Proof of Evidence

Alex Jones, BSc, MSc, CGeol, FGS

JBA Consulting

On behalf of

Yorkshire Wildlife Trust

15 October 2019

Planning Appeal (APP/C2741/W/19/3233973)

Appeal by Barwood Strategic Land II LLP

Appeal in respect of refusal of outline planning permission under (with all matters reserved except for means of access) for up to 516 residential units (Class C3) with local centre (Use Classes A1-A4, B1a, C3, D1) public open space with pavilion and associated infrastructure and full application for demolition of existing buildings and structures and creation of ecological protection and enhancement zone. | OS Fields 5475 7267 And 8384 Moor Lane Acomb York

Appeal Reference APP/C2741/W/19/3233973

Contents

Summary

Scope and Purpose

My name is Alex Jones. A statement of my qualifications and experience, and the circumstances of my appointment by Yorkshire Wildlife Trust are set out in my Proof of Evidence. My evidence addresses hydrology and hydrogeological related aspects arising specifically from the proposals, with particular reference to the Council's Reasons for Refusal as noted below:

> *The proposed drainage scheme and Environmental Protection and Enhancement Zone associated with the residential development are considered to have an adverse impact on Askham Bog Site of Special Scientific Interest as a result of changes likely to occur to the hydrological/ hydro-geological interaction between the development site and the Bog. The proposals are considered contrary to paragraph 175 of the National Planning Policy Framework and policies DP2 Sustainable Development, DP3 Sustainable Communities, GI2 Biodiversity and access to nature and GI3 Green Infrastructure Network of the emerging Local Plan.*

Methodology and Structure

In my Proof of Evidence, I followed standardised and well-recognised approaches to the assessment of hydrogeological and hydrological risk with a particular focus on the water supply mechanisms that support the habitats within Askham Bog SSSI. The evidence in main body of this document is structured as follows:

- Section 1 presents an introduction
- Section 2 sets out the scope of evidence,
- Section 3 sets out the methodology used in this evidence,
- Section 4 considers the existing environmental baseline,
- Section 5 considers the assessment of effects,
- Section 6 reviews the findings of the Appellant's assessment of effects,
- Section 7 provides the conclusions.

Baseline Summary / Conceptual Model

Based on the baseline description I have presented in Section 4 of my PoE, I have developed an ecohydrological conceptual model of Askham Bog which is shown in Fig 14 of the PoE. It has the following features:

- The bog lies in a depression surrounded by boundary drains and is underlain by strata including clays, muds, and peat.
- These deposits upon which the wetland has formed are surrounded by a geological formation known as the Alne Formation. In the base of the valley, this formation comprises of a relatively thick layer of sand deposits as evidenced by borehole logs.
- In the valley bottom and along the SSSI boundary with the proposed development, water level monitoring clearly demonstrates that the Alne Formation and boundary drain are hydraulically connected.
- Water levels in the peat body are supported by water levels in the boundary drains and Alne Formation by two mechanisms; (1) Where the peat body is contained within lake bed deposits, a high groundwater table in the Alne Formation limits the rate of lateral groundwater movement (or leakage) through the lake deposits; and, (2) Where peat or peaty deposits (and especially thin deposits) lie directly on the Alne Formation, high groundwater levels in the Alne Formation prevent the vertical loss of water out of the peat deposits.
- On higher areas, the bog is also supported by direct precipitation inputs. This results in lower nutrient conditions. On the lower-lying areas of the bog, water derived from the boundary drains and/or groundwater inputs from the Alne

Formation bring nutrients and minerals into the area, which support the habitat types present in there.

Impacts

I am concerned that the design of the attenuation basin within the Ecological Protection and Enhancement Zone that forms part of the full planning permission for the proposal will lead to changes in the water supply mechanisms that support the habitats on the SSSI. In my PoE, I provide details of the sensitivity of the habitats to changes in water supply mechanisms and then show how the attenuation basin could result in less flooding and decrease groundwater inputs to the bog, and increases in the rate of drainage from the bog.

