causing the scrub to die back.	Removing the denser areas of scrub and monitoring areas of scatter trees to ensure that they do not become denser.	
	37,39,52,53,54, 55,56,57,60,61, 65,66,68	Contour bunding or other method – in dry areas, blocking the ridge-and-furrow topography with peat bunds along contours in order to reduce runoff. These would aim to aid in rewetting whole fields (at present the lowest parts of the fields are wet but the higher parts are too dry).	Scrub removal then assess the need of contour bunding base on continued monitoring of the watertable and of scrub encroachment i.e. bund where scrub removal by itself it proved to be ineffective.	
	67, 68	Maintaining the areas of wet woodland in Pony Bridge and Limberlost Woods.		
	58	Replace Balley Bridge fixed weir near Bailey Bridge with an adjustable control structure.	Maintain existing Balley Bridge structure.	
	63	There are several possible options for Cassons Gardens: Filling in the small external boundary ditch and creating an HPZ which could be bounded by a clay levee to create an area suitable for colonisation by lagg vegetation. Improving the external peat 'cliff' through:	Assess the potential for the area to support a raised mire habitat after rhododendron removal.	Abandon area as a having the potential to be a raise mire in the future given the prohibitive topographical and rhododendron constraints.

Hydro-geological Sub-region	Management Compartments	Options 1 – Preferred Option	Option 2	Option 3
		- Re-profiling (engineering the 1 – 3 m tall 'cliff'). - Sheet piling. Clearing rhododendrons – this should only be done in conjunction with engineering works to raise the watertable. This is because the current depth of the watertable is such that scrub would be likely to recolonise the area following clearance.		
	51	Piling along the edge of the peat to re-wet this high area.	Assess the need for piling after the effects of scrub removal on the watertable have been assessed.	
	37	Adjustable control structure on the New Mill Drain at NGR 473515, 415928.	Fixed control structure on the New Mill Drain at NGR 473515, 415928.	
	37, 39, 44, 45, 51	Lagg habitat creation: Blocking boundary ditches and instating a new ditch up to 175 m away from the current boundary. The area between the site and Thorne Colliery's pit heap could be flooded with no provision for extra ditches, thereby defining the edge of the HPZ.	Lagg habitat creation along the boundaries of compartment 37, 39 and 44 (i.e. land owned by Natural England or is not land used for agriculture)	Maintain and review the effectiveness of the control structures within the boundary ditches.
North, South and West Crowle.	69,70,71,72,73, 74,75,76,83,84, 85	Clearing scrub – all dense woodland in this area should be cleared except the established woodland in Compartment 70.	Scrub clearance only in areas where it is likely to result in the restoration aims being achieved solely through scrub clearance or where accompanied in tandem by engineering works to raise the watertable. e.g. Scrub clearance in Compartment 76 should be accompanied by reprofiling of the peat cliff on its southern boundary at 475432, 414934.	Removing the denser areas of scrub and monitoring areas of scattered trees to ensure that they do not become denser.
	69, 70, 84, 85	HPZ – a topographic low lies around most of the edge of the south of Crowle, including some of the arable fields that bound the site. In order to re-wet this area an HPZ similar to that proposed on the North West Rand would help. This would entail ditch blocking and the creation of lagg habitat. Some reprofiling will be required	Assess raising the water level in the boundary ditch through a series of control structures which aid in limiting the drainage from the peat mass and maintain the drainage of the agricultural land adjacent to the	

Hydro-geological Sub-region	Management Compartments	Options 1 – Preferred Option	Option 2	Option 3
		on the peat cliff edge along part of boundary of Unit 85. The peat from this reprofiling can be used to infill the drain that runs along the base of the cliff.	bog.	
	71	The topography is such that the agricultural land lies approximately 0.5 to 1.5 m above the site therefore it would be difficult to establish a lagg habitat in this area. The current boundary ditch should be blocked (which lies lower than the site) and a new higher ditch dug that will be approximately 10 m into the agricultural land. In the north eastern corner, the current boundary drain is approximately 1.5 m wide and 1.5 m deep and was observed on a site walk over to have a discharge of approximately $4ls^{-1}$ Lagg creation may be suitable in one low lying corner of the field in the north western corner which currently requires significant drainage in order to maintain it.	Block the current on-site boundary ditch and install monitoring equipment to ensure this does not cause a detrimental effect upon the bordering agricultural land.	
	72	A number of small peat bunds are required to block ditches in this part of the site.		
	76	The peat cliff that bounds Compartments 76 and 77 could be improved through: - Re-profiling (engineering the 1 – 3 m tall 'cliff'). - Sheet piling.	Interventional restoration attempts are abandoned in this area and the peat mass is allowed to degrade/subside. The processes can be reviewed periodically to ensure that the degree of scrub encroachment is acceptable and a sustainable peat profile is forming.	
Ribbon Row	77	Options for Compartment 77 are dependent on the method adopted to deal with the peat 'cliff' between Compartments 77 and 78. Blocking the ditch that runs along the base of the northern cliff. Creating a bunded system like that implemented on the milled areas of Thorne.	Block ditch at the base of the northern cliff.	

Hydro-geological Sub-region	Management Compartments	Options 1 – Preferred Option	Option 2	Option 3
	78, 79, 80	The topography in this area will inhibit any attempt to restore the area to lowland raised mire in the short term. It is suggested that some peat in this area be used in restoration activities elsewhere on site, including for the creation of bunds in Compartments 77 and 81. The final surface topography in this area should be more subdued (and so easier to re-wet) than at present. After these works, targeted scrub clearance could aid in the creation of Nightjar habitat in these areas.		
	81	Creating a bunded system like that implemented on the milled areas of Thorne. The boundaries with Units 69 and 82 may require re-profiling, although the need for this could be assessed after other implementation measures have been put in place.	The boundaries with Unit 69 and 82 may require re-profiling, although the need for this could be assessed after other implementation measures have been put in place. Monitor the natural succession in the area and intervene if this is proved to be unacceptable.	Monitor the natural succession in the area and intervene if this is proved to be unacceptable.

8.5 Additional Work

During site walk-overs it was noted that not all sheet pile dams were working effectively (see Figure 8-12). As part of restoration works, these structures should be examined and, where found to be deficient, they should be repaired or replaced.

Figure 8-12 Examples of sheet pile dams working (left) and not working (right)

8.6 Cost Estimate

The estimated costs of recommended works outlined within Option 1 of Table 8-5 (above) are as follows:

Item	Estimated Cost (£)
Clearance of woodland/scrub	1,164,580.00
Piling and re-profiling peat cliffs	218,132.00
Disposal of peat on site locally	227,497.00
Major/minor agricultural dams	50,441.00
Major/minor peat dams	54,021.00
South Thorne contour bunding	471,351.00
Excavation and filling of ditches	31,366.00
Sub Total	***2,217,388.00***
Site investigation for pumping station	10,000.00
Structural and earthworks for pumping station	600,000.00
Pumps for pumping station	80,000.00
Weedscreen cleaner for pumping station	50,000.00
Telemetry for station and remote links to weirs	35,000.00
Electricity connection for pumping station	40,000.00
Sub Total	***815,000.00***
20% Preliminaries (site setup etc.)	606,478.00
TOTAL Estimated Construction Cost	**3,638,866.00**
Engineers Fees (Design, Tender, Site Supervision)	243,804.00
Environmental Impact Assessment	20,000.00
TOTAL Estimated Scheme Cost	**3,902,670.00**

Benefit per hectare (1,920 hectares)	***2,033.00***

These are the total costs for the entire scheme; however, for each of the areas specified in Figure 8-13 below, the costs have been subdivided. Each of these areas is a separate hydrological unit and can, therefore, be dealt with independently of any other, however, in essence the plan takes a holistic approach to managing the entire raised mire and the costing units should not be viewed as a menu, rather a programme of works that can be undertaken and will deliver 'favourable status' across the entire bog and to give an indication of how costs are spread over the site.

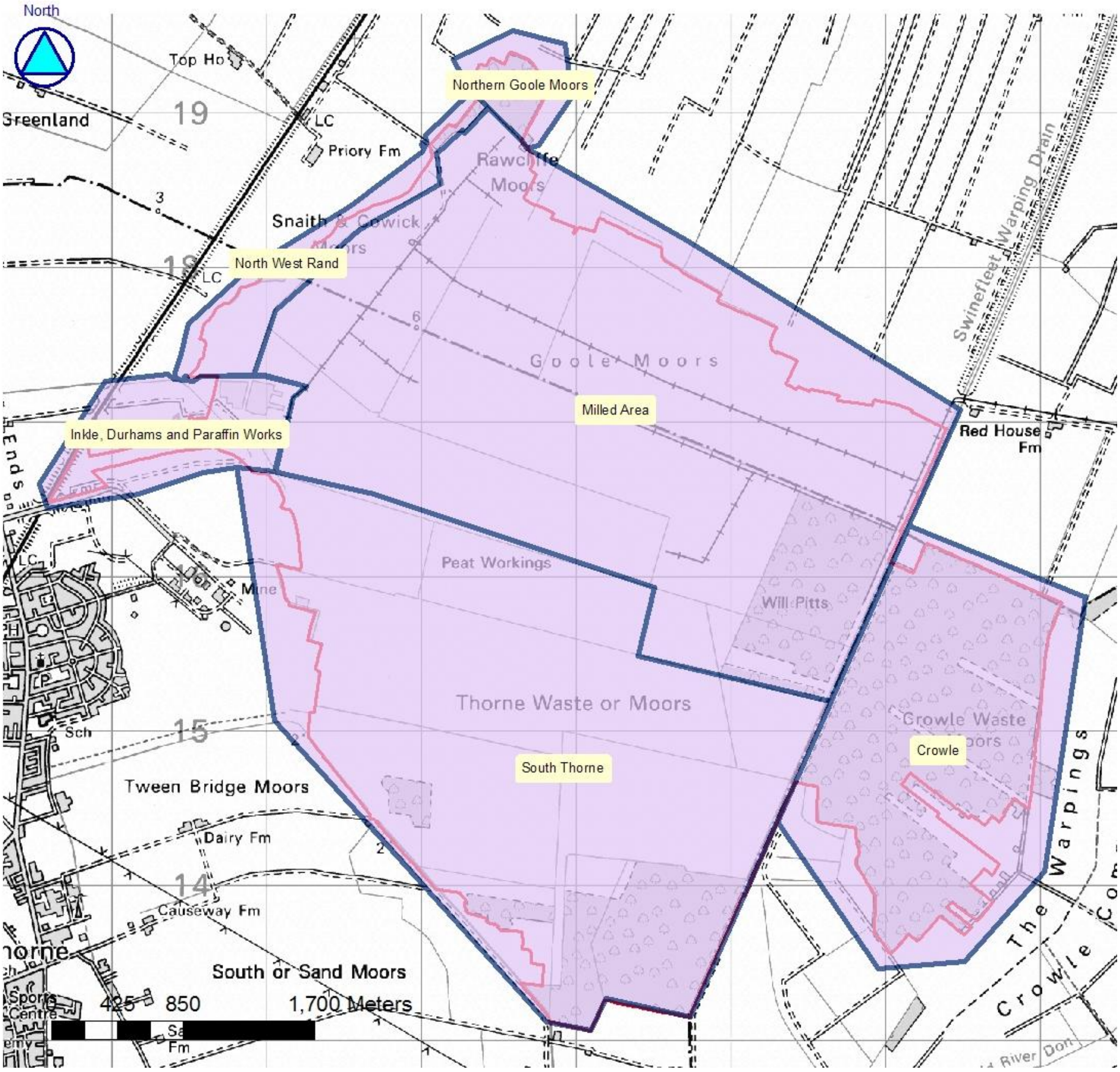

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Figure 8-13 Thorne Moors Costings Areas

8.6.1 Costing Area: Northern Goole Moors

Conceptual outline design

- Clear birch scrub from site to reduced evapotranspiration;
- Create lagg fen area around this management unit;
- Infill existing boundary drain;
- Block small drains using peat dams;

- Cut new agricultural drain at edge of lagg creation area on slightly higher ground to allow the agricultural land to freely drain but minimise drainage influence on Northern Goole Moors and the surrounding new lagg.

Advantages

- Resulting hydrological conditions likely to be appropriate for achieving favourable condition within a very few years;
- very low services costs once works have been completed;
- Lagg creation area will ensure unit meets water level requirements;
- Resilient to periods of low rainfall/drought;
- Low revenue costs.

Costs

- Capital works – approximately £75,500 (note - this includes the £20,000 EIA for the whole site).

Table 8-6 Capital Costs (Northern Goole Moors)

Works	Costs (£)
Clearance of woodland and scrub	31,000
Ditch blocking	1,500
Infilling of existing boundary drain	7,300
Excavation of new minor agricultural drain	3,500
Preliminaries	8,700
Engineer's Fees	3,500
EIA	20,000
Total	**75,500**

- Revenue costs – infrastructure maintenance and monitoring.

Disadvantages

- Will incur land purchase costs;
- Likely damage to the agricultural land during lagg creation works;
- Moderate capital cost (£2900 per hectare).

8.6.2 Costing Area: milled area

Conceptual outline design

- Clear birch scrub from linear woodlands on-site to reduced evapotranspiration;
- Construct a network of peat bunds;
- Install adjustable weirs at Durham's Warping Drain and Creykes Gate;
- Install new pumping station on Blackwater Dyke where it meets the Swinefleet Warping Drain;
- Telemetry system installed to control the drainage of the area.

Advantages

- Resulting hydrological conditions likely to be appropriate for achieving unfavourable recovering condition due to regenerating Sphagnum moss and cotton grasses;
- Very low services costs once works have been completed;
- Resilient to periods of low rainfall/drought
- Rapid, real-time responses to water level changes will reduce the amount of surface water.
- The telemetry system will allow the area to be drained without the presence of Natural England staff on site.

Costs

- Capital works – approximately £1,770k

Table 8-7 Capital Costs (milled area)

Works	Costs (£)
Clearance of woodland and scrub	112,500
Reprofiling	11,800
Construction of peat bunds	382,000
Handling peat	12,700
Install adjustable weirs	19,100
Piling	29,600
Installation of new pumping station	815,000
Preliminaries	276,600
Engineer's Fees	111,200
Total	**1,770,800**

- Revenue costs – infrastructure maintenance and monitoring.

Disadvantages

- High capital cost (£1900 per hectare).

8.6.3 Costing Area: South Thorne

Conceptual outline design

- Clear birch scrub from site to reduced evapotranspiration;
- Create lagg areas in locations where the water table is currently being lowered by external drains;
- Block sections of existing boundary drain;
- Block small drains using peat dams;
- Contour bund old peat workings to mitigate against the current topography's ability to drain the area;
- Install plastic and steel sheet piling;
- Install of control structures on Southern Boundary Drain and Angle Drain;
- Cut new agricultural drain at edge of the created lagg to hydrologically isolate the area from agricultural land.

Advantages

- Resulting hydrological conditions likely to be appropriate for achieving unfavourable recovering status due to growth of peat-forming vegetation;
- Very low services costs once works have been completed;
- Lagg creation will ensure areas on the periphery of the unit will meet water level requirements;
- Resilient to periods of low rainfall/drought;
- Low revenue costs.

Costs

- Capital works – approximately £924k

Table 8-8 Capital Costs (South Thorne)

Works	Costs (£)
Clearance of woodland and scrub	491,000
Reprofiling	47,800
Levees and new drains	19,200
Contour Bunding	18,500
Handling Peat	63,500
Install sheet piling	14,400
Install adjustable weirs	38,600
Preliminaries	144,200
Engineer's Fees	86,800
Total	**924,000**

- Revenue costs – infrastructure maintenance and monitoring

Disadvantages

- Will incur land purchase costs;
- Likely damage to the agricultural land during lagg creation works;
- Moderate capital cost (£1224 per hectare).

8.6.4 Costing Area: Crowle

Conceptual outline design

- Clear birch scrub from site to reduced evapotranspiration;
- Create lagg fen areas around parts of this unit;
- Infill sections of existing boundary drain;
- Block small drains using peat dams;
- Construct a network of peat bunds in areas of recent peat extraction;
- Installation of plastic and steel sheet piling;
- Regrading of peat cliff;
- Cut new agricultural drain at edge of the lagg creation area to hydrologically separate the area from agricultural land.

Advantages

- Resulting hydrological conditions likely to be appropriate for achieving unfavourable recovering status due to growth of peat-forming vegetation;
- Very low services costs once works have been completed;
- Lagg creation will aid water level requirements being achieved up to the periphery of the site;
- Resilient to periods of low rainfall/drought;
- Low revenue costs.

Costs

- Capital works – approximately £835k

Table 8-9 Capital Costs (Crowle)

Works	Costs (£)
Clearance of woodland and scrub	310,000
Creating and infilling drains	10,400
Reprofiling	113,800
Construction of peat bunds	47,900
Ditch blocking	2,400
Handling Peat	151,000
Install adjustable weirs	16,600
Preliminaries	130,500
Engineer's Fees	52,400
Total	835,000

- Revenue costs – infrastructure maintenance and monitoring

Disadvantages

- Will incur land purchase costs;
- Likely damage to the agricultural land during HPZ creation works;
- Moderate capital cost (£2800per hectare).

8.6.5 Costing Area: North West Rand

Conceptual outline design

- Clear birch scrub from site to reduced evapotranspiration;
- Create lagg fen area around this management unit;
- Infill sections of existing boundary drain;
- Cut new agricultural drain at edge of the lagg creation area to hydrologically separate the area from agricultural land.

Advantages

- Resulting hydrological conditions likely to be appropriate for achieving unfavourable recovering status due to growth of peat-forming vegetation;
- Very low services costs once works have been completed;
- Lagg creation will ensure unit meets water level requirements;
- Resilient to periods of low rainfall/drought;
- Low revenue costs.

Costs

- Capital works – approximately £61k

Table 8-10 Capital Costs (North West Rand)

Works	Costs (£)
Clearance of woodland and scrub	38,200
Creating drains	9,200
Drain Blocking	200
Preliminaries	9,500
Engineer's Fees	3,800
Total	**60,900**

- Revenue costs – infrastructure maintenance and monitoring

Disadvantages

- Will incur land purchase costs;
- Likely damage to the agricultural land during lagg creation works;
- Moderate capital cost (£1100 per hectare).

8.6.6 Costing Area: Inkle, Durham's and Paraffin Works

Conceptual outline design

- Clear birch scrub from site to reduced evapotranspiration;
- Create lagg fen area around this management unit;
- Cut new agricultural drain at edge of the lagg creation area to hydrologically separate the area from agricultural land.
- Reinstate and adopt Durham's Warping Drain into Thorne Moors.

Advantages

- Improve control over water levels in Inkle Moor and across Thorne Moors;
- Very low services costs once works have been completed;
- Lagg creation area will ensure unit meets water level requirements;
- Resilient to periods of low rainfall/drought;
- Low revenue costs.

Costs

- Capital works – approximately £41,000k

Table 8-11 Capital Costs (Inkle, Durham's and Paraffin Works)

Works	Costs (£)
Clearance of woodland and scrub	31,000
Contour bunding	1,000
Drain Blocking	100
Preliminaries	6,400
Engineer's Fees	2,600
Total	**41,100**

- Revenue costs – infrastructure maintenance and monitoring

Disadvantages

- Will incur land purchase costs;
- Likely damage to the agricultural land during lagg creation works;
- Moderate capital cost (£900 per hectare).

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The key features of this plan are the creation of lagg around parts of the site where the agricultural land is substantially lower than the raised mire surface, the reinstatement of an active bog surface at Northern Goole Moors within the lifetime of the plan and increased control over the water levels on the milled area using adjustable weirs and a new pumping station. At Northern Goole Moors the creation of favourable status will involve the purchase of land around the site and the cutting of a new drain to link up with the network of the Dempster IDB, eventually discharging into the Dutch River at South Grange.

On the milled area the installation of two new adjustable weirs on the western margin and a new pumping station on the Blackwater Dike will allow a greater control over the water levels on this key part of the site.

On South Thorne the installation of an adjustable weir on the Southern Boundary Drain and Angle Drain, combined with vegetation clearance will allow a greater degree of control over the water levels on site. This, combined with some contour bunding of the cut-over peat surface, will allow an increase in the overall water level and create ideal conditions for the colonisation of Sphagnum mosses.

On the North West Rand a programme of vegetation clearance and the creation of a lagg area will allow the water level to rise and promote the growth of an alder woodland along the site's edge. This, along with land purchase, will create a lagg fen and alder carr area that would mimic the historic vegetation of the bog margins.

Crowle is extremely complicated due to the nature of the small-scale peat workings in the area. Here the linear strips have affected the drainage and it is proposed to isolate those areas of ground that are recoverable from the large cut area in Ribbon Row in which only a thin layer of peat remains. This will be achieved through the creation of a peat profiles to mimic the natural watertable in this location. This, combined with vegetation clearance, the blocking of some of the drains, the creation of lagg in the south of the site, should create the conditions necessary to allow the colonisation of the site by *Sphagnum* mosses.

Inkle Moor and the surrounding area, including the paraffin works, will be connected, via Durham's Warping Drain to the land drainage network. This will allow a greater control over the water table in this area, much of which lies on clay rather than peat. The aim here is recreate the lagg fen that may once have surrounded the bog and bring this area into favourable condition.

In order to achieve the aims of the plan and bring the entire site into favourable or unfavourable recovering condition it is necessary to undertake all of the works recommended in this report. However, there is scope to do this in stages, focussing on the management unit mentioned above and doing them in the specified order. This will provide, on Northern Goole Moors, a bog in miniature which can then be utilised as an example of what can be achieved over the whole site, although this will take much longer. It is, therefore, felt appropriate that all initial resources be targeted at Northern Goole Moors as the recreation of active bog conditions here is achievable within a ten year period for a relatively modest sum. It is recommended that the remainder of the works on Thorne Moors should be undertaken following the programme of Works set out in Table 9-1. This will bring large areas of the moor into favourable management within a three to five year timescale and also begin work on Crowle and the other, less critical, areas on the western boundary of the moor.

9.2 Recommended Action Plan

In order to implement the above recommendations, the following works, specified in Table 8-5, are recommended (Table 9-1).