The impact mechanisms identified are in part a result of the design requirements of the scheme. The attenuation basin is integral to the Sustainable Drainage Strategy (SUDS) design and the proposed functioning of the Ecological Protection and Enhancement Zone (EPEZ) and therefore it has two main objectives; temporarily store and attenuate surface water flows so that there is a reduction in run-off rates below the current situation, and; replicate or improve the water supply mechanisms to the SSSI. These objectives, in my opinion, are not mutually compatible.

Review of Appellants Assessments

In addition to undertaking my own hydrogeological risk assessment process, I have reviewed the hydrogeological and hydrological documentation provided by the Appellant.

The assessment of impacts on the SSSI in the ES is based on the assumption that "Askham Bog is critically dependent on precipitation for water supply rather than surface water runoff or groundwater inputs". This is overly simplistic in my opinion. It is conceded that the quality of shallow groundwater across much of the site, is influenced by precipitation. However, through my conceptual model, I have shown that water levels in the Alne Formation and boundary ditch also play a crucial role in supporting the high groundwater levels within the peat. If these are not maintained, the peat will drain faster and water levels in the peat will drop and consequently there will be an impact upon the SSSI. As a result, in my opinion, the Appellant has not fully assessed how development may alter the water supply mechanisms that support the bog.

Consideration of the hydrological and hydrogeological impacts on Askham Bog are not well presented in the application. Each document acts as an addendum to the last, with no one document presenting the Appellant's full understanding in a coherent way. This issue has not been resolved through the additional hydrogeology documents supplied by the Appellant for the appeal, which have a number of technical issues as detailed in my full Proof of Evidence. As a result, the assumptions used in the various assessments are not always clear.

Conclusions

The reasons given for refusal of planning permission by York City Council is in part based on their assertion that the development is contrary to Paragraph 175 of the NPPF. This paragraph outlines development proposal requirements with respect to adverse effects on SSSI and the loss or deterioration of irreplaceable habitats such as the lowland fen habitats of the SSSI.

I am of the opinion that the Appellant has failed to identify key potential impact mechanisms associated with the proposed drainage scheme, that could affect the SSSI and the irreplaceable habitats within it. As a result, the Appellant has not been able to develop effective proposals for avoidance, mitigation or compensation of these impacts which is contrary to NPPF Paragraph 175.

Underlying the issues with the proposed scheme (or potential variants) is the difficulty, and potential contradictions, of requiring the Ecological Protection and Enhancement Zone (EPEZ) to store and attenuate water in line with the requirements of the drainage strategy, while replicating or improving upon the water supply mechanisms to the SSSI. Combining the two objectives within the same space will likely lead to compromise in any design achieving both those objectives.

1 Introduction

1.1 My name is Alex Jones and I am a Chartered Geologist specialising in hydrogeology. I have an MSc in Environmental Hydrogeology and a BSc (Hons) in Environmental Science. I am a consultant hydrogeologist by profession, with particular experience in the hydrology and hydrogeology of wetland systems including their conceptualisation and restoration.

1.2 I am currently employed as a Chartered Senior Hydrogeologist at JBA Consulting within the company's Groundwater Team. I have 11 years of continuous professional experience in consultancy within the field of environmental hydrogeology. My specialist fields in relation to this Proof of Evidence are hydrogeology and hydrology.

1.3 Over the course of my career I have advised clients on environmental risk related issues, particularly in relation to assessing the hydrological functioning of wetlands and the evaluation of development impacts for developers, regulators, and other public bodies. I have also designed peatland restoration schemes in England and Scotland. This includes producing the developed design for a Water Level Management Plan to restore the eco-hydrological conditions of the Thorne, Crowle and Goole Moors SSSI, which forms part of a Special Area of Conservation (SAC), National Nature Reserve (NNR) and Special Protection Area (SPA), the largest extent of lowland raised mire in England at approximately 1,918 hectares. I have also worked on many other smaller peatland and wetland sites.

1.4 The following is a summary of some of the hydrogeological investigations of peatland and wetland work which I have undertaken while at JBA across the UK and Ireland:

- **2011-Present - Bolton Fell Moss Hydrological Monitoring Programme (Natural England)** - Design, maintenance and analysis of a long-term water level monitoring array to capture the hydrological and hydrogeological response of an extensive lowland raised mire to restoration.
- **2017-Present Tufa Springs Impact Assessment Review (Dún Laoghaire Rathdown County Council)** Review of planning applications on behalf of the local planning authority for a mixed used development in the catchment of an Annex 1 Tufa spring habitat. This included reviewing planning documents, independent hydrogeological conceptualisation, developing conditions and site meetings with the developer.
- **2017-Present Wombwell Wetland Development (Garganey Trust and Environment Agency)** - Management of the creation of two wetlands near Barnsley providing extended wet woodland, reedbed and wet grassland habitat.
- **2018 - Choulton Moss Expert Witness (Newcastle-under-Lyme Borough Council)** - Acting as an expert witness and producing a Proof of Evidence for Newcastle-under-Lyme Council for a planning inquiry relating to the proposed development of a housing estate adjacent to a lowland raised mire.
- **2017-2018 - Wyre Upland Natural Flood Management Scoping Study (Environment Agency)** Designing and analysing a series of hydrological surveys of the upland catchment of the River Wyre in the Forest of Bowland to identify Natural Flood Management and habitat improvement opportunities over a large study area.
- **2009-2017 - Thorne Moors SSSI SAC SPA RAMSAR WLMP – Investigation and Implementation -** Eco-hydrological assessments to support the design and implementation of an extensive water level management plan on England’s largest lowland raised mire over a 5

year period to restore the site to favourable or unfavourable recovering status. This plan includes extensive peat plugging, contour bunding, weir systems and scrub clearance.

- **2015 Quarry Extension Wetland Impact Assessment (unnamed private client)** Project management and impact assessment based on the development of a detailed hydrogeological conceptual model of the potential interactions between a quarry extension and designated wetland in the surrounding area. The project included the design and implementation of a site investigation and liaison with the wider design team, and the county ecologist.
- **2013-2014 Blackfirs & Cranberry SSSI Conceptualisation and Restoration Plan – Staffordshire Wildlife Trust** Blackfirs and Cranberry Bog is a wet woodland and schwingmoor wetland complex which has been subject to drainage, forestry and nutrient enrichment. The project aimed to monitor water level conditions and review previous studies to produce a conceptual model of the site and a restoration plan for the Wildlife Trust and the Nature Improvement Area team.
- **2011-14 Rusland Valley Mosses Restoration and Hydrological Monitoring Rusland Valley Mosses SSSI, South Cumbria (Natural England)** is a lowland raised bog system which has been subjected to extensive peat cutting, drainage and scrub encroachment. This was a multiple stage project, consisting of an initial restoration plan, followed by the design and installation of an extensive surface and groundwater monitoring array which aims to help validate an initial restoration plan assessment, completed in 2011, followed by a modified restoration plan taking into account the finding of the monitoring and the results of stakeholder engagement.
- **2009-13 Tarn Moss Eco-hydrological Study and Restoration Scheme – National Trust** A multi-phase project with and initial eco-hydrological conceptualisation of 4 mires followed by the design of a restoration. A scheme involving small contour bunding, peat plugs and plastic sheet pile dams was recommended to tackle a range of issues including cuts areas, grips and gullies. A further phase assessed engineering management options for a large peat cliff.

1.5 I have delivered presentations organised by Natural England, the British Hydrological Society and the Geological Society of London on several projects listed above.

2 Scope and Purpose

2.1 JBA Consulting (JBA) was appointed by Yorkshire Wildlife Trust (YWT) in January 2019 to review the Planning Application ref 18/02687/FULM resulting in the production of a report with formed part of YWT evidence base for the planning application. In July 2019, the Council refused permission for application identifying a number of reasons for refusal. On 23rd September 2019, I was instructed by YWT to prepare a Proof of Evidence on their behalf in relation to hydrological and hydrogeological impacts of the proposal on Askham Bog SSSI. The focus of this Proof of Evidence is on the following reason for refusal:

> *The proposed drainage scheme and Environmental Protection and Enhancement Zone associated with the residential development are considered to have an adverse impact on Askham Bog Site of Special Scientific Interest as a result of changes likely to occur to the hydrological/ hydro-geological interaction between the development site and the Bog. The proposals are considered contrary to paragraph 175 of the National Planning Policy Framework and policies DP2 Sustainable Development, DP3 Sustainable Communities, GI2 Biodiversity and access to nature and GI3 Green Infrastructure Network of the emerging Local Plan*

2.2 I have visited Askham Bog and viewed the proposed site from the boundary, but did not enter, in February 2019 and the information, drawings, documents and plans that I have relied on in preparation of my evidence includes:

- GVA How Planning (October 2018) Environmental Statement - Land at Moor Lane York focusing upon the following:
  - Chapter 12: Hydrology, Groundwater and Surface Water Quality and associated appendices (ESD 013);
  - Environmental Statement Addendum - Appendix 3: WWT Consulting (June 2019), Review of Consultee Responses; and,
  - Environmental Statement Addendum - Appendix 4: Peter Bretts Associates (19th June 2019), Technical Note - Water Balance Calculations for Development Site.
- WWT (2013), Investigating the hydrological relationship between the Moor Lane site and Askham Bog SSSI (CD039).
- Ove Arup & Partners Ltd (March 2003) Yorkshire Wildlife Trust - Askham Bog Restoration Project - Technical Report (CD037).

2.3 I have also considered responses obtained from various consultees obtained during the planning consultation period including those of Natural England and the City of York Council.

2.4 Guidance that I have considered when preparing this Proof of Evidence includes the following:

- Wheeler, B.D., Shaw, S., & Tanner, K. 2009 A wetland framework for impact assessment at statutory sites in England and Wales Integrated Catchment Science Programme Science Report (CD067).
- Natural England (2011), A review of techniques for monitoring the success of peatland restoration NECR086 (Appendix E).
- Lindsay R., Birnie R., and Clough J. (2014), Programme Briefing Note No3, Impacts of Artificial Drainage on Peatlands, IUCN UK Committee Peatland (Appendix F).

2.5 I declare that the evidence which I have prepared and provided for this appeal is true. It has been prepared and is given in accordance with relevant guidance and I confirm that the opinions expressed are my true and professional opinions.

3 Methodology

3.1 The approach that I have taken in this document is to identify through the development of a hydrogeological conceptual model, the likely water supply mechanisms that Askham Bog SSSI and the wider peat body depend upon and then identify how these might be affected by the proposed development. A conceptual model is defined as "a synthesis of the current understanding of how the real system behaves, based on both qualitative and quantitative analysis of the field data"[1](Appendix B).

3.2 Development of a conceptual model as the basis of an impact assessment is a standard and well-recognised approach in the UK to assess impacts to groundwater and sensitive receptors which may be dependent upon groundwater to support their functioning and existence. Current Environment Agency guidance (Appendix C) with regard to groundwater risk assessment[2] states: ' You need to develop a conceptual model. This will form the basis for your risk assessments and will help you successfully evaluate environmental risks.' The guidance goes on to state that a Hydrogeological Impact Assessment (HIA)"*must:*

- *be risk-based; that is, the effort and resources used to assess the impacts should be matched to the level of risk of environmental damage.*
- *emphasise the importance of developing a robust conceptual model of the site that is continually reviewed and updated as new information is collected.*
- *be able to distinguish between impacts caused by changes in flow, and those caused by changes in water level, and deal with them appropriately.*
- *result in an appropriate level of on-going monitoring, targeted at the issues of real concern.*
- *if relevant, take into account the mitigation of impacts by the return of water to the groundwater or surface water system.*
- *be able to cope with a variety of spatial scales (regional and local, for example)."*

3.3 This guidance was the basis of the structure of my Proof of Evidence. The baseline used to inform the conceptualisation is presented in Section 4, with the conceptualisation itself presented at the end of that section. This is supported by a series of maps and figures appended to this document. Section 5 presents how I have used the conceptual model of the SSSI to identify three main potential impact mechanisms from the proposed development. Section 6 presents the following: 1) a summary of how the Appellant's understanding of how Askham Bog is supported from a hydrological and hydrogeological perspective differs from my own, 2) implications of this in terms of the impact assessments which have been presented by the Appellant, and 3) specific critiques of assessments provided by the Appellant.