Table 9-1 Programme of Works

Timing	Location	Works Undertaken	Value (£)
2010 Quarter 4	N Goole Moors	Scrub Clearance	31,000
2011 Quarter 1	N Goole Moors	Scrub Clearance (continued)	
	Milled area	Scrub Clearance	112,500
2011 Quarter 2	Milled area	Construct a network of peat bunds Piling Reprofiling	509000 29,600 11,800
2011 Quarter 3	N Goole Moors	Lagg creation – drain infilling, levee building drain blocking	**12,300**
	Milled area	Construct a network of peat bunds (continued) Scrub Clearance (continued)	
2011 Quarter 4	N Goole Moors		
	South Thorne	Scrub Clearance	491,000
2012 Quarter 1	South Thorne	Scrub Clearance (continued)	
2012 Quarter 2	Milled Area	Adjustable Weirs Pumping Station	19,100 815,000
2012 Quarter 3	South Thorne	Scrub Clearance (continued)	
2012 Quarter 4	South Thorne	Contour Bunding (and material handling)	82,000
2013 Quarter 1	South Thorne	Scrub Clearance (continued) Contour Bunding (continued)	
	North West Rand	Scrub Clearance	38,200
2013 Quarter 2	North West Rand	Lagg Creation - Infilling and digging new ditches	9,400
2013 Quarter 3	Crowle	Bunding	47,900
2013 Quarter 4	South Thorne	Re-profling Scrub Clearance (continued) Contour Bunding (continued)	47,800
2014 Quarter 1	South Thorne	Lagg Creation Piling Control Structures Scrub Clearance (continued) Contour Bunding (continued)	19,200 14,400 38,600
2014 Quarter 2	Inkle, Durham's, Paraffin Works	Scrub clearance Drain Blocking	31,000 1,100
2014 Quarter 3	Crowle	Scrub clearance	310,000
2014	Crowle	Reprofiling	264,800

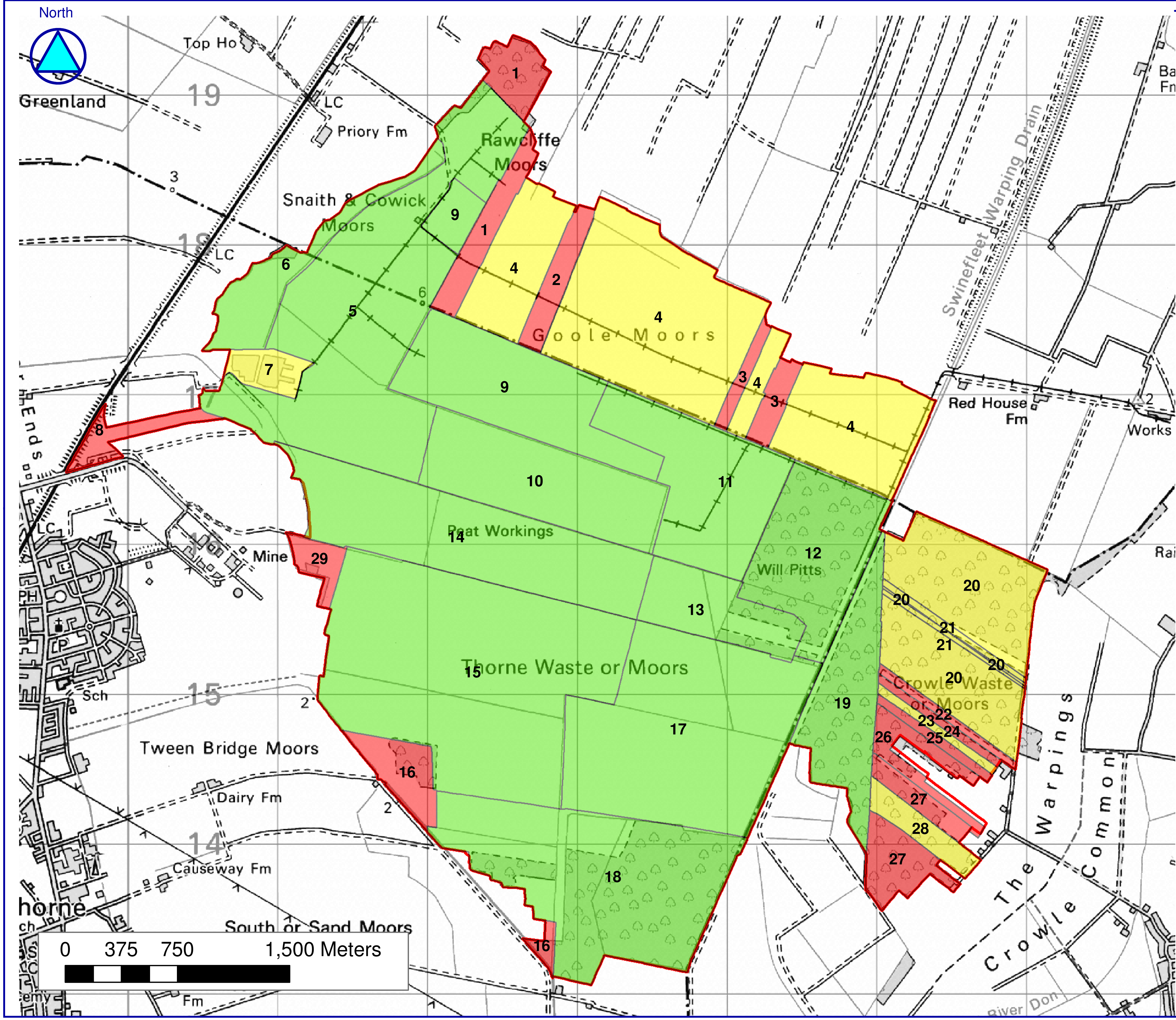
Timing	Location	Works Undertaken	Value (£)
Quarter 4			
2015 Quarter 1	Crowle	Lagg creation Control Structures	12,800 16,600
	Inkle, Durham's, Paraffin Works	Scrub Clearance (continued)	
2015 Quarter 2	Crowle	Lagg creation (continued) Scrub Clearance (continued)	
2015 Quarter 3	Crowle	Lagg creation (continued) Scrub Clearance (continued)	
2015 Quarter 4	Crowle	Scrub Clearance (continued)	
Notes: Costs do not include EIA, Preliminary Works and Engineer's fees. Where works are spread over several quarters the total cost is shown in the first quarter of those works.			

9.3 Further Investigations

Following on from this study the following investigations should be continued or instigated as part of this plan:

- Continue datalogger downloads on JBA installed dipwells;
- Continue regular monthly dips of all Natural England dipwells;
- Continue with monthly programme of reading gaugeboards;
- Continue with monitoring rainfall across the site using Natural England and JBA installed equipment;
- Monitor water flows over new weir at Creykes Gate to ensure that the rate does not exceed 1.4l/ha/sec and does not overload the Dempster IDB network;
- Monitor water flows over the new weir at Durham's Warping Drain to ensure that the rate does not exceed 1.4l/ha/sec and does not overload the Black Drain IDB network;
- Monitor discharges from the new pumping station to refine the levels in response to rainfall events;
- Monitor discharges from the new pumping station on Blackwater Dike to ensure that the rate does not exceed 1.4l/ha/sec and does not overload the Reedness and Swinefleet drainage network;
- Carry out ground investigations in advance of the installation of the new pumping station to determine depth to a hard substrate;
- Carry out ground investigations in advance of the installation of the new weirs to ensure that they are installed with a good seal all round
- Install a fixed monitoring regime and a sampling points to determine vegetation change on the site in response to the new water level management regime.

FIGURES



LEGEND

SSSI Unit Classification

- Unfavourable Decline
- Unfavourable No Change
- Unfavourable Recovery
- Thorne Moor Boundary

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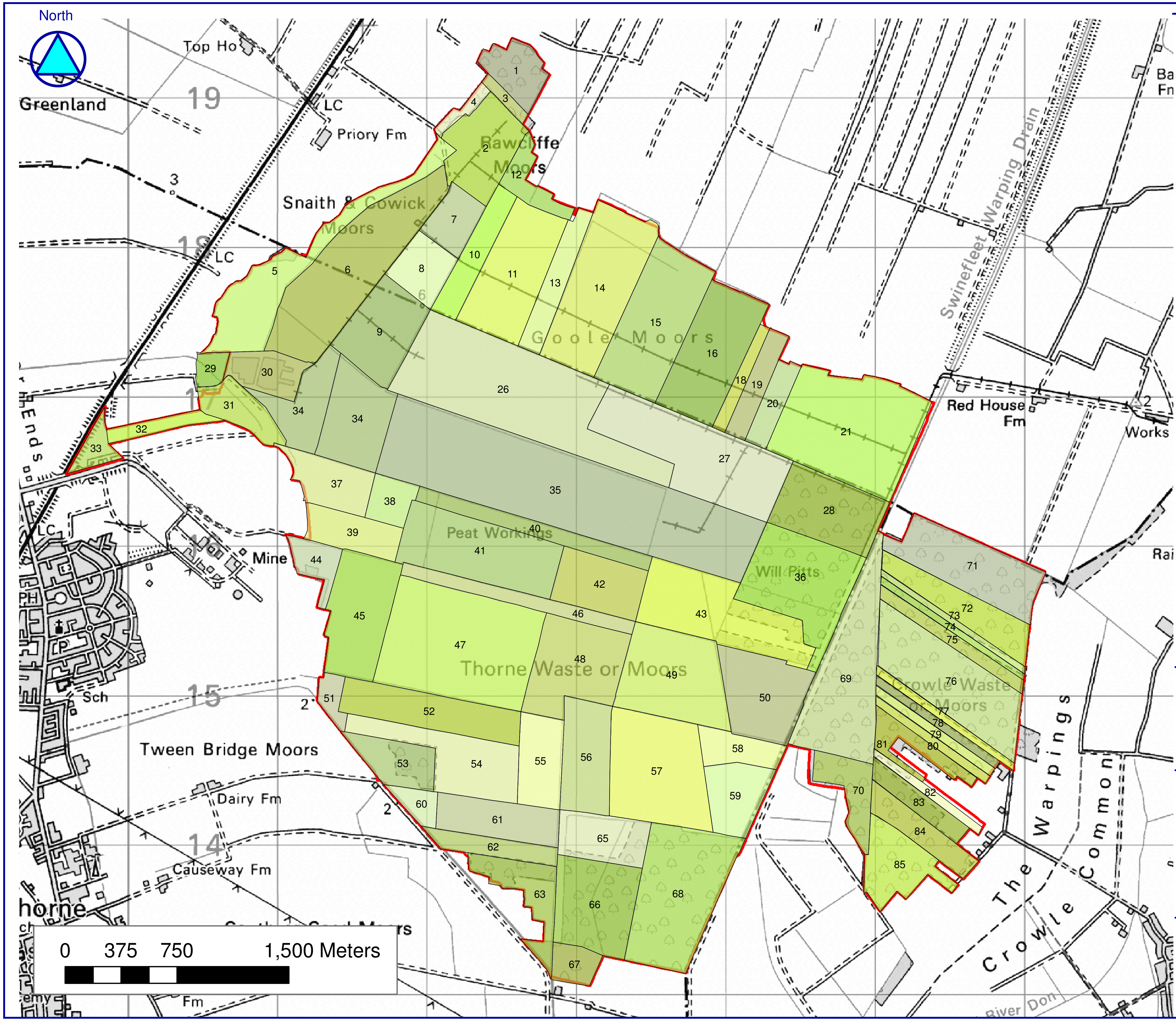
FIGURE A 1

SSSI Unit Classification



LEGEND

Management Compartments

Thorne Moor Boundary

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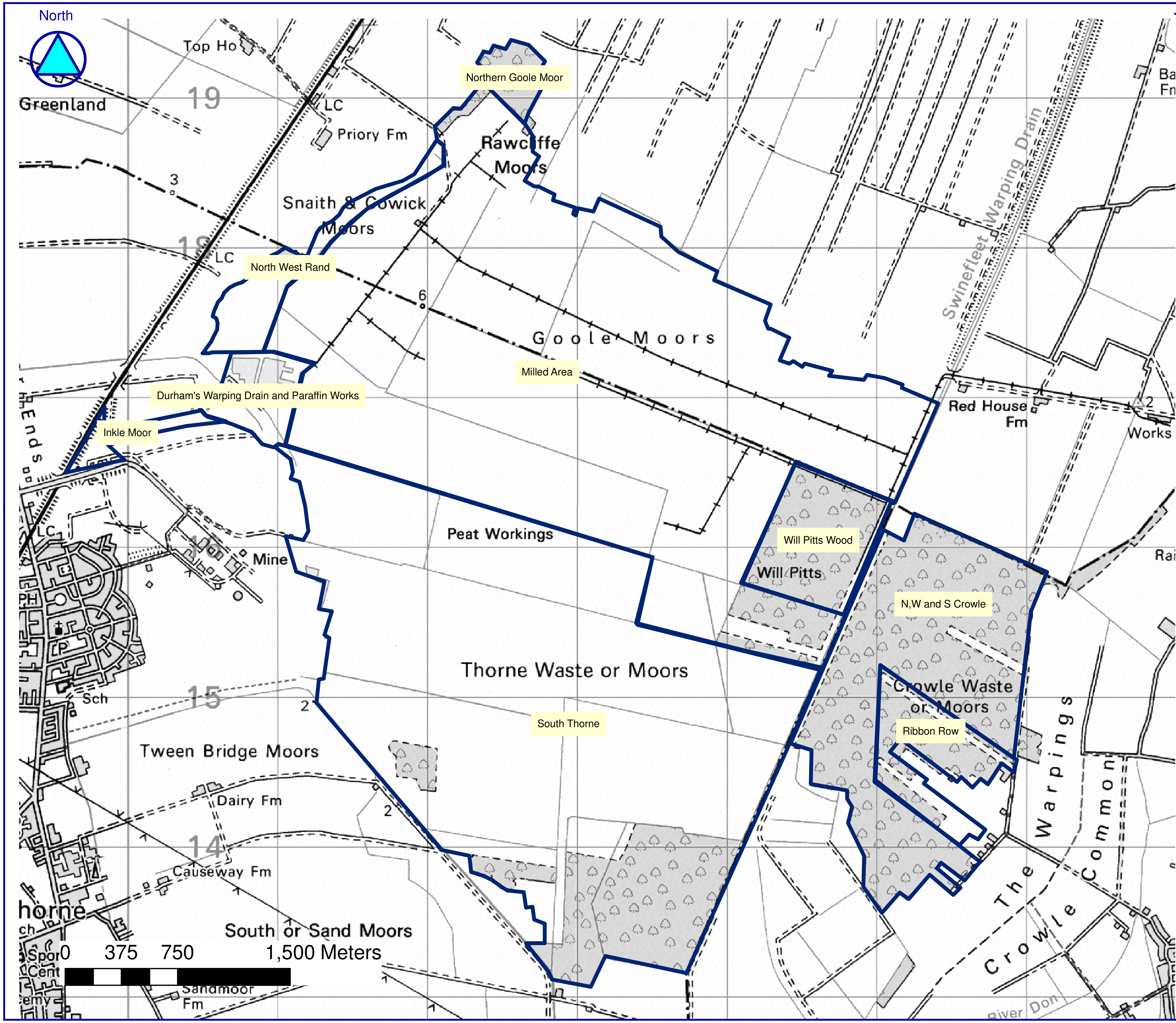
FIGURE A 2

Management Compartments



LEGEND

Conceptualisation Units

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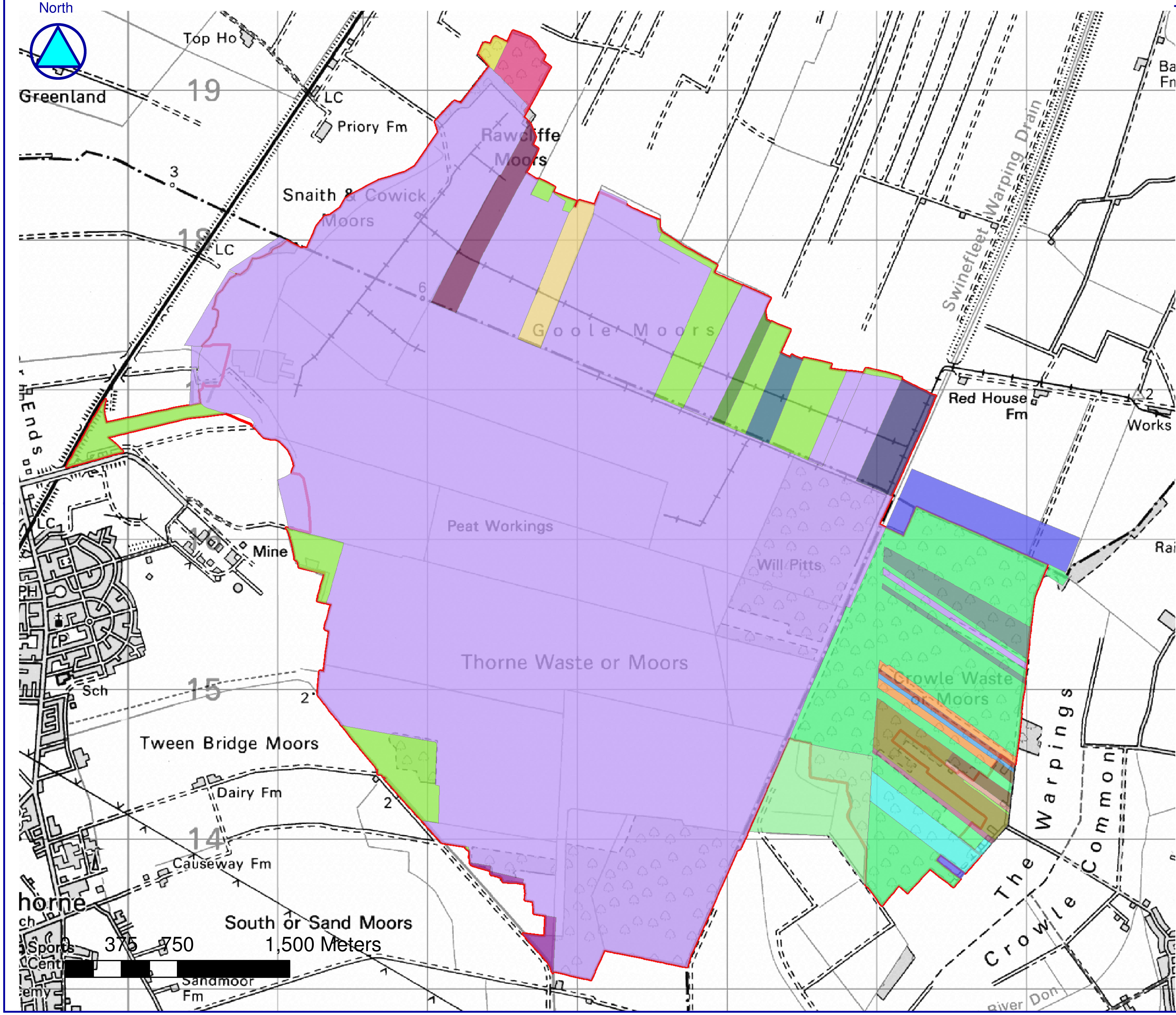
FIGURE A 3

Hydrogeological Conceptualisation Units



LEGEND

Land Owners

- Allbones
- B W Dougherty & Sons
- Charlie Calladine
- Natural England
- Flears
- H Crow
- Jim Johnson
- John Isle
- LWT
- Lovell's
- Mark Johnson
- Mason
- Mr Birtwistle?
- Mr Corkwell
- Mr Tindall & Mr Glue
- Mrs & Julian Crow
- Mrs Roberts
- N Lincs Council
- R B Phillipson
- Stephen Backhouse
- Stringfellow
- Unknown
- Thorne Moor Boundary

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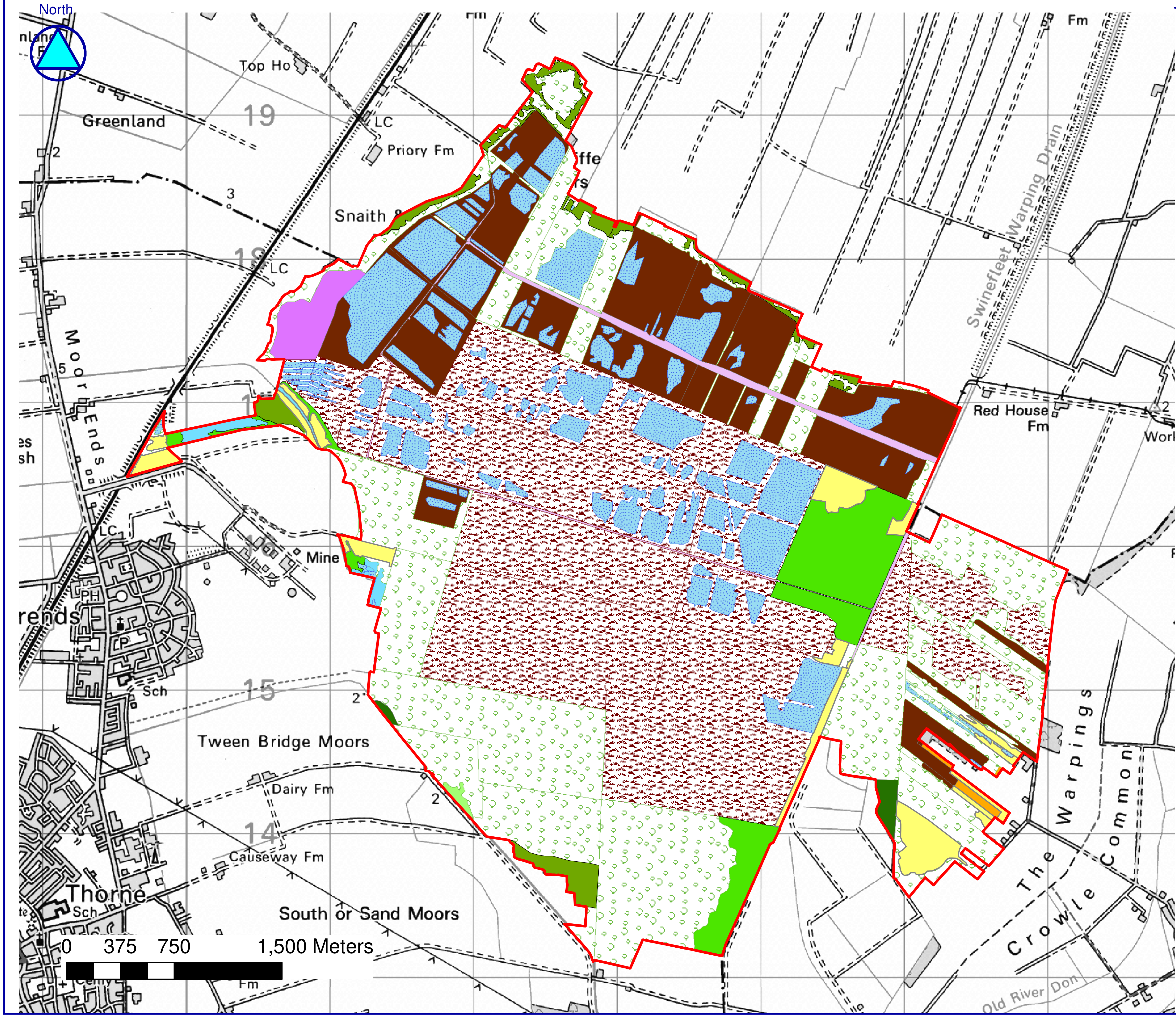
FIGURE A4

Land Ownership



LEGEND

- Thorne Moor Boundary
- Grassland
- Bracken
- Mature Woodland
- Birch Woodland
- Wet Woodland
- Standing Water
- Poor Fen
- Bare Peat
- Arable
- Dwarf Shrub Heath
- Tall Herb Fen
- Reedbed
- Road Surface

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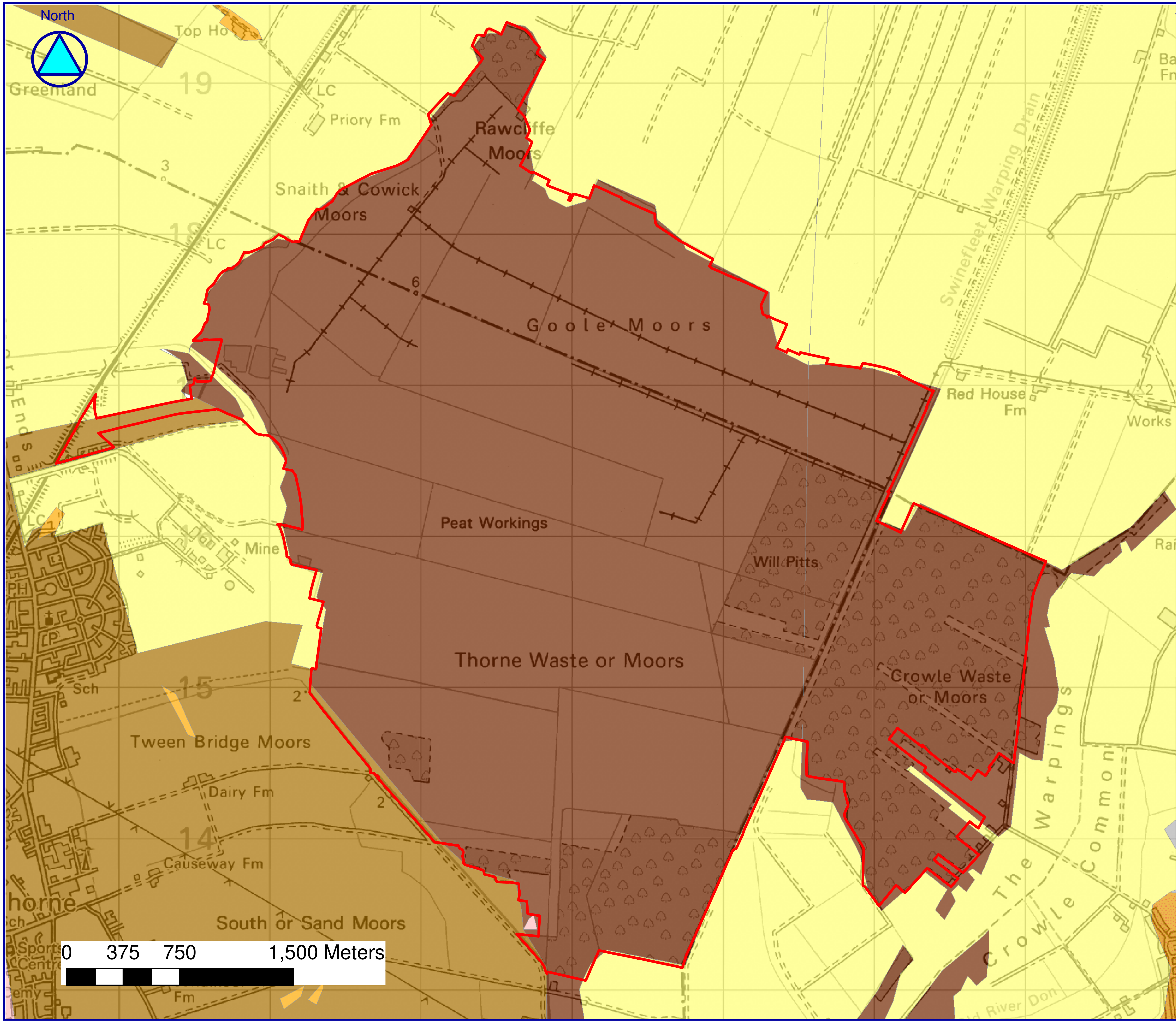
FIGURE A 5

Vegetation Survey



LEGEND

Thorne Moor Boundary

Drift Geology

- Alluvium or Warp
- Peat
- Blown Sand, Older
- Sand
- Silt and Clay
- Glacial Sand and Gravel
- Drift Absent

Geology Data Based on BGS 1971

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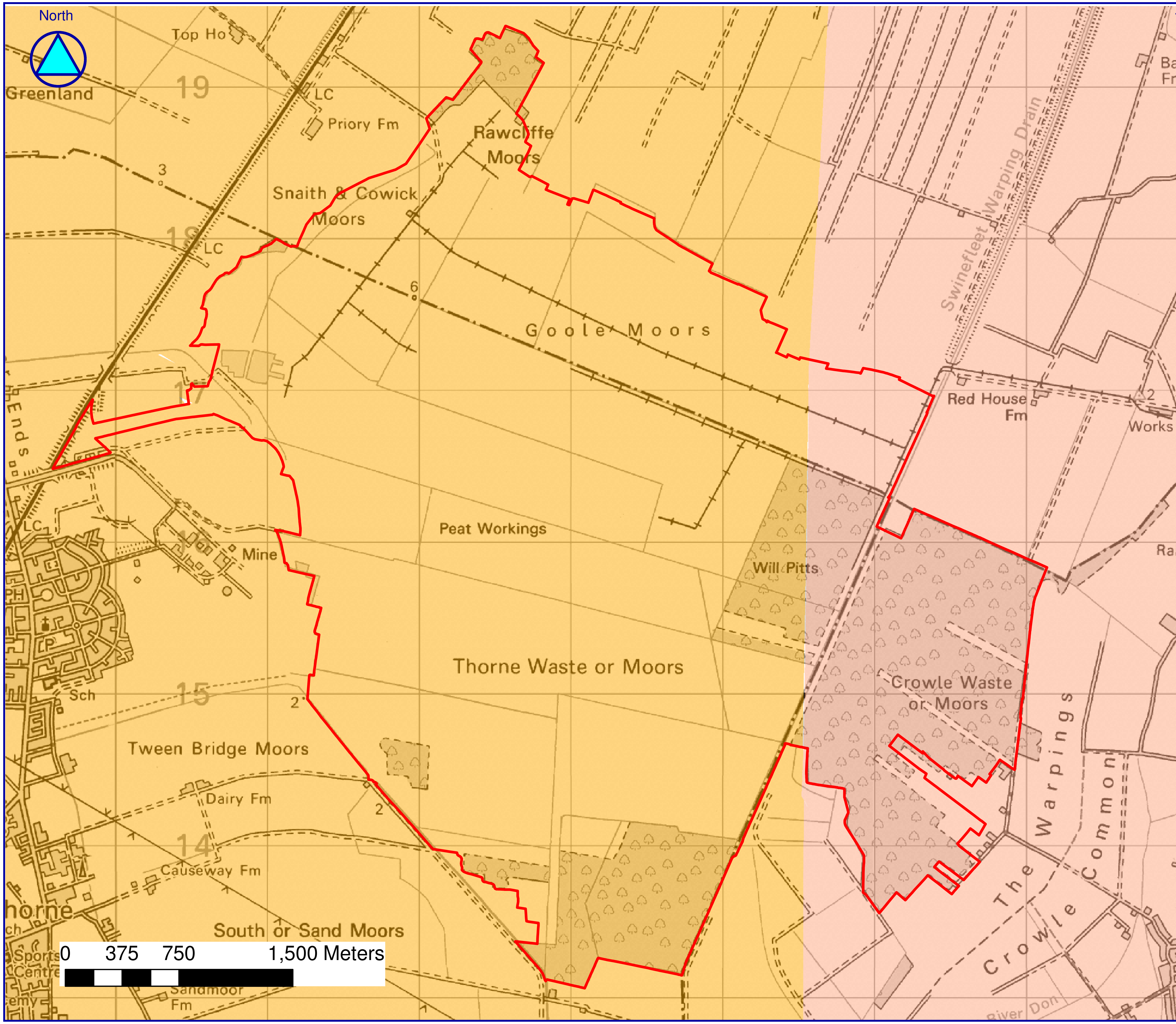
FIGURE A 6

Drift Geology



LEGEND

- Thorne Moor Boundary
- Bunter Sandstone
- Merica Mudstone

Geology Based on BGS 1971

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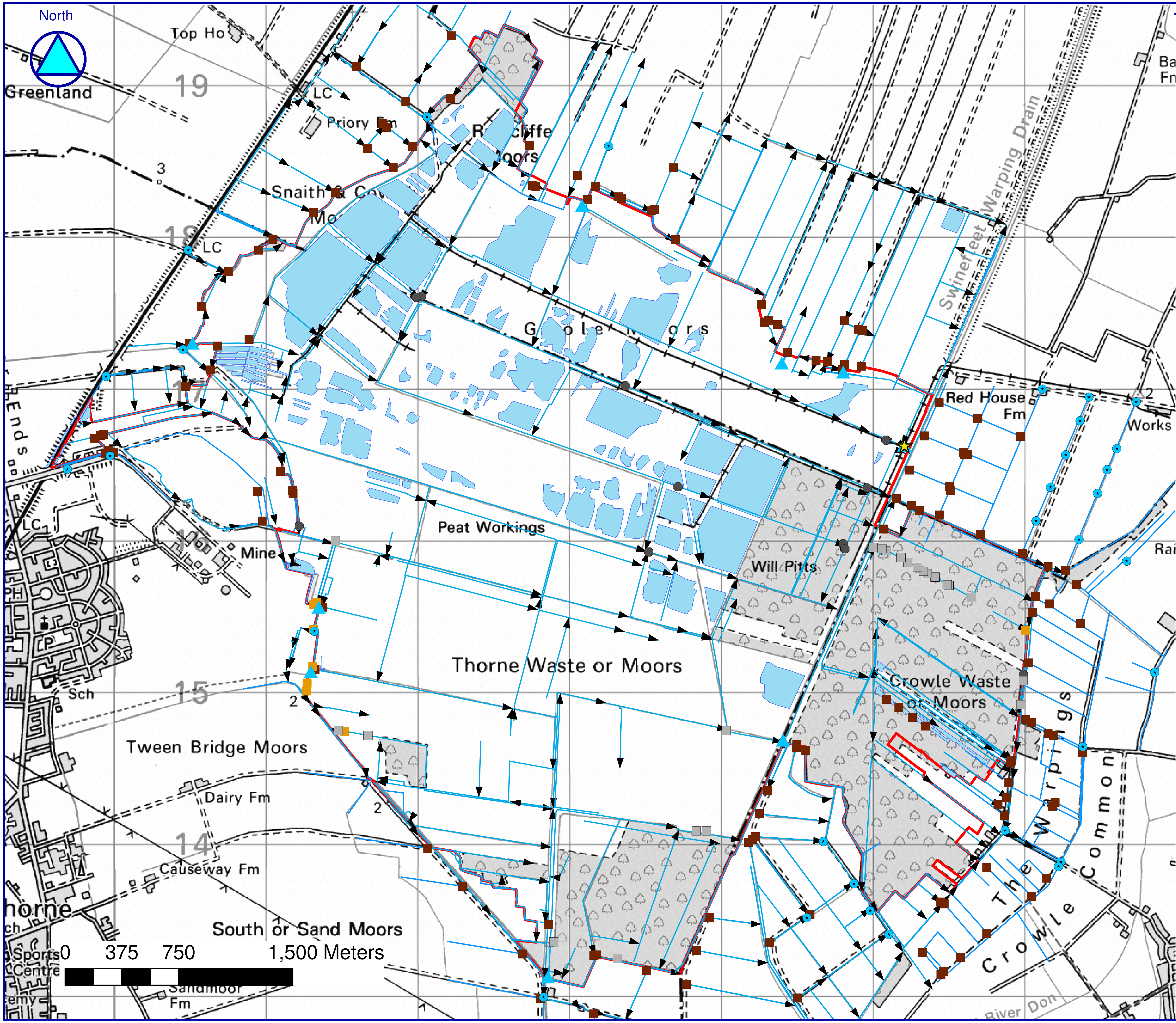
FIGURE A 7

Solid Geology



LEGEND

- Swinefleet Pump
- Major Discharge Points
- Drains
- Areas of standing water
- Thorne Moor Boundary

Control Structures

- Culverts
- Earth Bund
- Pile Dam
- Plastic Pile
- Steel Pile

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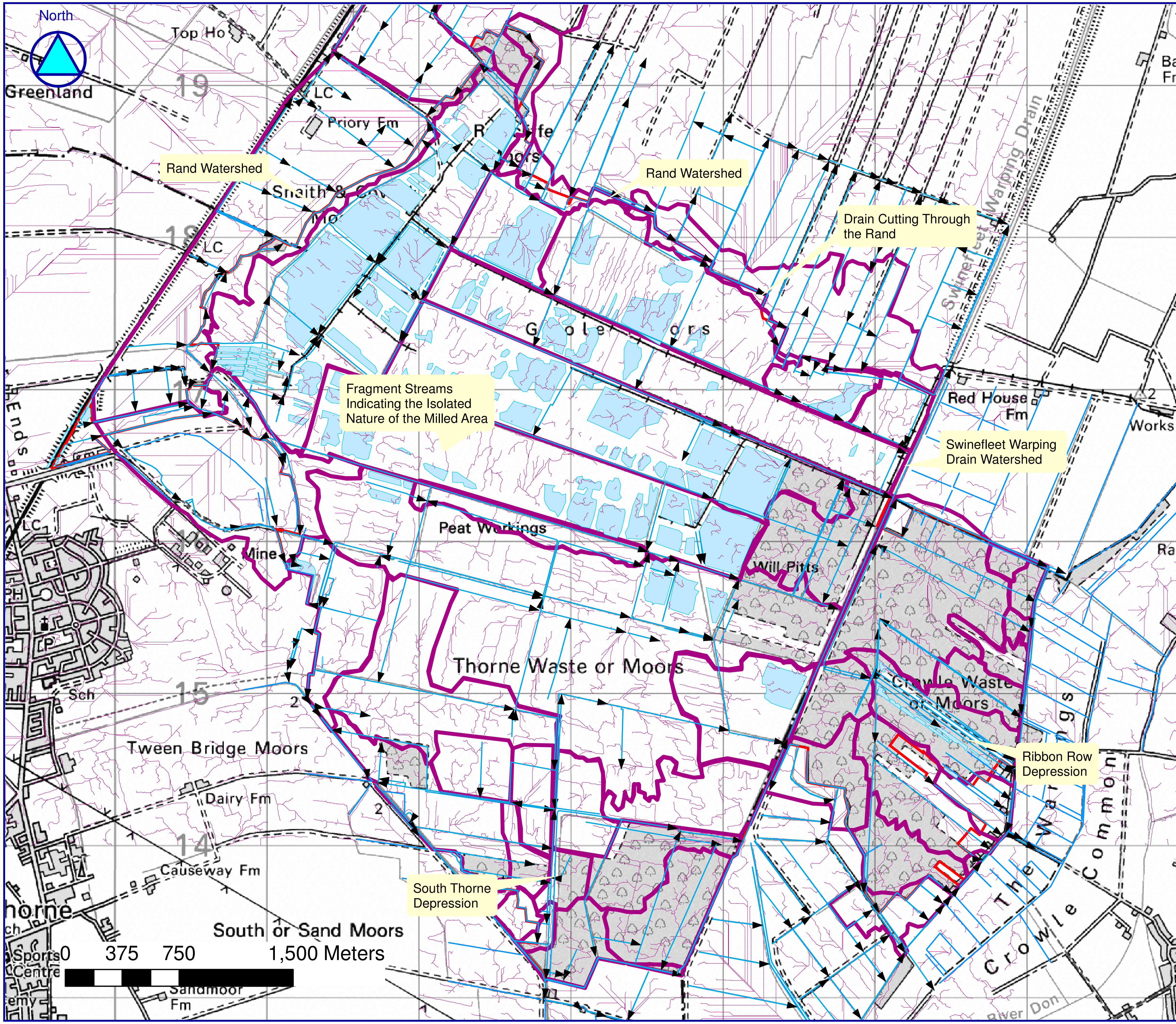
FIGURE A 8

Surface Water Features and Control Structures



LEGEND

- Real Drains
- Arc Derived Streams
- Areas of standing water
- Thorne Moor Boundary

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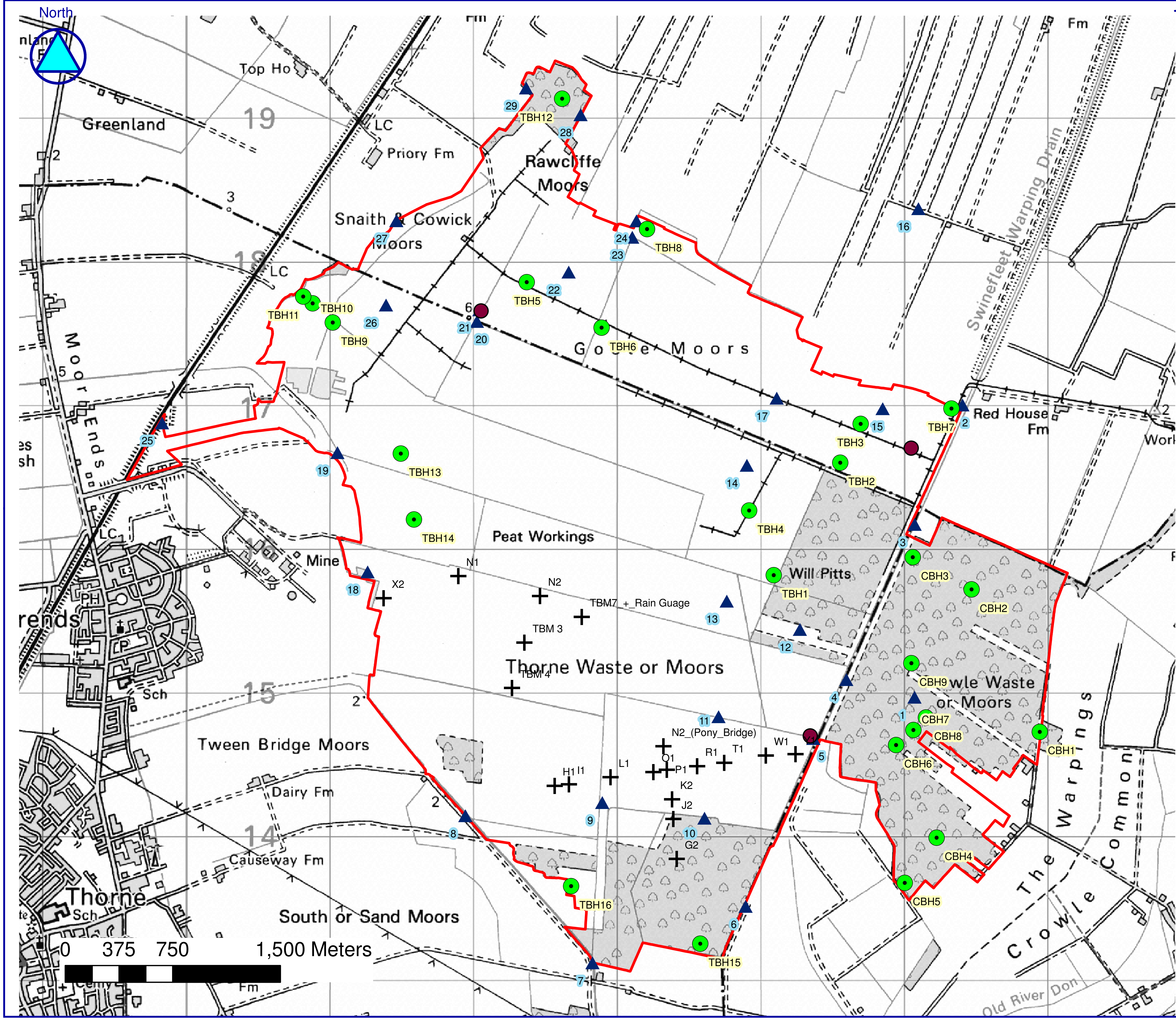
FIGURE A9

ArcGIS Derived Catchments



LEGEND

- Stilling Wells
- JBA Boreholes
- JBA Gaugeboards
- Existing NE Boreholes
- Thorne Moor Boundary

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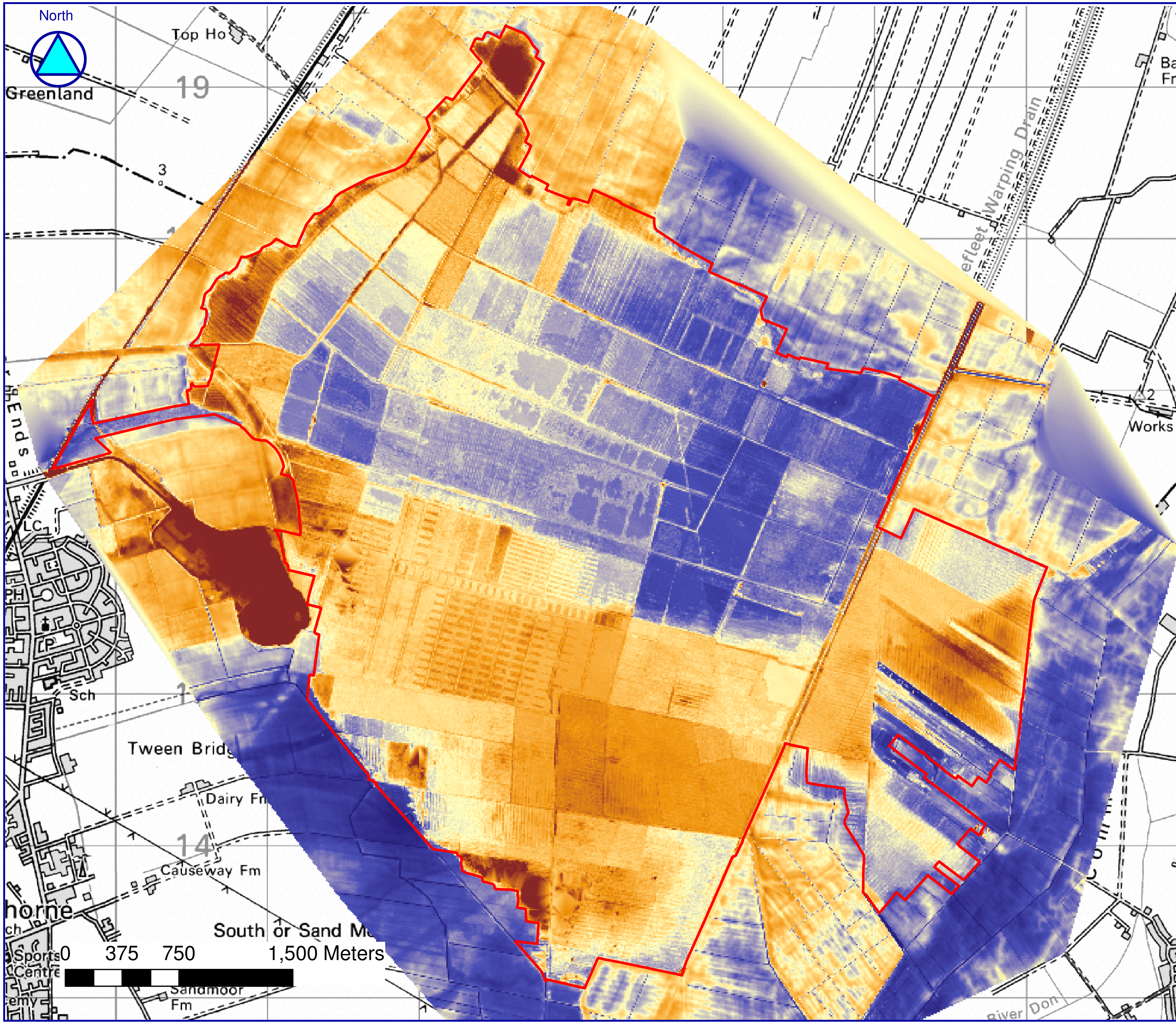
FIGURE A 10

Monitoring Array



LEGEND

LIDAR Togography

mAOD

High : 13.9

Low : -1.67

Thorne Moor Boundary

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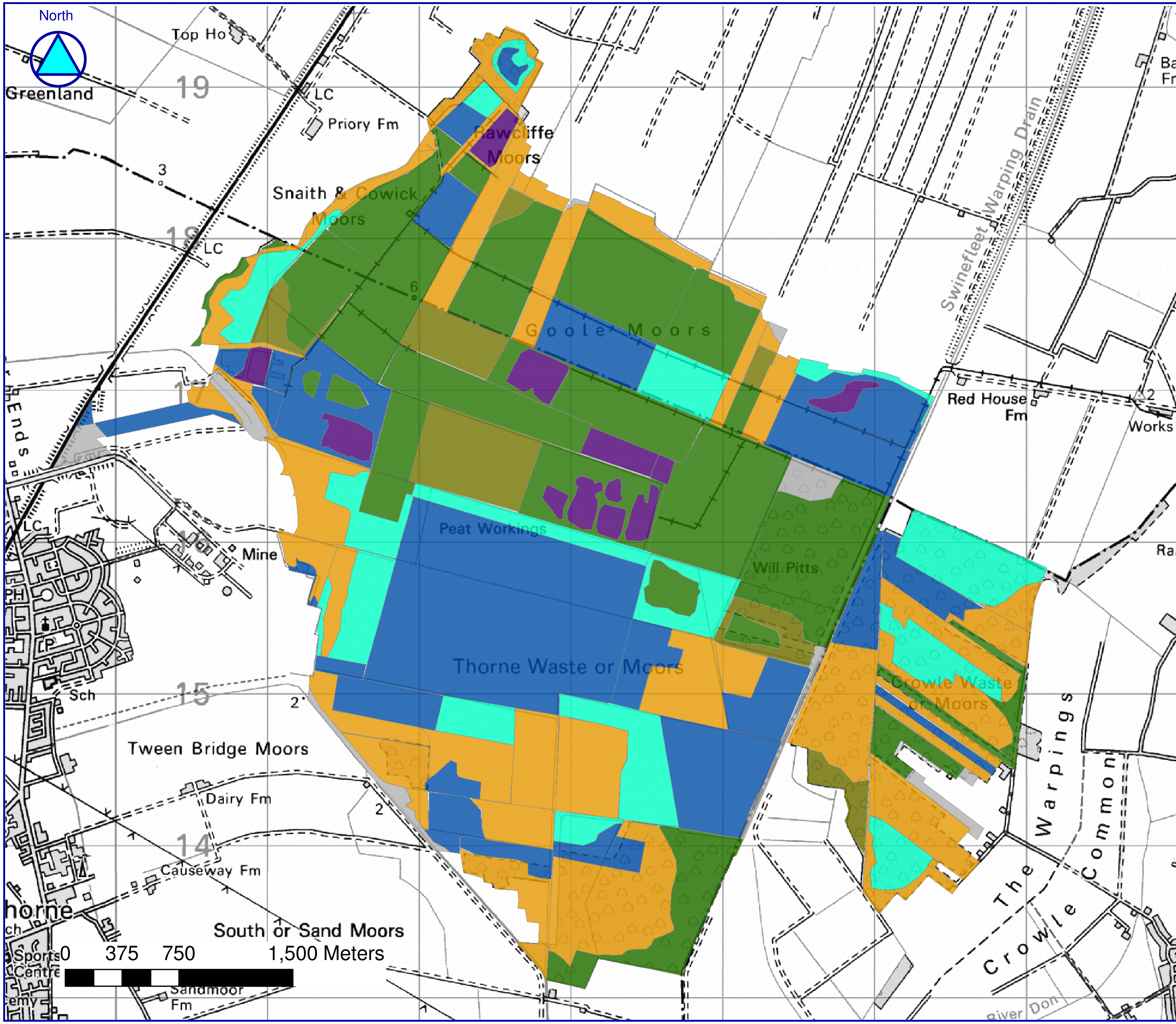
FIGURE A 11

LIDAR Topography



LEGEND

Water Level Classification

- Sufficiently Wet
- Slightly Dry
- Flucuates - wet
- Flucuates - dry
- Too Dry
- Too Wet
- Not Applicable