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1 Environment Agency (2007) Hydrogeological impact appraisal for dewatering abstractions.

2 Environment Agency, Groundwater Risk Assessment for your Environmental Permit (accessed on 02/10/19) (https://www.gov.uk/guidance/groundwater-risk-assessment-for-your-environmental-permit).

4 Baseline Conditions and Water Supply Mechanisms to the Bog

4.1 This section provides a baseline description of the proposal site and Askham Bog SSSI to assist in my analysis of the impacts of the scheme upon the hydrogeology of the wetland. The comprehensive nature of the baseline section reflects limitations of baseline information provided by the Appellant and how that information is structured across a number of supporting documents. A summary of my understanding is provided in the conceptualisation in Paragraph 4.28.

4.2 The section is supported by a series of maps and figures (including diagrams, borehole logs and hydrographs presented in Appendix A.

Askham Bog Citation

4.3 Askham Bog SSSI was first notified in 1961. The site citation (Appendix D) states the following:

> *Askham Bog is the remnant of a valley-mire which formed between two ridges of glacial moraine in the Vale of York just southwest of the City. Base-rich ground-water draining the moraines has led to the development of a rich-fen community which demonstrates stages in seral succession to fen woodland. In the central areas there is a poor-fen community, thought to represent incipient raised-bog, where vegetation has grown above the influence of the ground-water and conditions have become acidic through the leaching action of rain-water and the growth of bog mosses Sphagnum spp.*
>
> *The present habitats are considered to be secondary, raised-bog having largely replaced the original fen before peat-cutting in the Middle Ages brought the vegetation back within the influence of base-rich ground-water with the consequent reversion to fen conditions.*

Hydrology and Topography

4.4 Map 1 shows the current topography of Askham Bog and the proposed development site. Fig 1 presents a figure from the Flood Risk Assessment (FRA) (Appendix 13 of the Environmental Statement (ES) (ESD 013) which accompanied the planning application) detailing the names of the main surface watercourses.

Askham Bog SSSI lies in a topographic hollow as can be seen on

4.5 Map 1. The northern edge of the SSSI is bounded by Askham Bog Drain, and forming the southern boundary is Pike Hill Drain. These join at the eastern edge of the bog and discharge to Holgate Beck. At the north-west corner of the development site, Holgate Beck discharges to an Internal Drainage Board pumping station (Note: In this Proof, I refer to the Askham Bog Drain as 'the boundary drain' as it forms the boundary between the SSSI and the proposed development.).

4.6 The development site lies on rising ground to the north-east of the SSSI. Between the railway line and Holgate Beck is an area of raised ground formed by a historic landfill (see artificial ground in Map 2)). Two shallow mounds (up to 0.5m higher than the surrounding land) occur on Askham Bog. These are surrounded by lower lying areas on the boundary.

Geological Conditions at Askham Bog

4.7 Geological conditions at Askham Bog and the development site are relatively complex. The table below summarises the geological units that are mapped by the British Geological Survey as being present. The distribution of the superficial units (i.e. those geological formations excluding bedrock) across the area is shown in Map 2.

Table 4-1: Geological Unit Summary

Age	Formation / Member /Group	Description	Thickness	Location
Quaternary	Peat	Varied due to complex history of the site. Some areas thin and oxidised, other areas deep and amorphous	0-2m+	Thin peat around the edge of Askham bog Thickens towards centre and west of the bog
	Lacustrine /Fen Deposits	Deposits laid down as lake transitioned to fen. Deepest deposits are lakebed clays and change into organic rich mud	0-4m	Within the Askham bog basin. Extent in some areas is less than the peat body as the wetland extends beyond the lake area
	Alne Formation	Glaciolacustrine deposits described by the BGS as Clay and Silty. However, in the valley it is dominated by Medium SAND in the borehole logs	0-8m+ Thinner on higher ground and thickest in the valley bottom	Underlies the Askham Bog basin and the majority of the development site
	Till (Vale of York Formation)	Site investigations show it to comprise in the main gravelly CLAY with sand layers	10+	On high ground of the site and under the Alne Formation
	York Moraine	Gravelly, Sands and clays with boulders	10+	Forms the ridge that lies to the south and west of Askham Bog
Triassic	Sherwood Sandstone Group	Sandstone		Circa 20m+ below ground surface
Sources; BGS Mapping, Appellant's Site Investigation (CD041), Ove Arup (2003) (CD037), BGS (2003) (CD038).				