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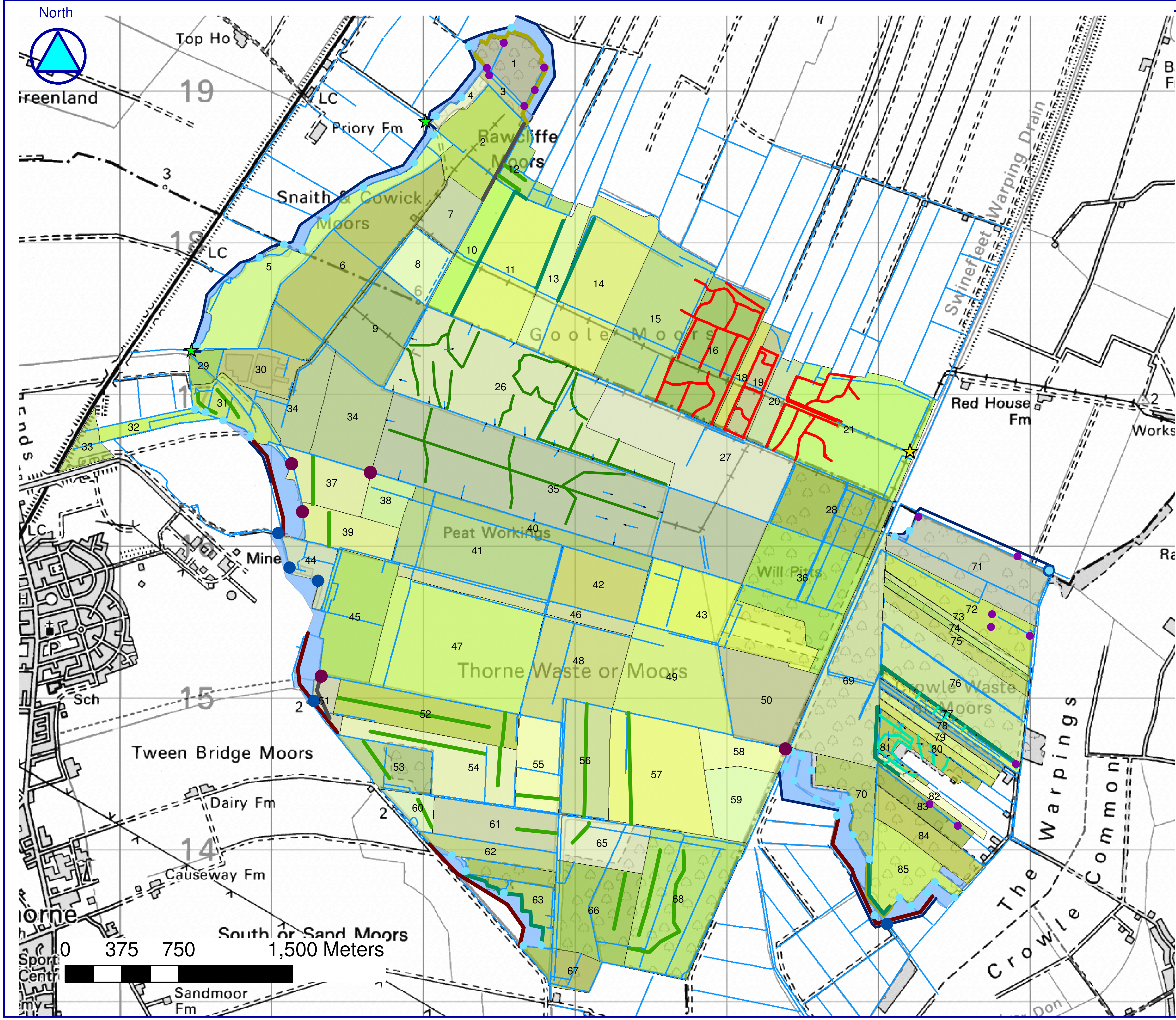
FIGURE A 12

Water Level Classifications



LEGEND

- Swinefleet Pump
- Proposed New Outlets
- Minor Dams on Peat
- Major Dams on Peat
- Minor Dams on Agricultural Land
- Major Dams on Agricultural Land
- Flow through bunds
- Milled Area Bunds
- Milled Area Bunds off NE Land
- South Thorne Bunds
- Ribbon Row Bunds
- Reprofiling
- Piling
- Infilled Ditch
- New Ditches
- Lagg Creation Area Levees
- Lagg Creation Area
- Drains
- Management Compartments

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FIGURE A 13

Implementation Plan - Engineering Works

LEGEND

Proposed Scrub Clearance

Wood Type

- Dense
- Less dense
- Scattered trees
- Management Compartments

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FIGURE A 14

Implementation Plan - Scrub Clearance

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APPENDICES

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Appendix A: - Borehole Logs

CBH1

Depths (cm)	Description
0 – 5	H6 Black woody PEAT
5 – 30	H4 Dark Orange Sphagnum and cotton grass PEAT (WATER STRIKE at 15cm)
30 -150	H4 Dark brown wood PEAT
Location: E:475945, N:414727 Western Edge of Crowle Moor	
Vegetation: Wet woodland	
Construction: 1 slotted, 1 plain, 48 cmagl (centimetres above ground level)	

CBH2

Depths (cm)	Description
0 – 5	H1 Sphagnum PEAT
5 – 35	H3 orange brown Sphagnum PEAT
35 – 40	H3 Sphagnum and cotton grass PEAT
40 – 70	NO RETURNS
70 +	H4 Sphagnum and cotton grass PEAT
Location: E:475468, N:415719 Side of LWT north track	
Vegetation: Very wet Sphagnum, cotton grass and occasional small birch	
Construction: 1 slotted, 1 plain, 52 cmagl	

CBH3

Depths (cm)	Description
0 – 40	H8 Peaty Black SOIL
40 – 50	H4 Orange Sphagnum and cotton grass PEAT
50 – 200	H3-2 Light orange brown Sphagnum PEAT
Location: E:475058, N: 415950	
Vegetation: Wet woodland (willow, birch sited on a slight bank (maybe the reason for the soil).	
Construction: 2 slotted, 1 plain, 77 cmagl	

CBH4

Depths (cm)	Description
0 – 20	H7 Black PEAT (WATER STRIKE at 20 cm)
20 – 30	H5 Dark brown cotton grass PEAT
30 – 70	H5 Sphagnum and cotton grass PEAT
70 – 90	H4 Sphagnum and cotton grass PEAT

Depths (cm)	Description
90 – 140	H4 wood PEAT
140 -180	H5 very wet wood PEAT
180 +	NO RETURNS
Location: E:475226, N:413989	
Vegetation: Heather on ridges and cotton grass in furrows	
Construction: 2 slotted, 1 plain, 60 cmagl approx	

CBH5

Depths (cm)	Description
0 – 10	H8 Dry black PEAT
10 – 60	H5 Orange brown wood PEAT
60 – 200	H3-4 Dark orange brown Sphagnum PEAT
Location: E:475005, N:413677	
Vegetation:	
Construction: 2 slotted, 1/2 plain, 42 cmagl	

CBH6

Depths (cm)	Description
0 – 15	H7 very dry brown PEAT
15 – 20	H3 Black heather and cotton grass PEAT
20 – 60	H3 Dark brown cotton grass and woody material PEAT
60 – 140	H4 Orange Sphagnum and cotton grass PEAT
150 +	NO RETURNS (too liquid)
Location: E:474945, N:414635	
Vegetation: Birch wood with bracken	
Construction:	

CBH7

Depths (cm)	Description
0 – 10	H5 Dark brown reedy PEAT
10 – 130	H6 Black wood PEAT
130 +	Gleyed grey CLAY
Location: E:475118, N:414652	
Vegetation: Bare peat with rushes	
Construction: 1 plain,1 slotted	

CBH8

Depths (cm)	Description
0 – 15	H8 Dry black PEAT
15 – 40	H5 Very dry dark orange woody and Sphagnum PEAT
40 – 70	H7 Very dry PEAT
70 – 80	H5 Dark orange brown cotton grass PEAT

Depths (cm)	Description
80 – 150	H6 Dark brown PEAT
150 -170	H4 Damp cotton grass and woody PEAT
170 - 240	H4 Wood PEAT
Location: E:475154, N:414819	
Vegetation: Birchwood and bracken	
Construction: 2 slotted, 1 plain	

CBH9

Depths (cm)	Description
0 – 40	H6 Dry dark brown with some woody material PEAT
40 – 70	H5 Moist dark brown cotton grass with some woody material PEAT
70 – 100	H3-4 Wet dark brown cotton grass PEAT
100 – 180	H2-3 Orange brown cotton grass, Sphagnum and wood PEAT (WATER STRIKE at 130)
180 +	Gleyed pale grey CLAY and woody material
Location: E:475150, N:415134 Cliff Edge	
Vegetation: Heather and birch scrub	
Construction: 1 slotted, 1 plain	

TBH1

Depths (cm)	Description
0 – 20	H9 Sloppy Black PEAT
20 – 50	H5-6 Dark orange brown cotton grass PEAT
50 - 100	H4-5 Dark orange brown cotton grass PEAT
Location: E:474191, N:415746 Will Pitts	
Vegetation: Wet woodland	
Construction: 1 plain,1 slotted	

TBH2

Depths (cm)	Description
0 – 5	H4 Black Sphagnum and cotton grass PEAT
5 – 60	H4 Dark orange brown cotton grass and Sphagnum PEAT
60 – 85	H4 Orange brown cotton grass with woody material PEAT
85 +	Coarse grain SAND
Location: E:474654, N:416522 North of Will Pitts	
Vegetation: Marshy grass and cotton grass	
Construction: 1 plain,1 slotted, 124 cmagl	

TBH3

Depths (cm)	Description
0-40	H8 Black PEAT with some sand
40-70	H5-6 Dark orange brown cotton grass PEAT
70-100	H4 Orange brown cotton grass PEAT with some woody material
100	Coarse-grained grey SAND and evidence of burning
Location: E:474796, N:416797	
Vegetation: Marshy grass and open scrub	
Construction: 1 plain, 1 slotted, 111cmagl	

TBH4

Depths (cm)	Description
0 – 10	H8 Black PEAT with some sand
10 -60	H5-6 Dark brown wood PEAT with some cotton grass and Sphagnum
60 – 90	H4 Brown cotton grass PEAT and some woody material (charcoal at 90 cmbgl)
90 – 110	H4 wood PEAT
110 +	Light Grey Gleyed CLAY
Location: E:473922, N:416271 Edge of bund next to open water	
Vegetation: Marshy grass	
Construction: 1 plain,1 slotted 104 cmabl	

TBH5

Depths (cm)	Description
0 – 2	H9 Black powered PEAT
2 – 30	H5 Dark brown cotton grass with woody material PEAT
30 - 70	H3-4 Orange brown cotton grass PEAT and some woody material
70 – 140	H5 Sloppy wood PEAT
140	Clayey SAND
Location: E:472373, N:417860 Goole Moors	
Vegetation: Cotton grass, heather and bare peat.	
Construction: 1 plain,1 slotted 76 cmabl	

TBH6

Depths (cm)	Description
0 – 5	H8 Black powered PEAT
5 – 40	H5-6 Dark orange brown cotton grass with woody material

Depths (cm)	Description
	PEAT
40 - 60	H4 Dark orange brown cotton grass with woody material PEAT
60 – 80	H5 Dark brown wood PEAT
80	Coarse grain SAND
Location: E:472898, N:417591 Goole Moors	
Vegetation:	
Construction: 1 slotted 26 cmabl	

TBH7

Depths (cm)	Description
0 – 5	H8 Black powered PEAT
5 – 60	H5-6 Dark orange brown cotton grass and Sphagnum with woody material PEAT
60 - 120	H4 Orange cotton grass PEAT
120 -140	H4-5 wood PEAT (WATER SRIKE at 120 cmbgl)
140	Fine grey SAND
Location: E:475331, N:416978	
Vegetation: Bare peat and birch scrub	
Construction: 1 slotted 1 plain 69 cmabl	

TBH8

Depths (cm)	Description
0-10	H3 Dark brown PEAT
10-60	H4-5 Dark brown Sphagnum PEAT
60-100	H5 Dark brown PEAT with light brown patches. Moist.
100-150	H5 Medium brown PEAT containing reeds, woody material and Sphagnum
150-170	H6 Light brown woody PEAT containing Sphagnum and roots
170	H6 woody PEAT
Location: E:473210, N:418233 Rawcliffe Moors	
Vegetation: Bracken and birch scrub	
Construction:	

TBH9

Depths (cm)	Description
0-20	H6 Black PEAT
20-30	H5 Dark brown Sphagnum PEAT containing woody material
30-40	H4-5 Medium brown fibrous PEAT containing cotton grass(?) and woody material. WATER STRIKE at 40 cmbgl.
40-90	H5 Medium brown PEAT with woody material

Depths (cm)	Description
90	Grey CLAY
Location: E:471021, N:417579	
Vegetation: Heather, bracken and bare peat	
Construction:	

TBH10

Depths (cm)	Description
0-20	H5 Dark brown and light brown (mottled) fibrous PEAT
20-40	H4-5 Dark brown very fibrous PEAT. Very moist.
40-100	H4-5 Medium brown PEAT containing woody material
100-165	H3-4 Light brown fibrous PEAT
165	Grey CLAY
Location: E:470883, N:417711	
Vegetation: Heather, bracken and bare peat. Edge of birch scrub.	
Construction:	

TBH11

Depths (cm)	Description
0-80	H4 Dark brown sandy PEAT containing woody material. Dry.
80-95	H4 Dark brown sloppy PEAT containing woody material. WATER STRIKE at 80 cmbgl.
95	Grey silty CLAY.
Location: E:470816, N:417759	
Vegetation: Bracken; edge of wet woodland.	
Construction:	

TBH12

Depths (cm)	Description
0-10	H5 Dark brown Sphagnum PEAT
10-20	H5 Medium brown Sphagnum PEAT
20-60	H3-4 Light brown very fibrous PEAT containing Sphagnum and cotton grass
60-90	H3 Light brown PEAT containing Sphagnum and cotton grass
90-245	H3 Medium brown PEAT containing Sphagnum and cotton grass. Wet.
245	NO RECOVERY
Location: E:472615, N:419138	
Vegetation: Dense heather and birch shrub	
Construction:	

TBH13

Depths (cm)	Description
0-25	H5 Dark brown PEAT
25-50	H5 Medium brown Sphagnum PEAT containing some woody material
50-70	H4 Medium brown fibrous PEAT
70-110	H3-4 Light brown fibrous PEAT containing Sphagnum, cotton grass and woody material
110	Grey sandy CLAY
Location: E:471495, N:416664 Off Limestone Road. Side of bund. Next to open water.	
Vegetation:	
Construction:	

TBH14

Depths (cm)	Description
0-20	H3 Medium brown Sphagnum PEAT with reeds
20-40	H4 Dark brown Sphagnum PEAT. WATER STRIKE at 30 cmbgl.
40-100	H3-4 Light brown Sphagnum PEAT containing woody material. Pasty.
100-140	H4-5 Light brown reedy PEAT. Sloppy.
140	Grey clayey fine-grained SAND
Location: E:471587, N:416208 9.3.1	
Vegetation: Birch scrub, heather and bracken	
Construction:	

TBH15

Depths (cm)	Description
0-5	H5 Medium brown PEAT
5-15	H5 Dark brown PEAT
15-80	H3 Orange brown Sphagnum PEAT
80-135	H3 Orange brown reedy Sphagnum PEAT containing woody material
135	Grey/buff fine-grained SAND
Location: E:473581, N:413253 Southwest corner	
Vegetation: Birch, bracken and oak woodland	
Construction:	

TBH16

Depths (cm)	Description
0 – 25	H5 Black wood (with charcoal) PEAT
25 – 70	H3-4 Dark brown Sphagnum PEAT
70 - 80	H4-5 Moist dark brown cotton grass PEAT (some charcoal)
80 -140	H4 Dark brown Sphagnum PEAT
140 – 220	H4 becoming H3 Dark brown Sphagnum, cotton grass and some woody material PEAT
220 – 260	H2 Sphagnum PEAT
Location: E:472683, N:413656 Raised uncut area on southern boundary of Thorne Moors	
Vegetation: Bracken, mature birch and Rhododendron	
Construction: 2 slotted, 1 plain 26 cmabl	

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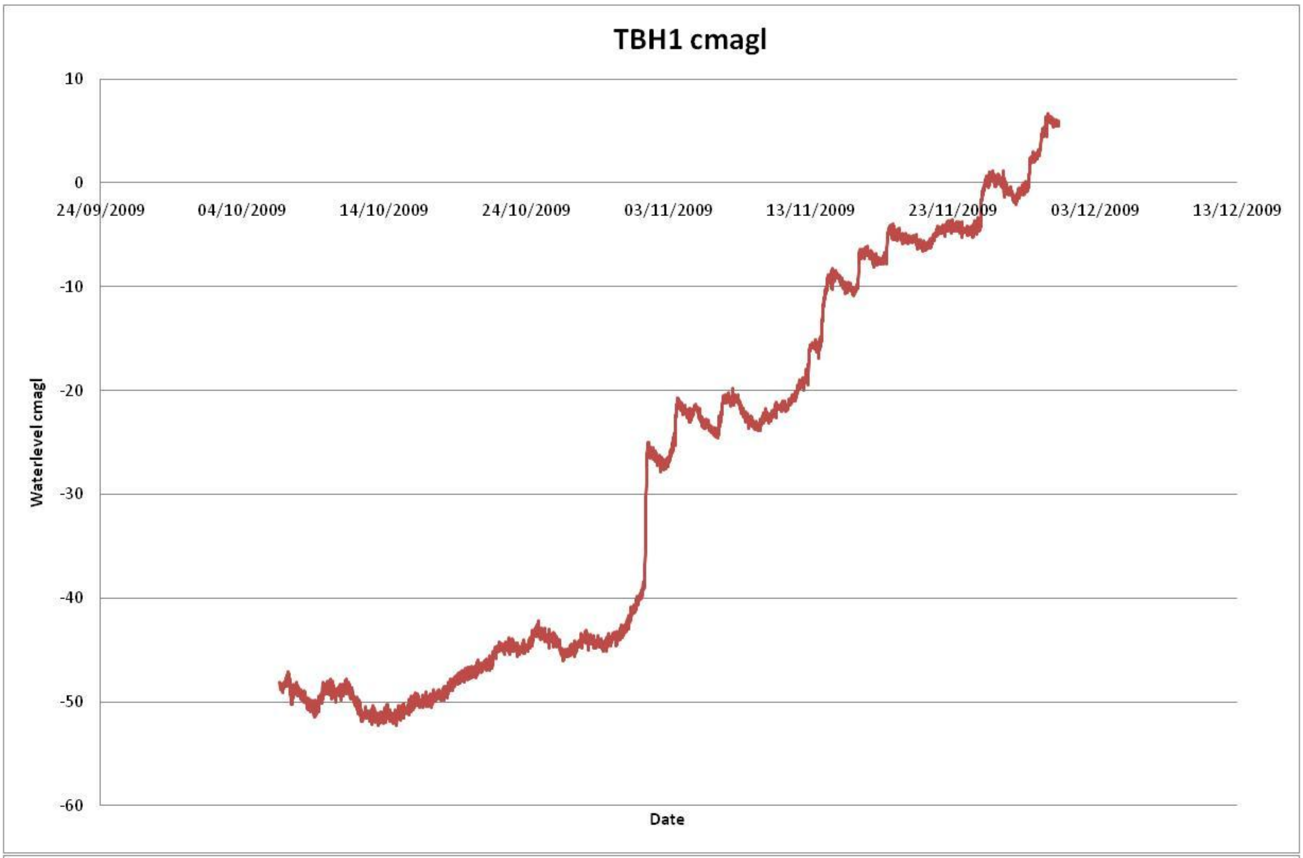
Appendix B: - Groundwater Monitoring

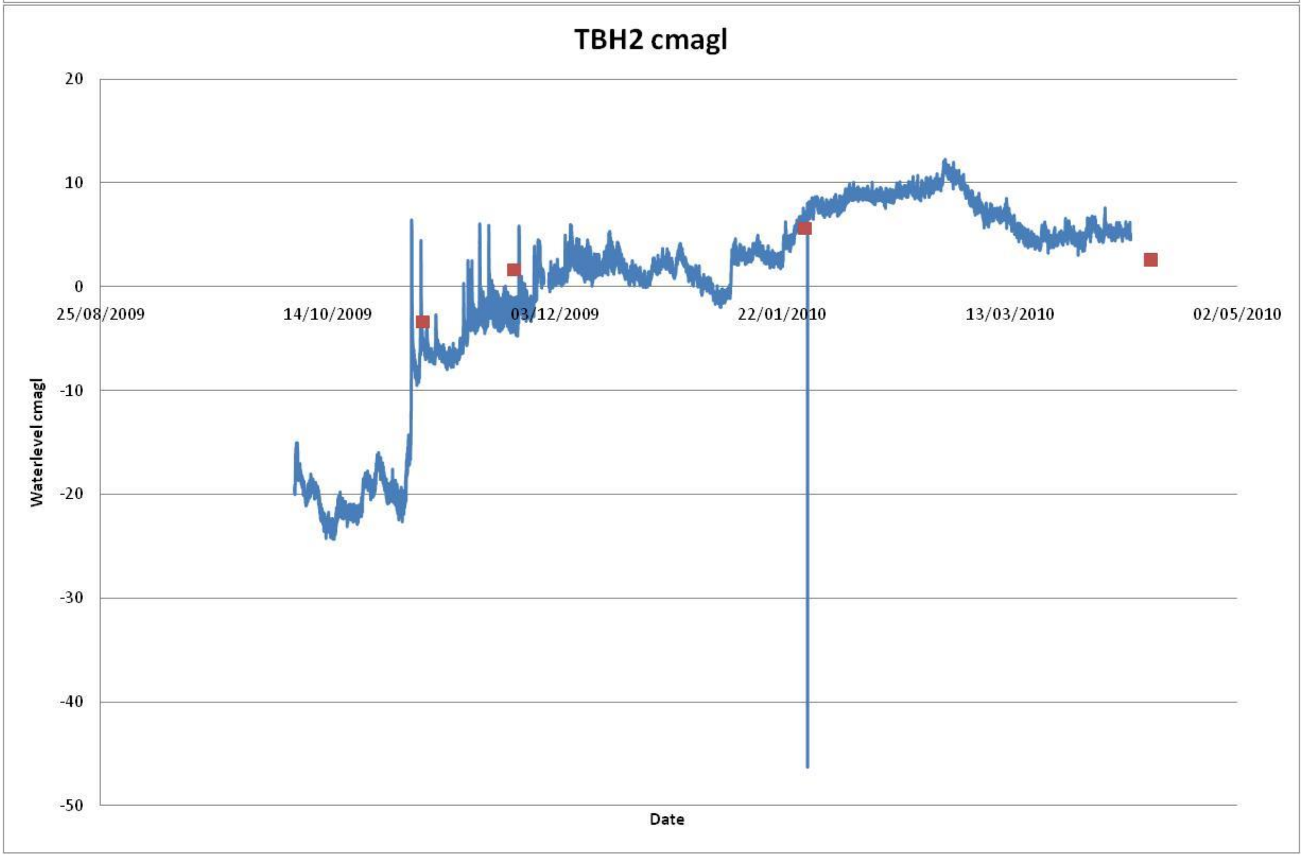
B.1.1 Groundwater Level Graphs

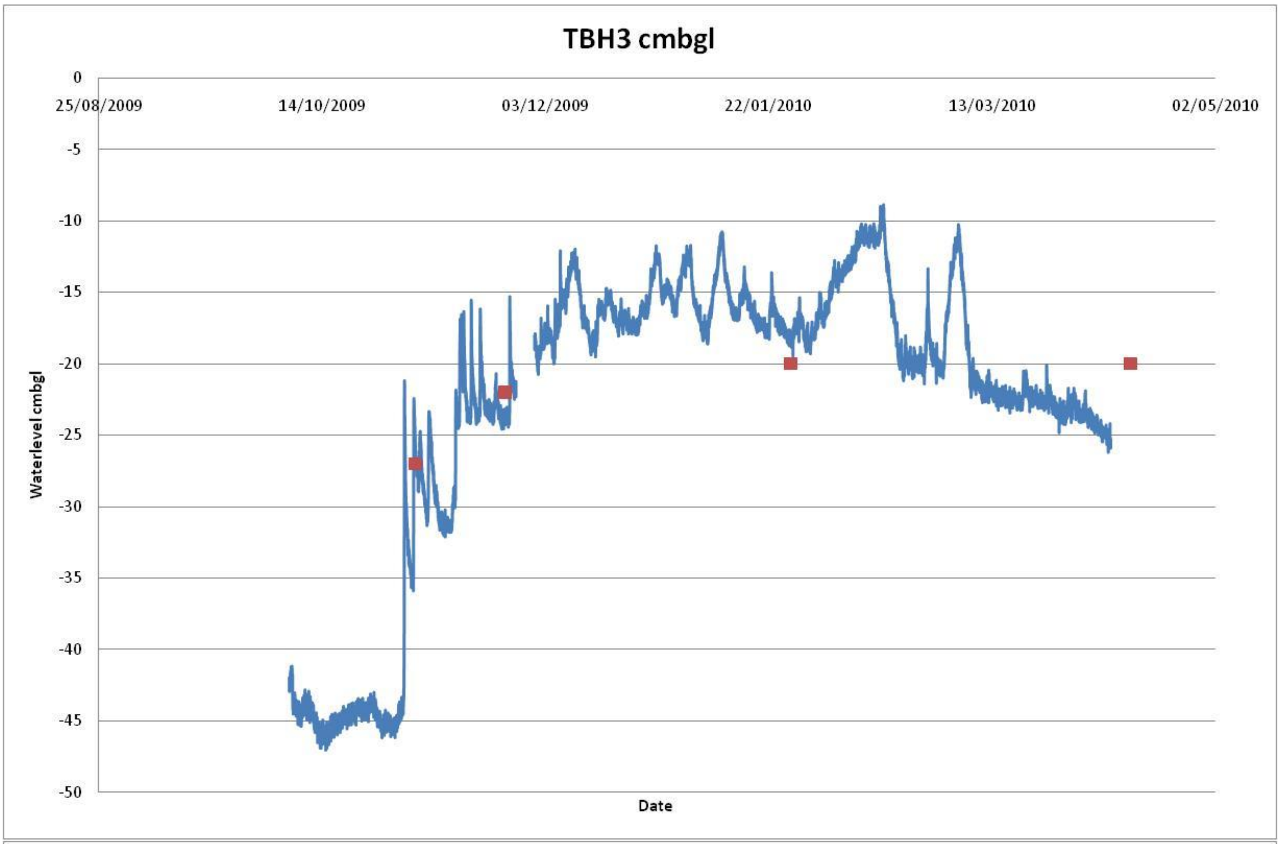
This section shows the groundwater levels recorded by the pressure transducers in the boreholes installed by JBA.

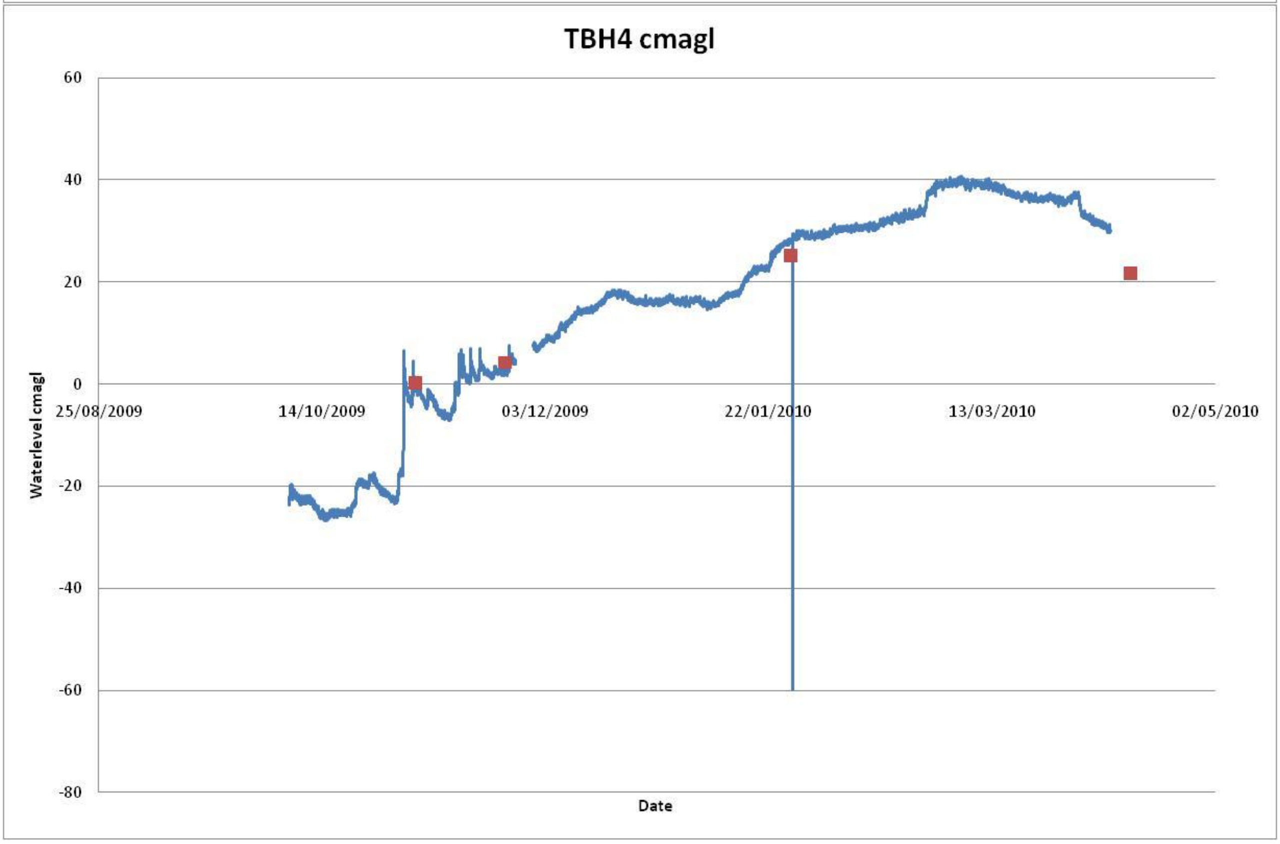
The graphs show individual plots for each borehole in metres below ground level (mbgl) and compilations for Thorne and Crowle both in mbgl and meters Above Ordnance Datum (mAOD). Each of these plots has been analysed to aid in the water level management plan (WLMP). In general the following features can be seen;

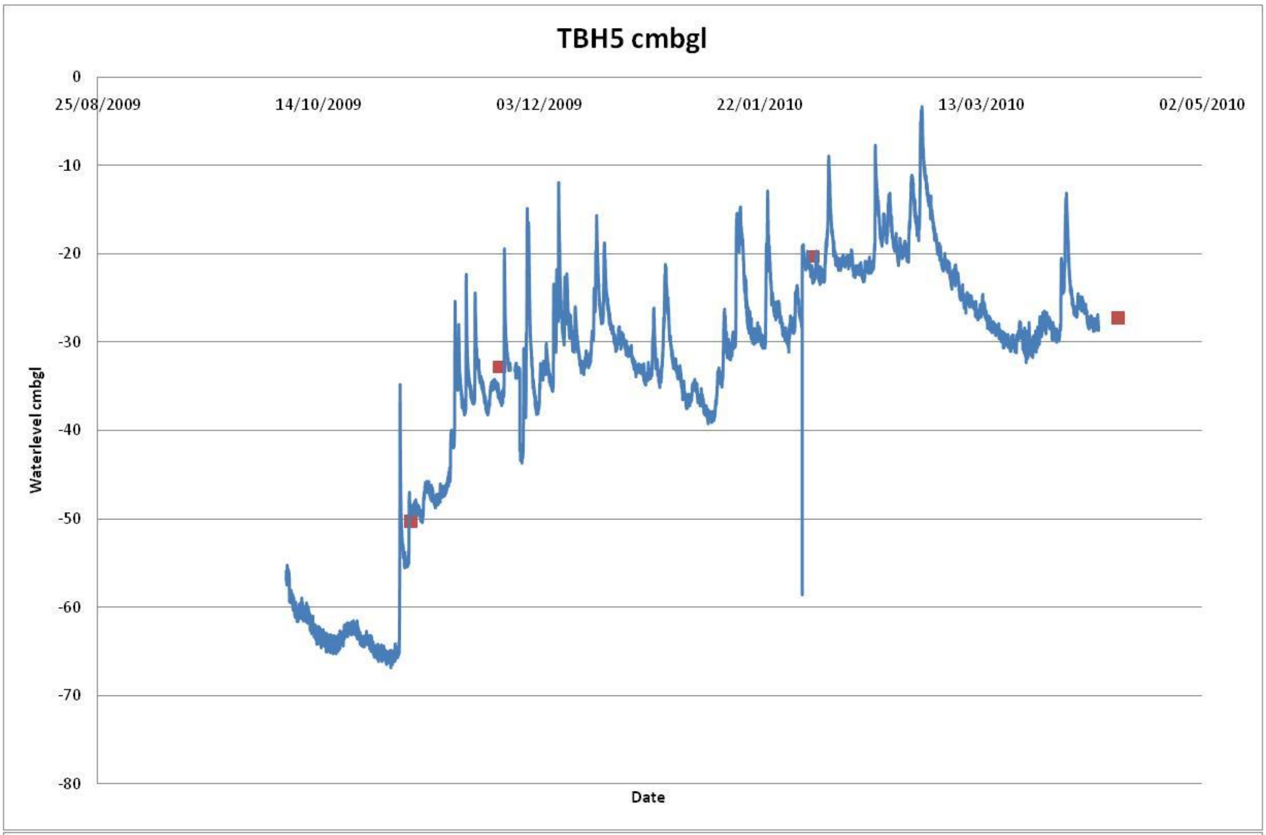
- Groundwater levels in areas which have been milled show greater fluctuations and responses to rainfall events. This is mainly in part due to the degraded nature of the remnant peat;
- The water level plots across the milled areas and the areas of greatest excavation on Crowle are very similar;
- Areas of more intact peat show less short term fluctuations;
- Areas of more intact peat which are near large drains, on the edge of cliffs, or similar, show small amounts of short term fluctuation but appear to slowly drain through the summer months (when recharge is less) and recover during the winter (e.g. TBH16, CBH9 and TBH12);
- When a watertable emerges from the ground surface, short term fluctuations lessen, as the porosity of air is 100%.

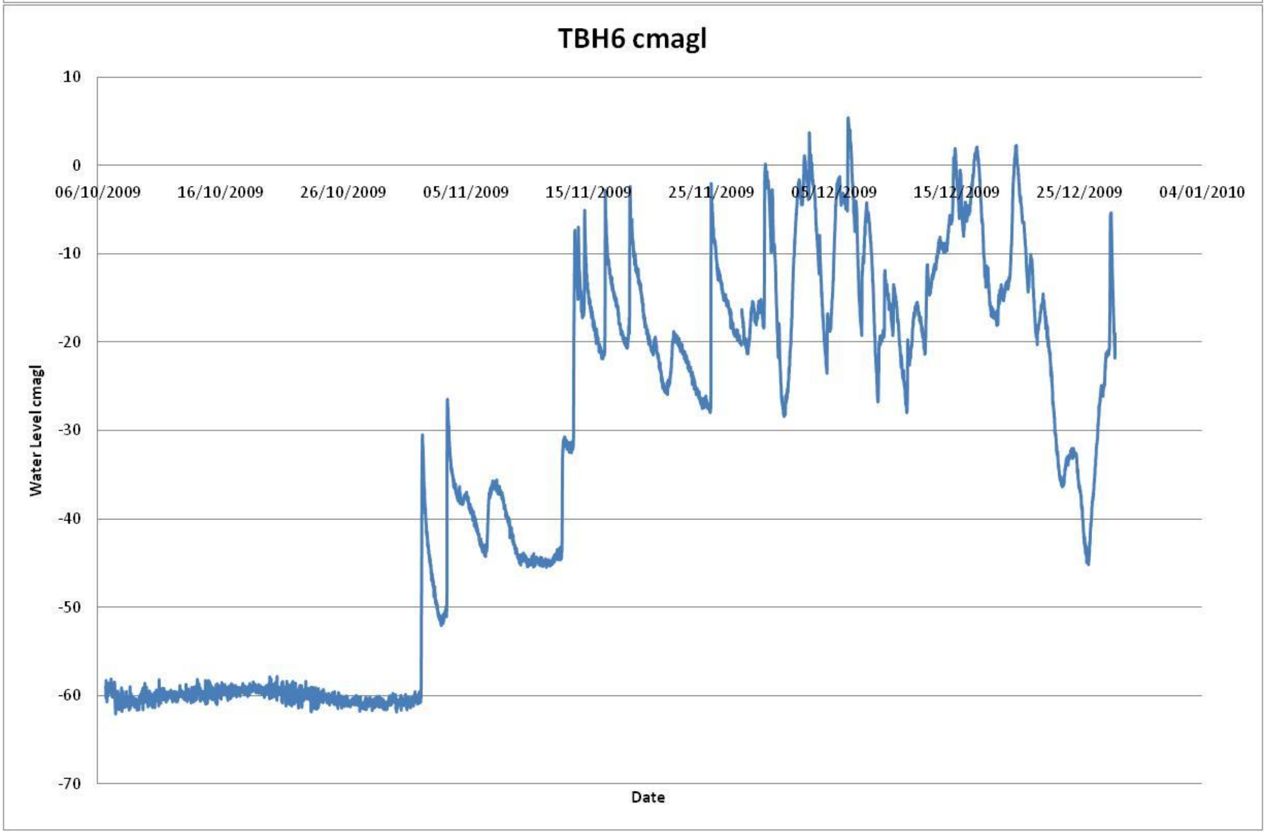

TBH1 cmagl
Waterlevel cmagl
Date
10
0
-10
-20
-30
-40
-50
-60
24/09/2009
04/10/2009
14/10/2009
24/10/2009
03/11/2009
13/11/2009
23/11/2009
03/12/2009
13/12/2009

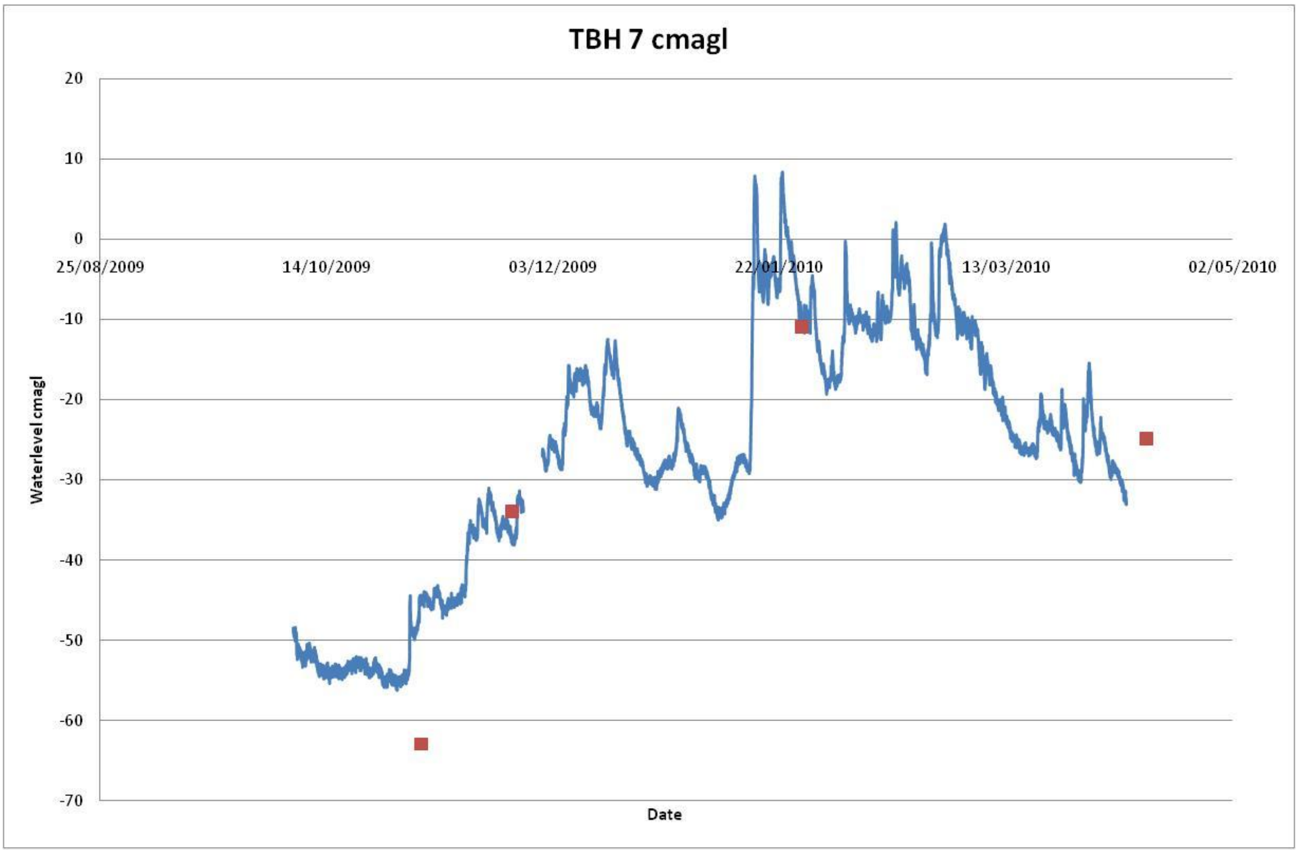

TBH2 cmagl
Waterlevel cmagl
Date
20
10
0
-10
-20
-30
-40
-50
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010

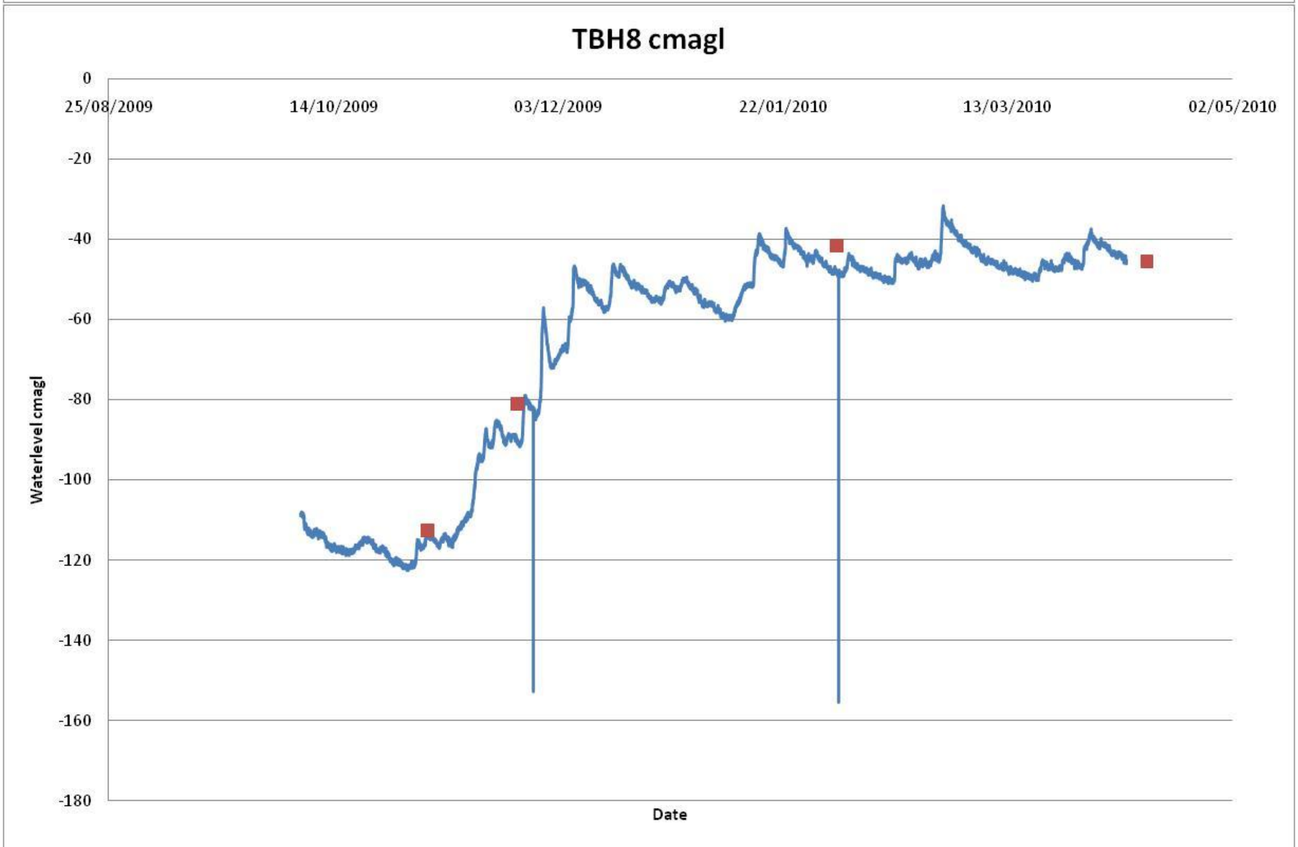

TBH3 cmbgl
Waterlevel cmbgl
Date
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010

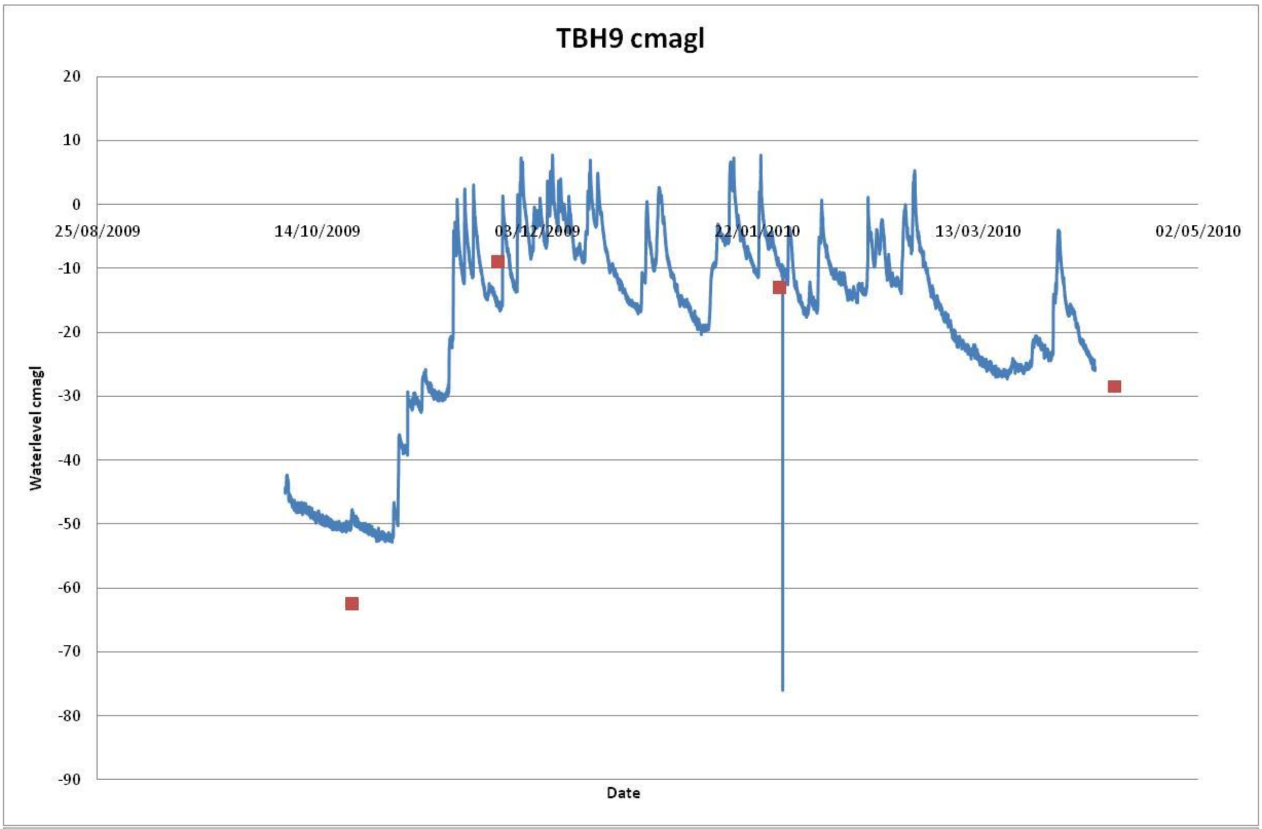

TBH4 cmagl
Waterlevel cmagl
Date
60
40
20
0
-20
-40
-60
-80
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010

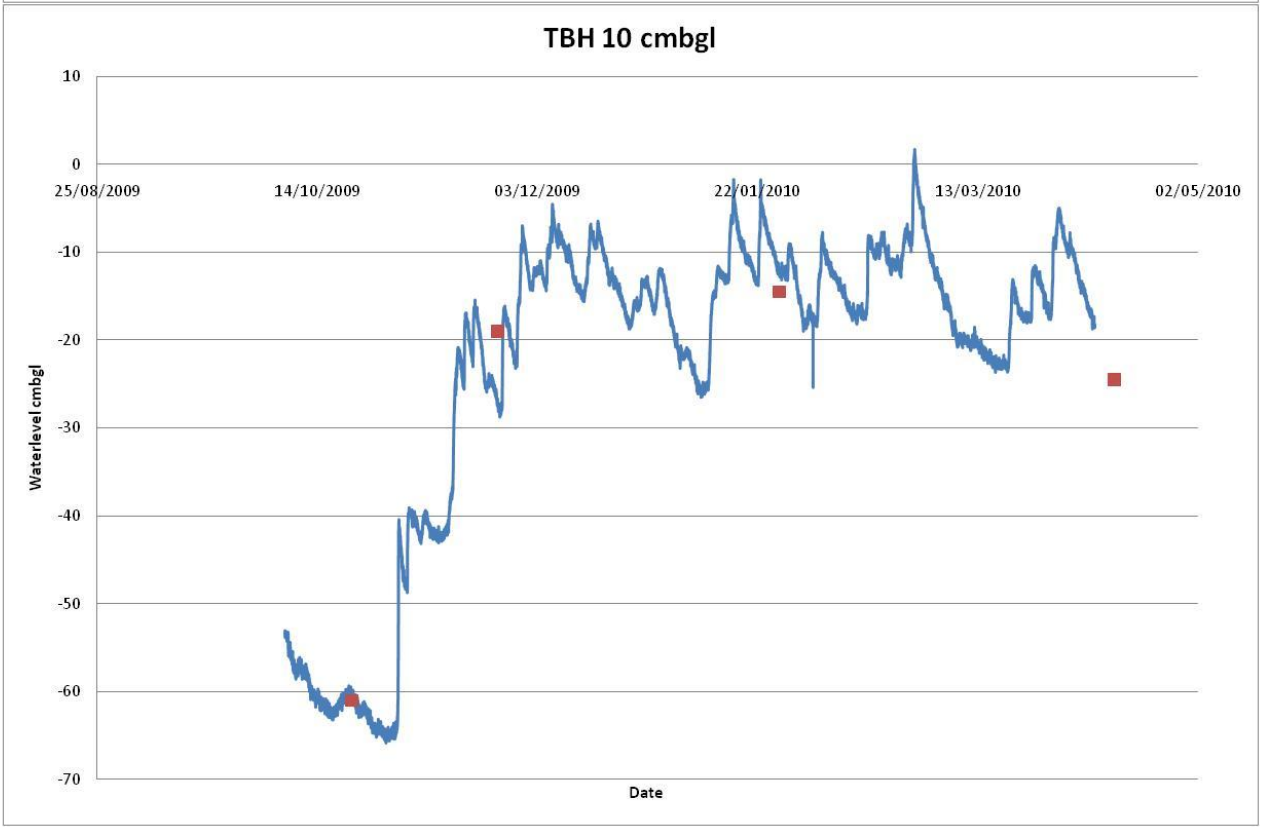

TBH5 cmbgl
0
-10
-20
-30
-40
-50
-60
-70
-80
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010
Waterlevel cmbgl
Date

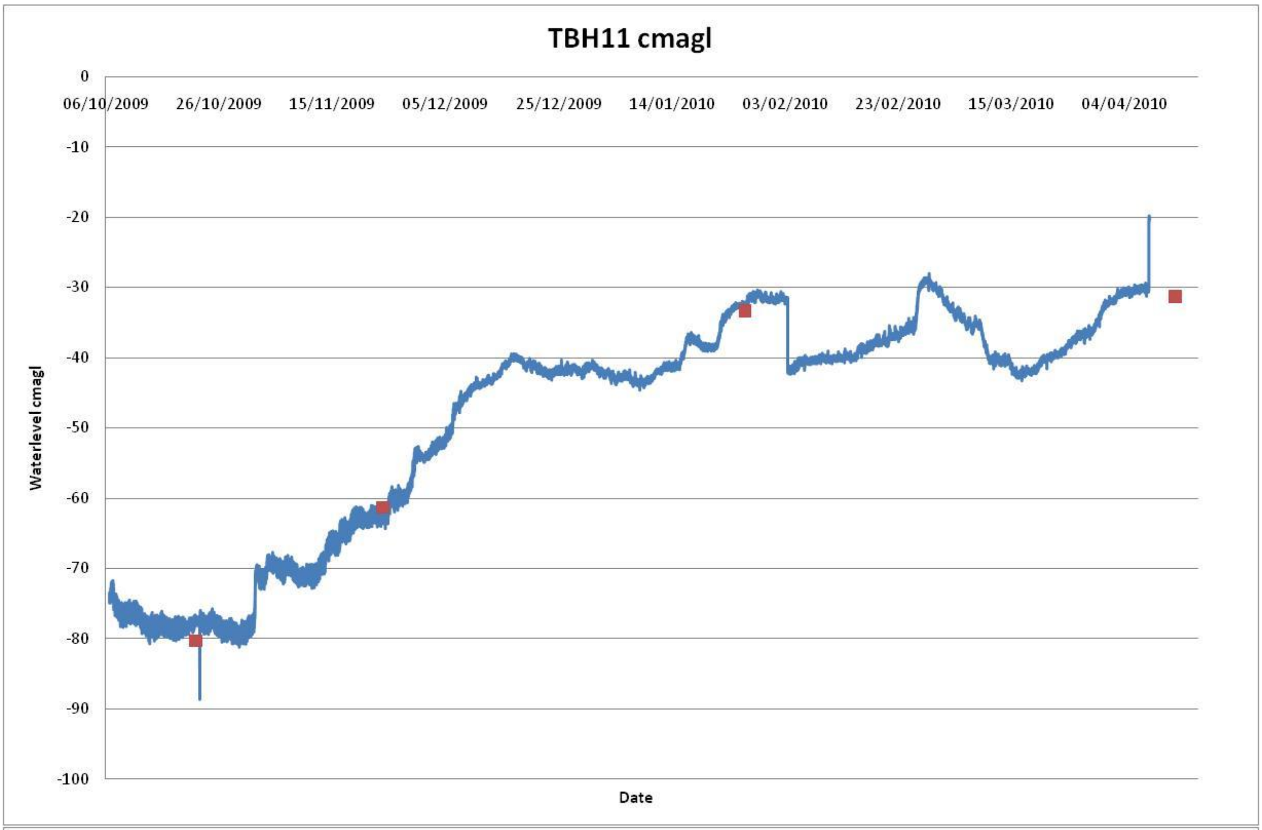

TBH6 cmagl
10
0
-10
-20
-30
-40
-50
-60
-70
06/10/2009
16/10/2009
26/10/2009
05/11/2009
15/11/2009
25/11/2009
05/12/2009
15/12/2009
25/12/2009
04/01/2010
Water Level cmagl
Date

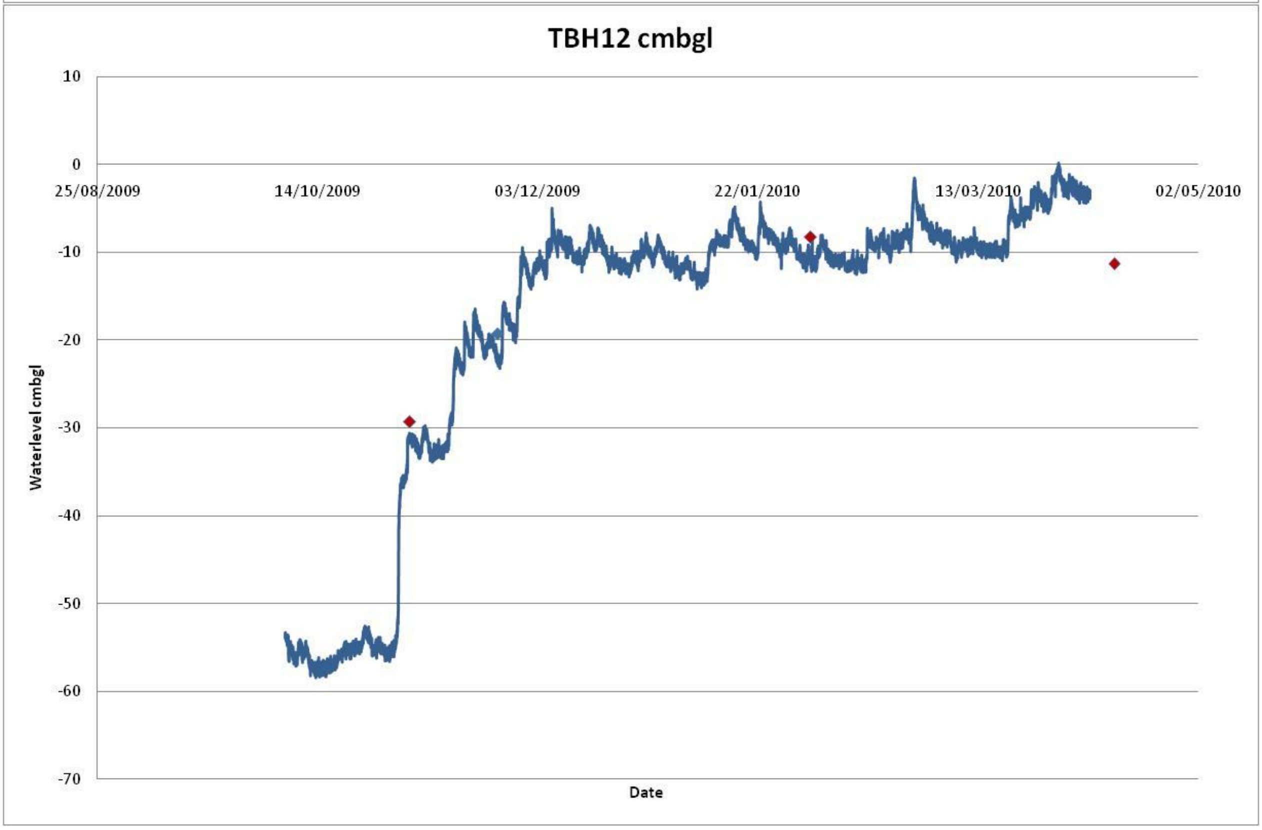

TBH 7 cmagl
20
10
0
-10
-20
-30
-40
-50
-60
-70
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010
Waterlevel cmagl
Date

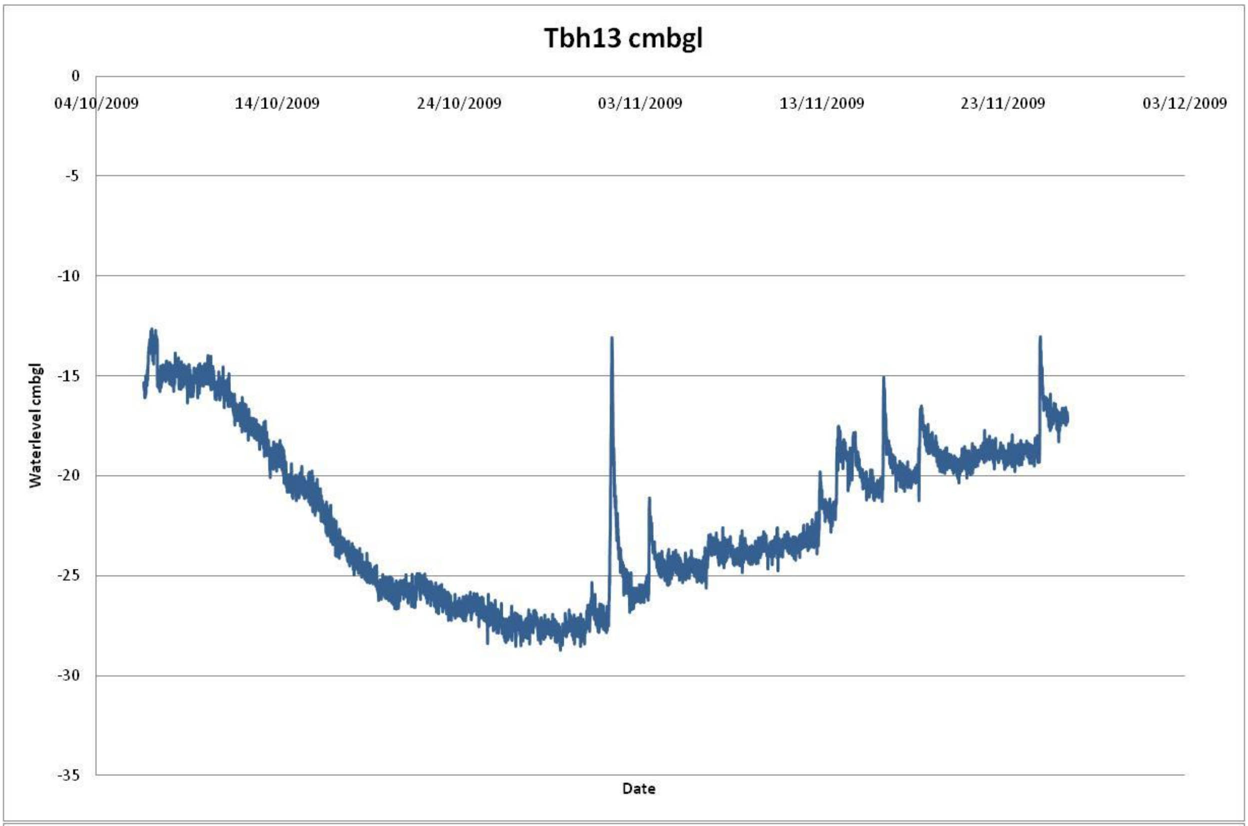

TBH8 cmagl
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010
Waterlevel cmagl
Date

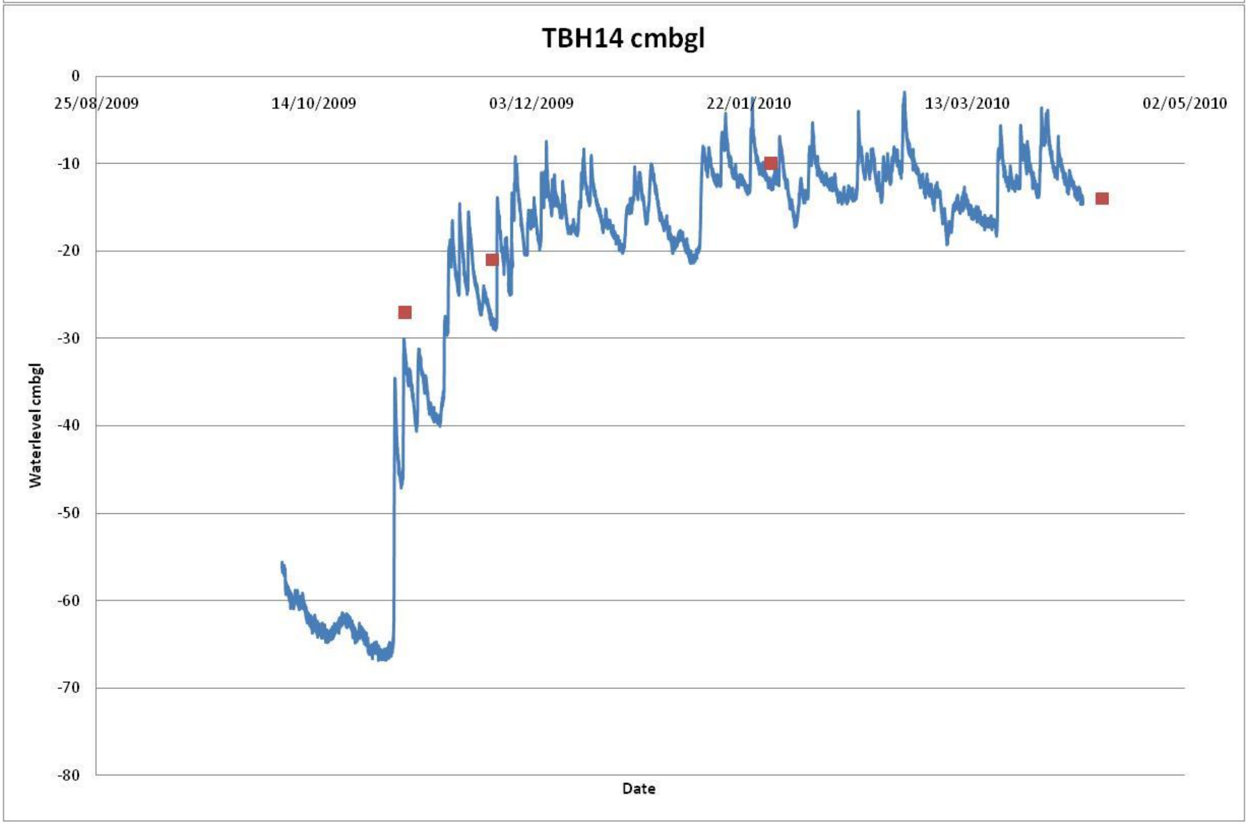

TBH9 cmagl
Waterlevel cmagl
Date
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90


TBH 10 cmbgl
Waterlevel cmbgl
Date
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010
10
0
-10
-20
-30
-40
-50
-60
-70


TBH11 cmagl
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
06/10/2009
26/10/2009
15/11/2009
05/12/2009
25/12/2009
14/01/2010
03/02/2010
23/02/2010
15/03/2010
04/04/2010
Waterlevel cmagl
Date


TBH12 cmbgl
10
0
-10
-20
-30
-40
-50
-60
-70
25/08/2009
14/10/2009
03/12/2009
22/01/2010
13/03/2010
02/05/2010
Waterlevel cmbgl
Date


Tbh13 cmbgl
0
-5
-10
-15
-20
-25
-30
-35
04/10/2009
14/10/2009
24/10/2009
03/11/2009
13/11/2009
23/11/2009
03/12/2009
Waterlevel cmbgl
Date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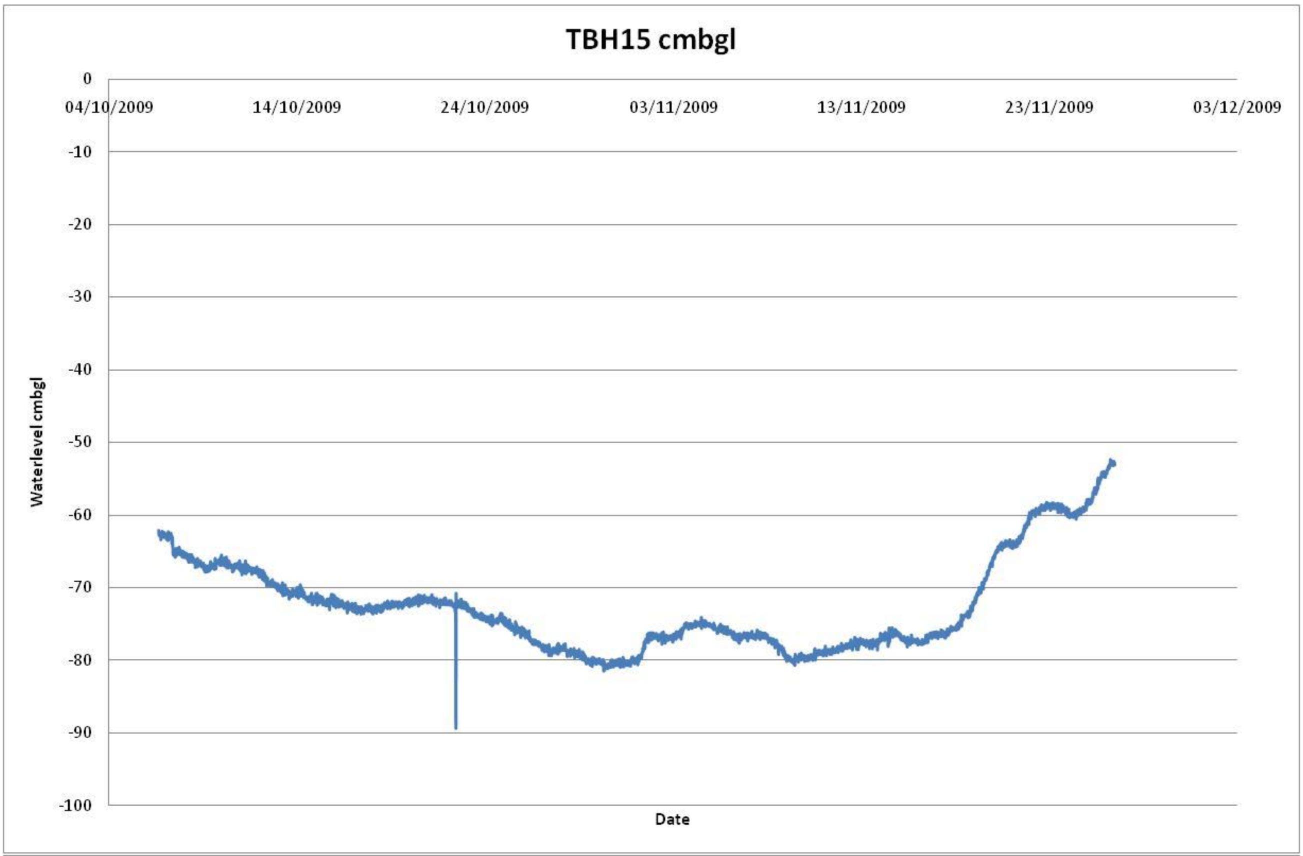
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-60
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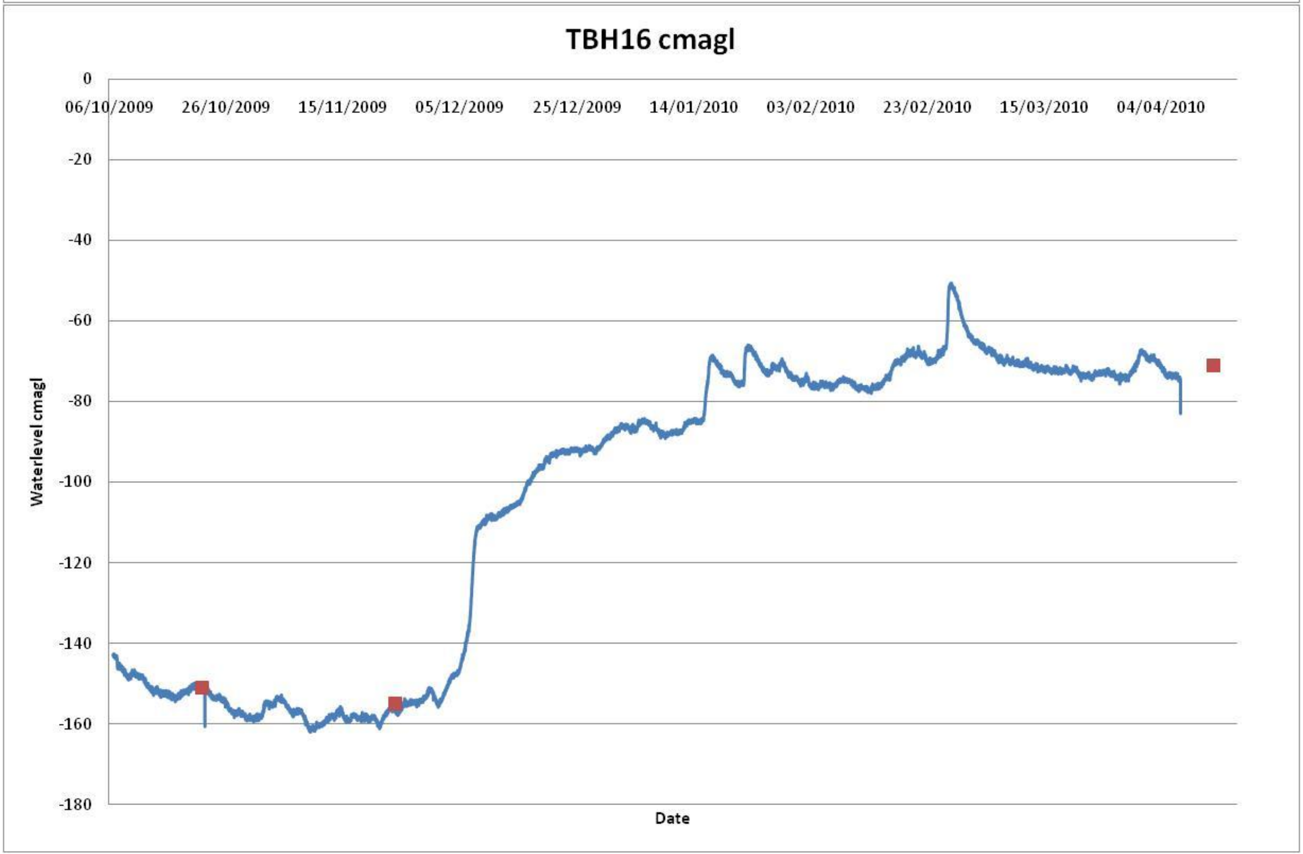
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23/02/2010
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04/04/2010
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-60
-80
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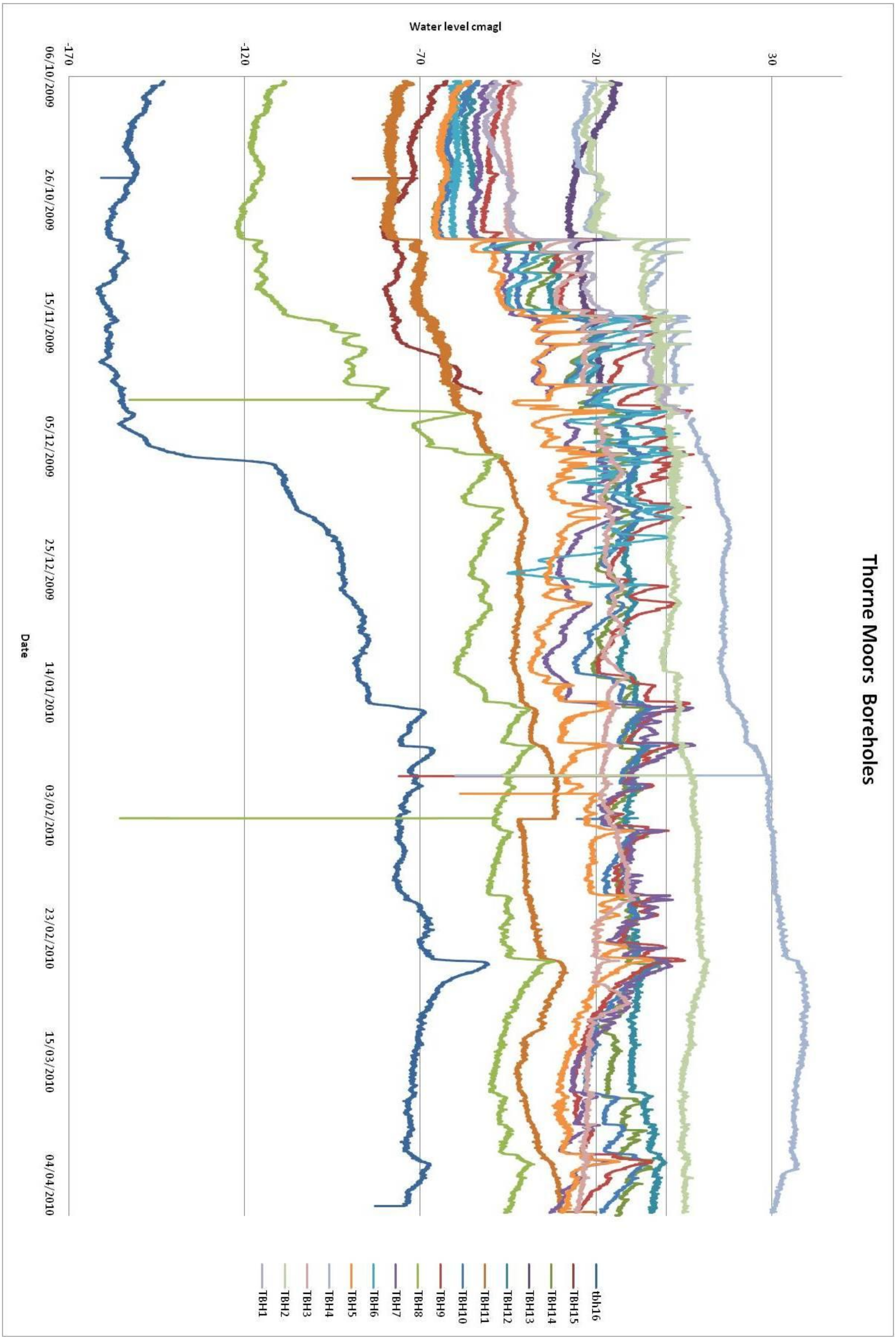
-140
-160
-180
Waterlevel cmagl
Date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15/03/2010
04/04/2010
Date
TBH1
TBH2
TBH3
TBH4
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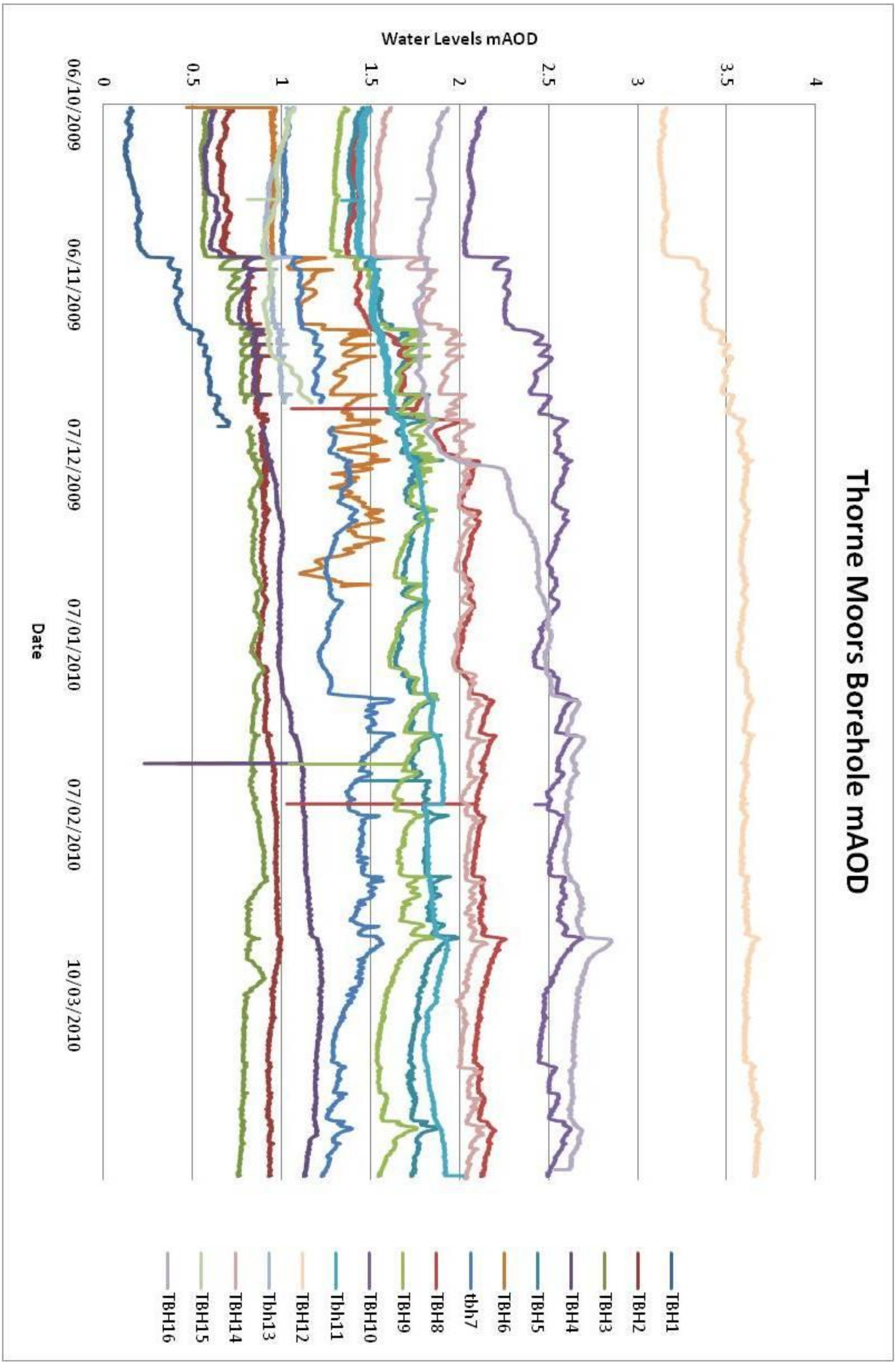
TBH14
TBH15
tbh16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Date
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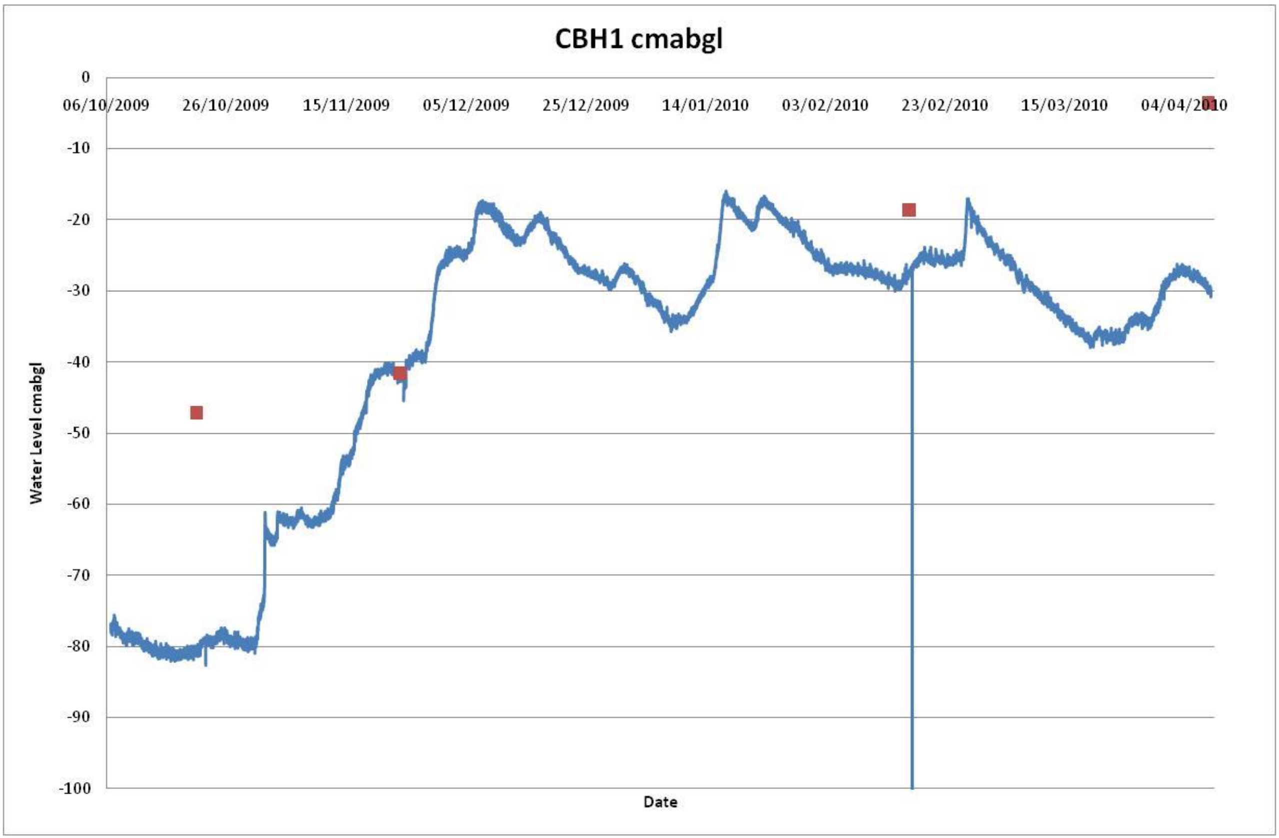
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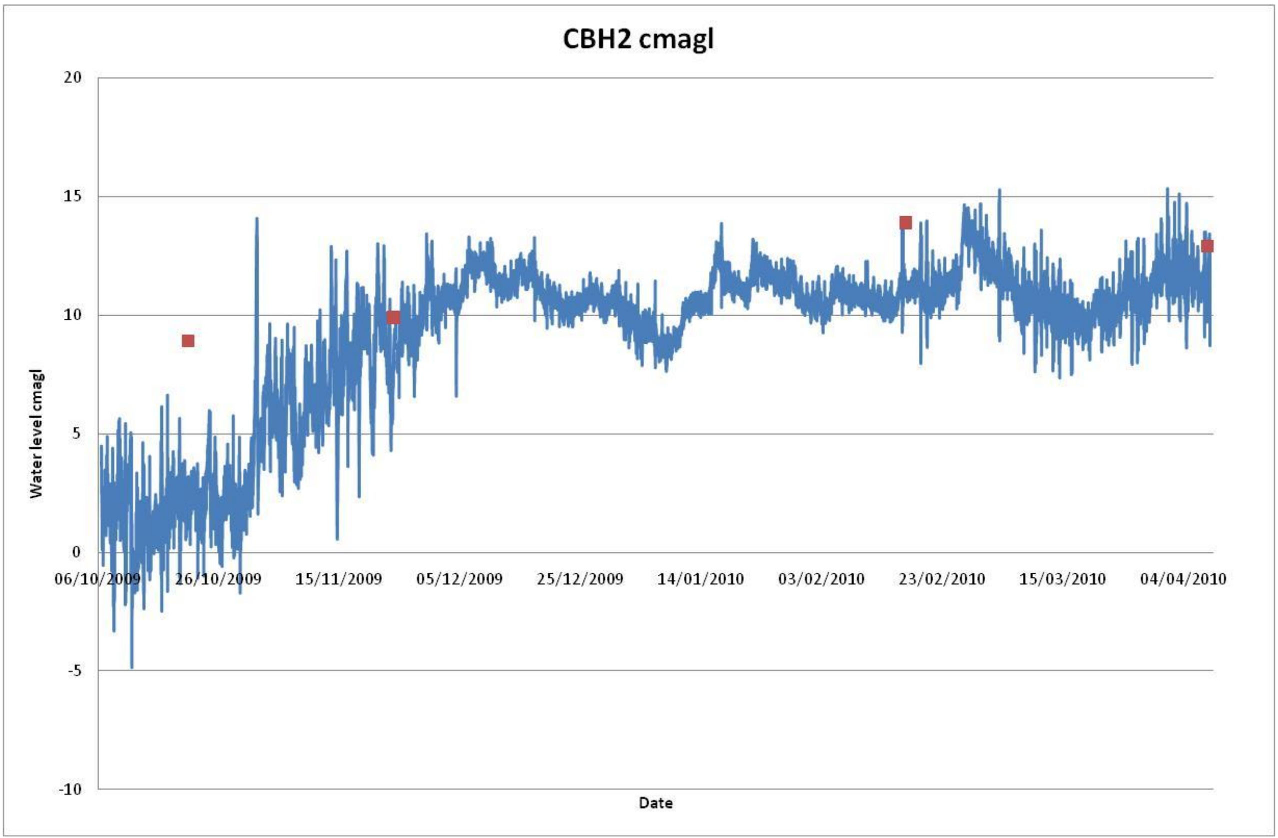
04/04/2010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5
0
-5
-10
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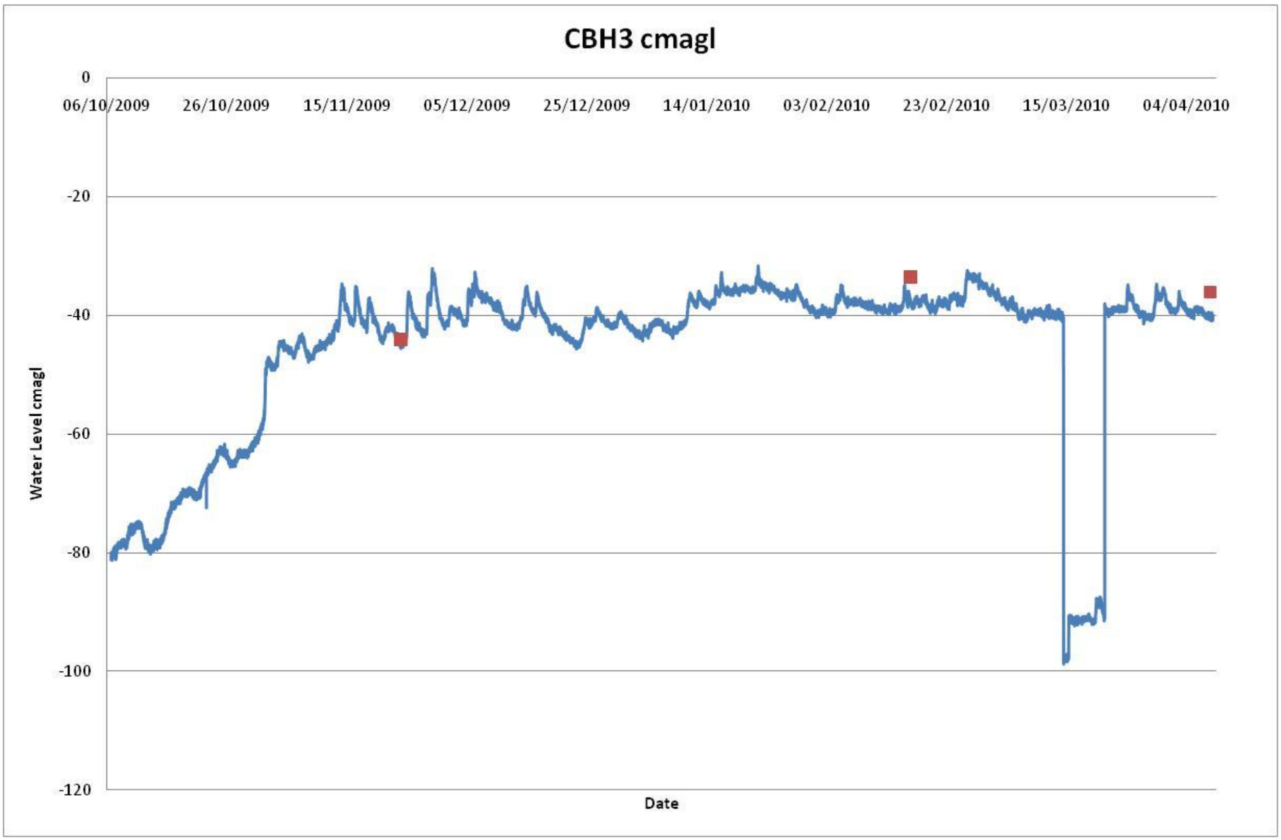
04/04/2010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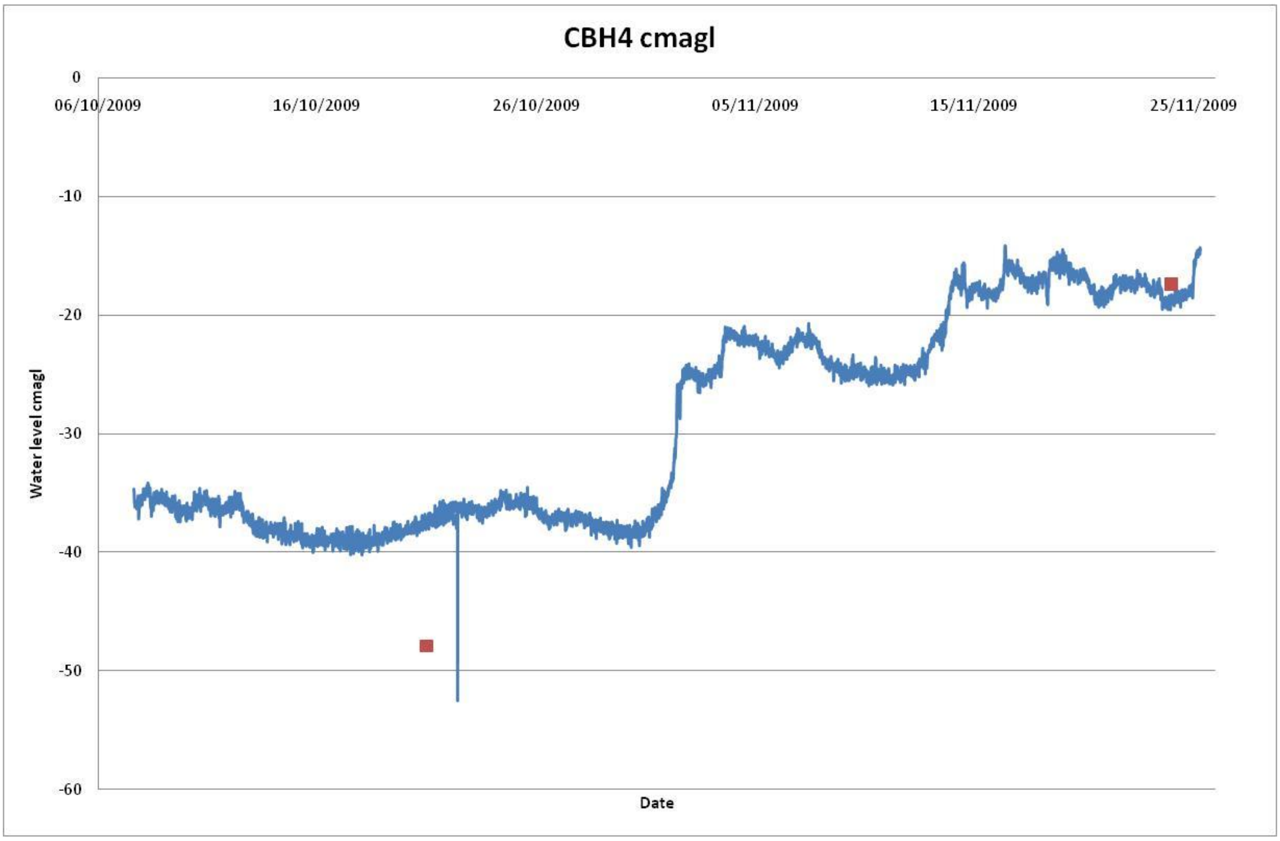
04/04/2010
Water Level cmagl
Date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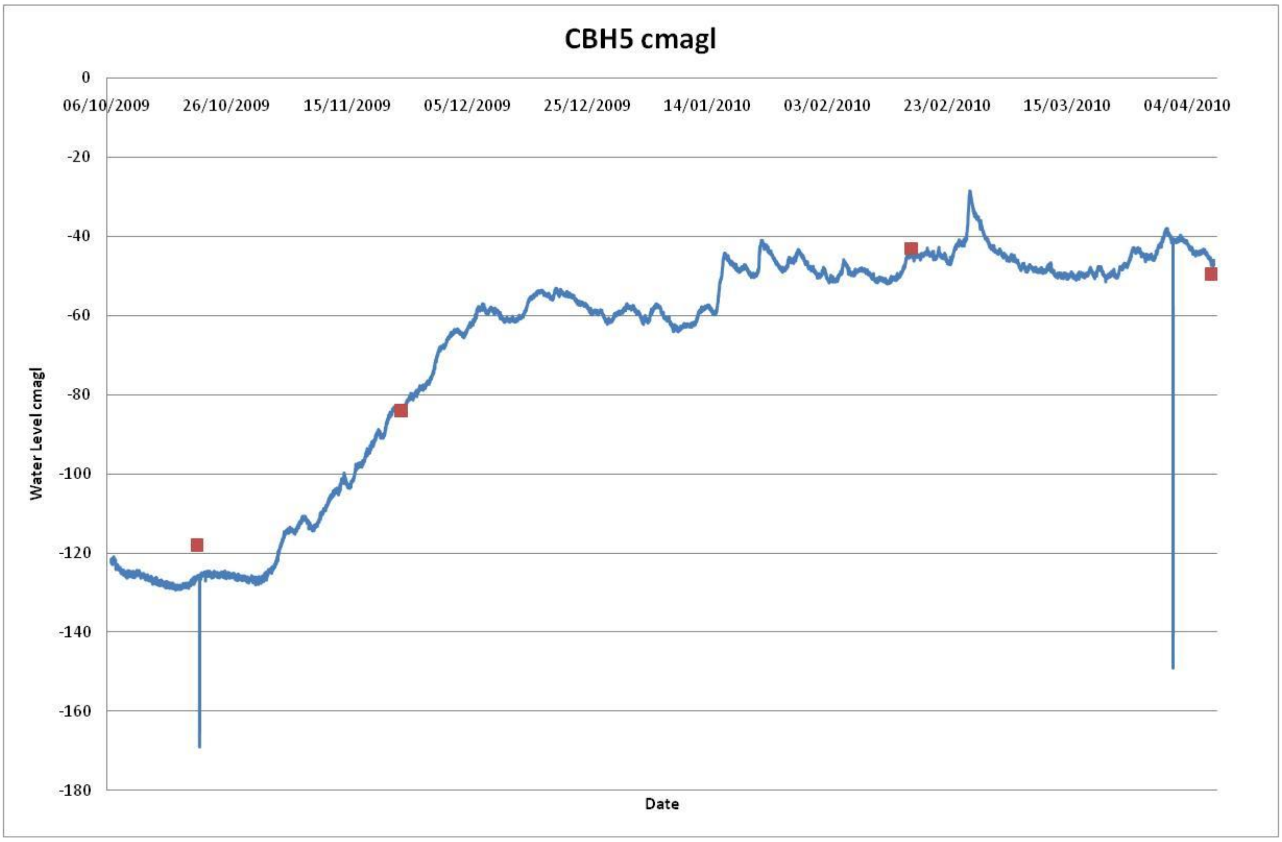
25/11/2009
Water level cmagl
Date


CBH5 cmagl
Water Level cmagl
Date
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-20
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-60
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-140
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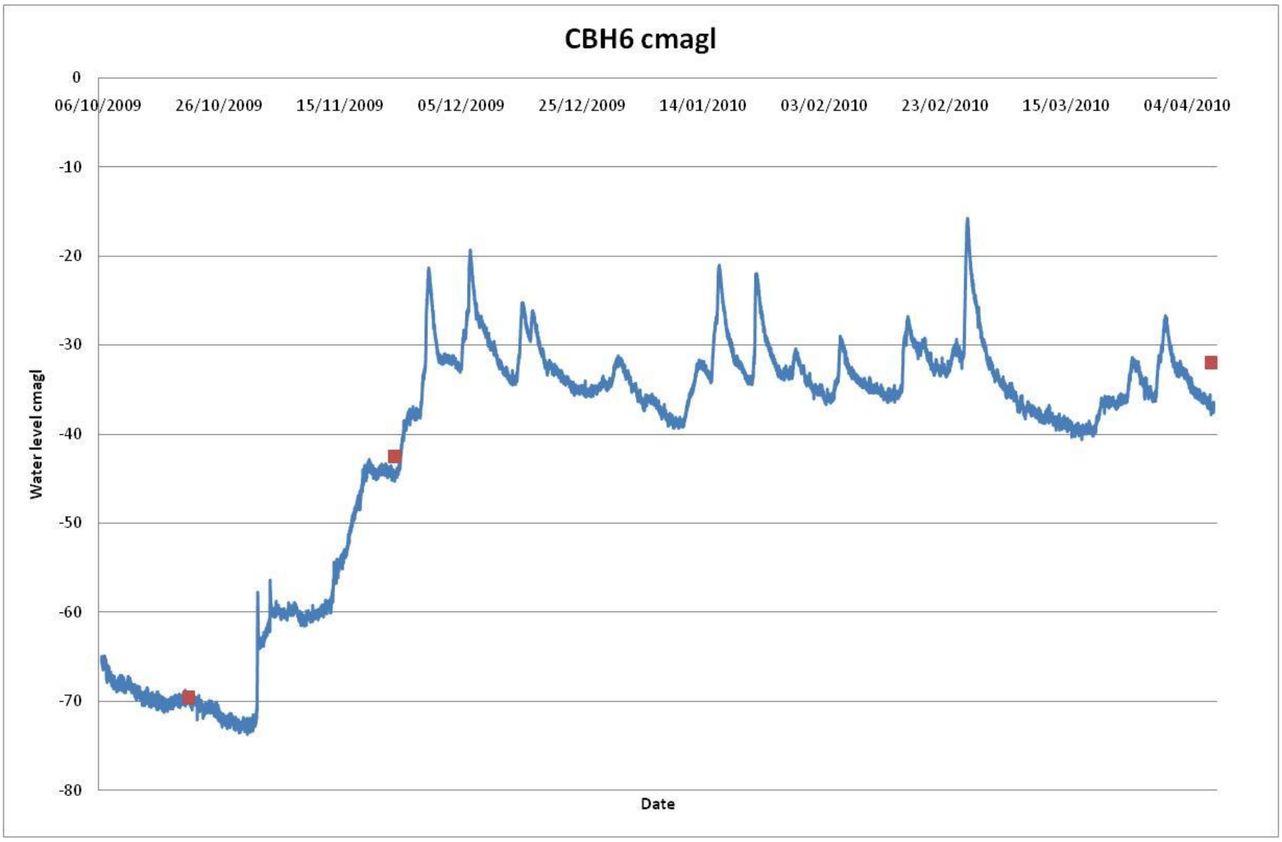
04/04/2010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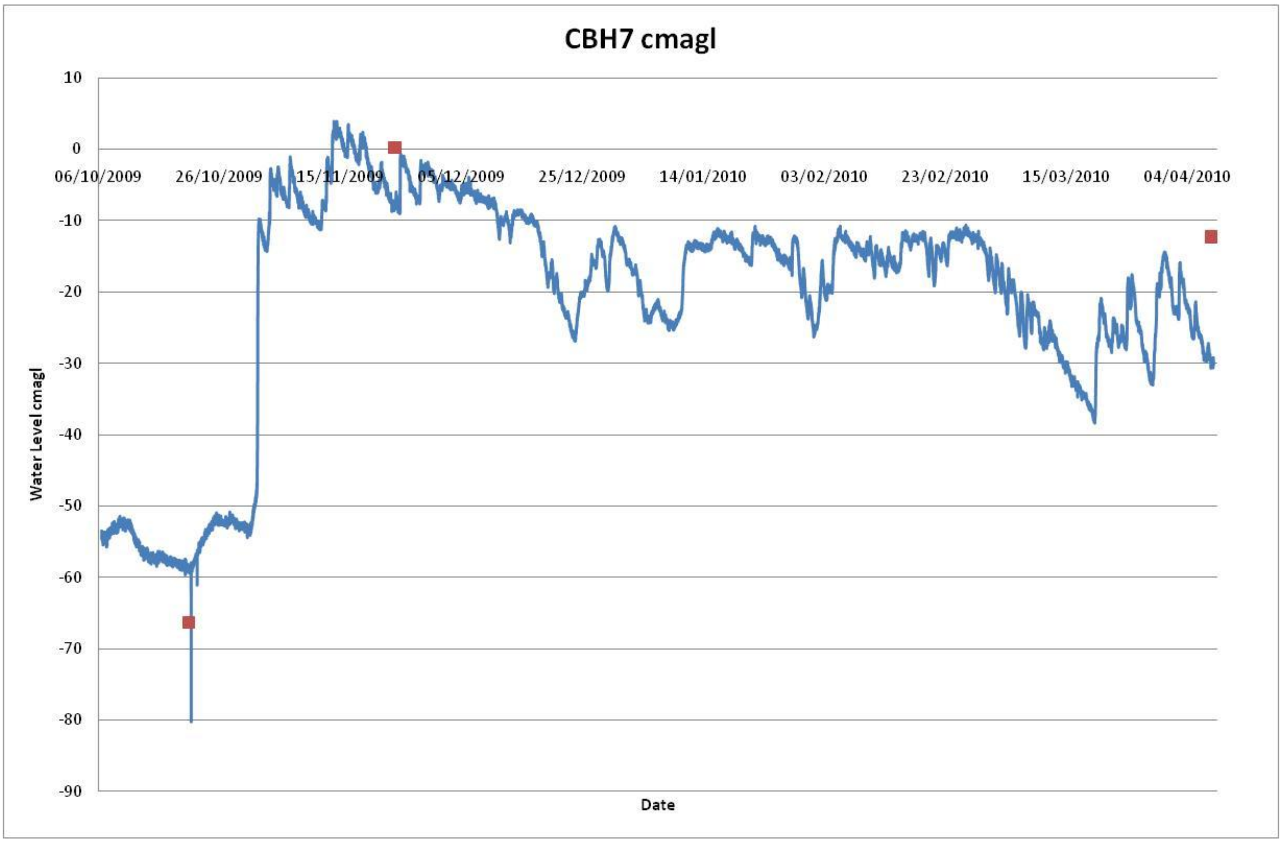
04/04/2010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Water Level cmagl
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-30
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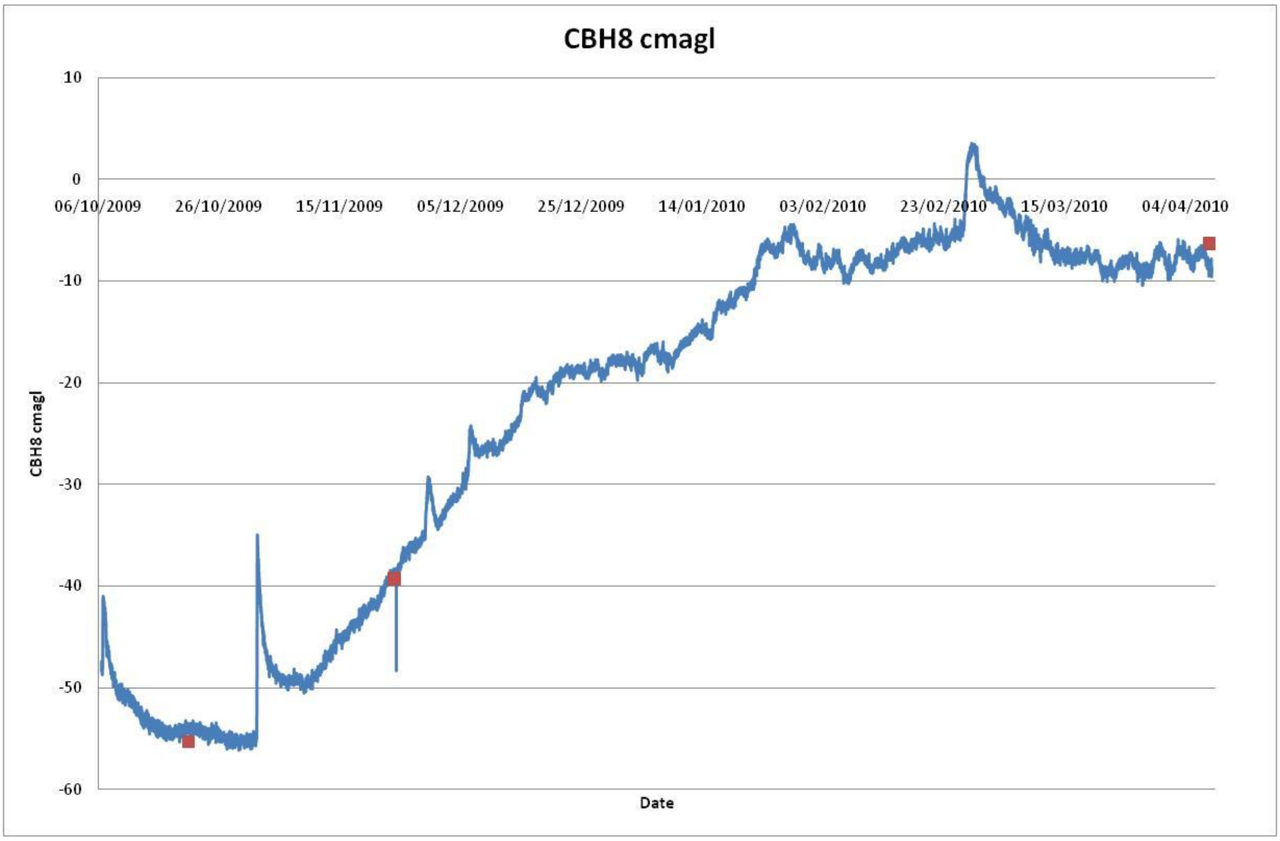
04/04/2010
Date


CBH8 cmagl
CBH8 cmagl
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-10
-20
-30
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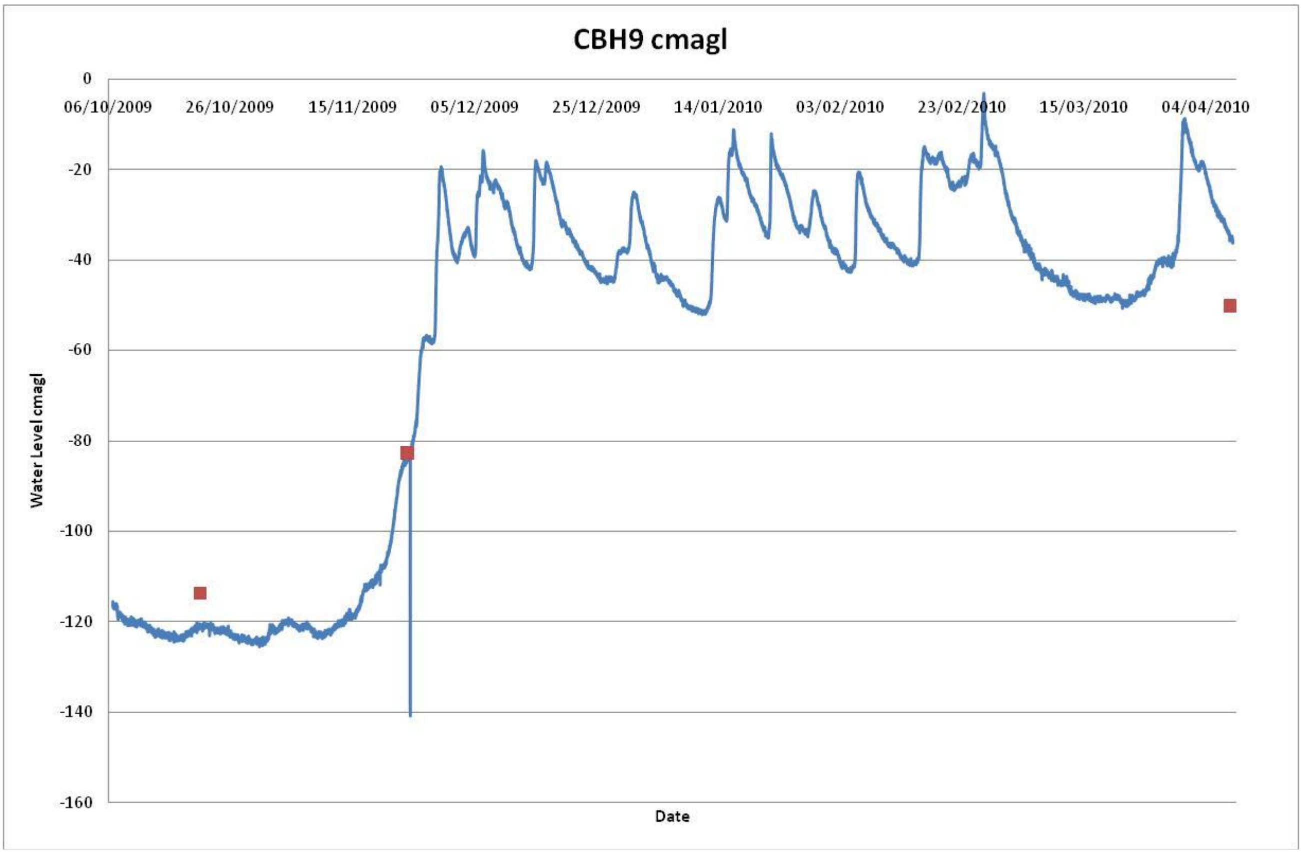
04/04/2010
Date


CBH9 cmagl
0
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-40
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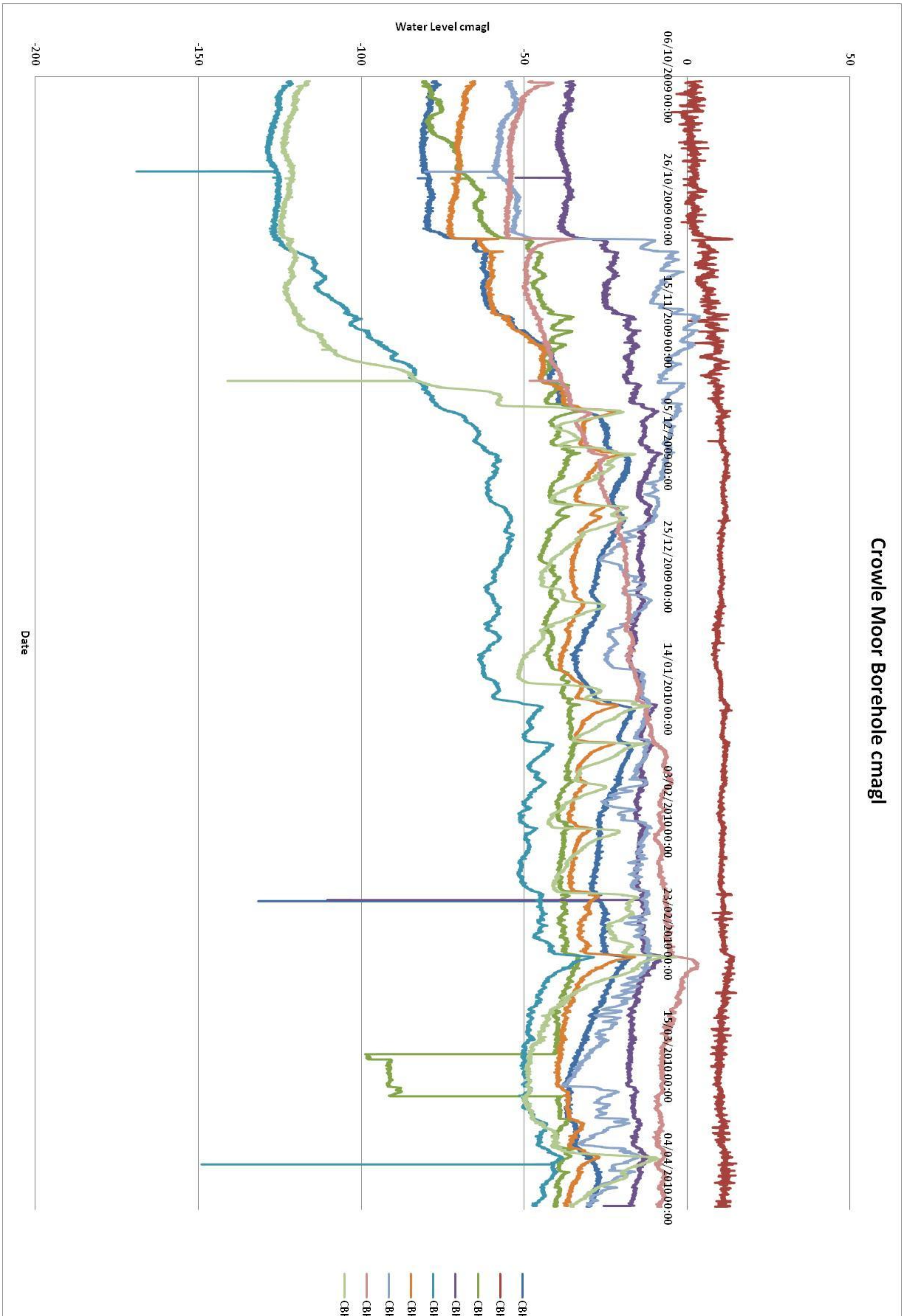
04/04/2010
Water Level cmagl
Date


Crowle Moor Borehole cmagl
Water Level cmagl
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-150
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26/10/2009 00:00
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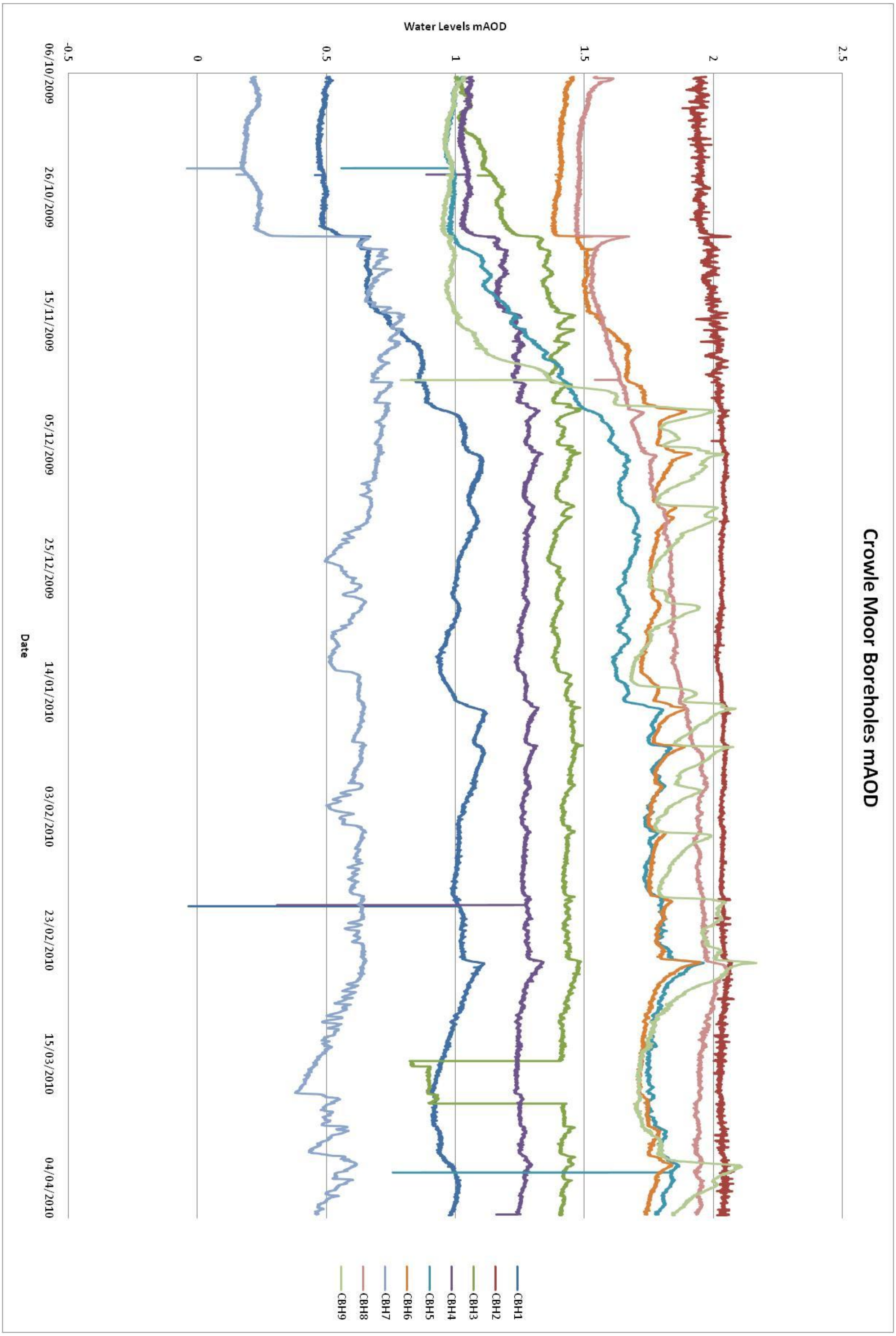
15/03/2010 00:00
04/04/2010 00:00
Date
CBH1
CBH2
CBH3
CBH4
CBH5
CBH6
CBH7
CBH8
CBH9


Crowle Moor Boreholes mAOD
Water Levels mAOD
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0
0.5
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1.5
2
2.5
06/10/2009
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15/11/2009
05/12/2009
25/12/2009
14/01/2010
03/02/2010
23/02/2010
15/03/2010
04/04/2010
Date
CBH1
CBH2
CBH3
CBH4
CBH5
CBH6
CBH7
CBH8
CBH9

Appendix C: - Costings

	Unit	Quantity	Rate	Amount
CLASS D - Demolition and Site Clearance				
Clearance of dense woodland/scrub	Ha.	219	£2,500.00	£547,500.00
Clearance of less dense woodland/scrub	Ha.	220	£2,000.00	£440,000.00
Clearance of scattered trees	Ha.	111	£250.00	£27,750.00
CLASS E - Earthworks				
General excavation of clay forming new drains.	m³	17,913	£1.11	£19,882.88
Trimming of excavated surfaces to form new drains.	m²	8,598	£0.15	£1,289.70
Filling of existing ditches with clay. To include for storing material and double handling.	m³	4,078	£2.50	£10,193.75
Excavation to re-profile peat cliffs 1-4m deep, 0-35m wide	m³	132,169	£1.11	£146,707.31
Excavation to re-profile peat cliffs >1m deep, 0-10m wide	m³	7,710	£1.11	£8,558.10
Trimming of excavated surfaces to form peat cliffs.	m²	126,295	£0.15	£18,944.25
Filling to block ditches/furrows with peat	m³	8,088	£2.50	£20,220.00
Two stage fixed PVC sheet pile weirs	Nr	19	£8.00	£152.00
Filling to form peat bunds (Milled Area/Ribbon Row)	m³	18,043	£2.50	£45,106.25
Polyethylene sheeting	m³	34,028	£11.00	£374,302.50
4" pipes @ 200 metre c/c (Milled Area/Ribbon Row)	Nr	41	£8.00	£328.00
Filling to form clay lag levees	m³	5,369	£2.50	£13,421.25
Additional Lagg Levees	m³	5,644	£2.50	£14,110.83
Filling with clay to form Minor Agricultural Dams	m³	277	£2.50	£691.88
Disposal of excavated clay material on site locally.	m³	2,545	£2.00	
Disposal of excavated clay material off site. All charges for transport and tip to be included (provisional)	m³	2,545	£15.00	£38,181.25
Disposal of excavated peat material on site locally.	m³	113,748	£2.00	£227,496.50
Disposal of excavated Peat material off site. All charges for transport and tip to be included (provisional)	m³	113,748	£15.00	£1,706,223.75
CLASS P - Piles				
PVC Interlocking Full Pan Pile 310mm overall width (Section Modulus TBC). Include for installing to manufacturers guidelines. 2000mm depth.				
Driven area of PVC pile run.	m²	1,692	£8.50	£14,382.00
Area of PVC pile run length not exceeding 14m.	m²	1,692	£17.50	£29,610.00
Driven area of PVC pile Minor Peat Dam	m²	140	£8.50	£1,190.00
Area of PVC pile run length not exceeding 14m.	m²	140	£17.50	£2,450.00

	Unit	Quantity	Rate	Amount
Interlocking Steel Sheet Piles PAL3030 (Section Modulus TBC). 2000mm depth.				
Driven area of Steel pile run (provisional).	m²	1,692	£8.70	£14,720.40
Area of Steel pile run length not exceeding 14m (provisional).	m²	1,692	£25.00	£42,300.00
Driven area of Steel pile Major Peat Dam	m²	123	£11.00	£1,347.50
Area of Steel pile run length not exceeding 14m.	m²	123	£30.00	£3,675.00
Driven area of Steel pile Major Agricultural Dam	m²	189	£11.00	£2,079.00
Area of Steel pile run length not exceeding 14m.	m²	189	£30.00	£5,670.00
CLASS X - Miscellaneous Work				
Supply and install Compact Tilting Weir for Major Agricultural Dams	Nr.	6	£7,000.00	£42,000.00
Supply and install Compact Tilting Weir for Major Peat Dams	Nr.	7	£7,000.00	£49,000.00
Sub Total (deducting provisional items)				***£2,068,058.70***
1000 l/s (2no. pump) Pumping Station Costs				
Site Investigation	Sum	1	£10,000.00	£10,000.00
Structural and Earthworks	Sum	1	£600,000.00	£600,000.00
Pumps	Sum	1	£80,000.00	£80,000.00
Weedscreen Cleaner	Sum	1	£50,000.00	£50,000.00
Telemetry (include. 4no. remote links for tilting weirs)	Sum	1	£35,000.00	£35,000.00
Electricity Connection	Sum	1	£40,000.00	£40,000.00
Sub Total				***£815,000.00***
20% Preliminaries (site setup etc.)	%	0.20	£2,883,058.70	£576,611.74
TOTAL Estimated Construction Cost				**£3,459,670.44**
Engineers Fees (Design, Tender, Site Supervision)	%	0.067	£3,459,670.44	£231,797.92
Environmental Impact Assessment	Sum	1	£20,000.00	£20,000.00
TOTAL Estimated Scheme Cost				**£3,711,468.35**
Benefit per hectare (751 hectares)	**Ha.**	**1,920**		**£1,933.06**

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