4.8 The complex geology results from a pattern of retreating and advancing glaciers in the last ice age[3]. Askham Bog itself formed in a hollow following the retreat of the last glacier. This retreating glacier left a deposit known as the York Moraine, which forms the ridge to the south and west of the site. Behind the York Moraine, a glacial lake formed and the material deposited in that lake is known as the Alne Formation (see Fig 2). Deposits of Vale of York Formation (till) forms the higher ground to the west of the site.

4.9 Askham Bog formed from the infilling of a late-glacial lake, which involved deposition of sediments which are referred to as the Alne Formation. A succession of habitats occurred within the hollow, leaving behind a complex series of deposits. These are described in the paragraph below and shown in Fig 3 (from Ove Arup 2003 (CD037)):

> *About one-third of the basin has been filled by late-glacial lake clay (layer 2), with an organic band (layer 3) that Fitter and Smith attributed to an interstadial, a relatively brief warmer period. Above the clay there is a thick layer of organic mud consisting of the remains of aquatic plants (layer 4). The open water stage in the*

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3 British Geological Survey (1999). Field Guide to the Glacial Evolution of the Vale of York Internal Report IR/04/106.

site's development was brought to an end by the spread of reedswamp and the build-up of fen peat (layer 5). The growth of the peat above the maximum water level led to acidification, and possibly to a transition to raised mire (see Section 5.4.2). An unknown quantity of raised mire peat (layers 6 and 7) may have been removed for fuel during the 18th and early 19th Centuries, but sampling of the remaining acid peat shows that surrounding woodland was dominated by alder, indicating that the base-rich margins of the site, which could have been much more extensive than at present, may have consisted of fen carr. A return to fen conditions, perhaps as a result of increased flooding after peat-digging ended, has led to an almost complete cover of fen peat (layer 8).

4.10 In summary, the deposits beneath the bog, within the lake area, transition from clays, to organic rich muds to peat as the lake filled in. Along the northern fringe of the site, there are areas where the accumulated peat lies directly on the Alne Formation, where the wetland developed and extended beyond the original lake extent (see DW216 in Fig 4 and Fig 5).

Summary of Bog Formation

4.11 Drawing on existing information, the mechanism of formation of the bog can be summarised as follows (The key deposits and features of the development of the bog are shown in Fig 6):

- Several glaciers passed over the area during the last Ice Age,
- The last formed a deposit known as the York Moraine,
- In the hollow behind the moraine a large lake formed in which sediments were deposited which form the Alne Formation,
- The large lake retreated and within the Alne Formation a smaller lake formed, which became infilled with clays, and organic rich muds,
- As this process continued and the lake filled, fen habitats became established and peat accumulation commenced,
- The peat layer which now forms the SSSI extended beyond the boundary of the old lake directly onto the underlying Alne Formation,
- Peat accumulated such that the ground surface became raised above the surrounding area, reducing surface water flow from the surrounding areas to the centre of the site. This reduced the nutrient input feeding the habitats, leading to change,
- Peat extraction is thought to have occurred up until the 18th Century lowering the ground surface and further changing the habitats,
- A possible combination of the wasting of peat through drainage around the fringes, and/or the accumulation of peat in the centre, has led to centre of the site forming a done shape which can currently be observed.

Groundwater (Hydrogeological) Conditions at Askham Bog

4.12 Geological conditions and the movement of groundwater through various geological strata can exert a strong influence on the functioning of wetland environments such as Askham Bog.

4.13 A hydrogeological unit can be considered as a geological material or layer which by virtue of its hydraulic properties (permeability and porosity) exerts an influence on the flow (movement) and storage of groundwater. The table below presents the key hydrogeological units present on the development site and peat bog.

4.14 Peat forms when plant material does not fully decay in anaerobic conditions, which can develop when the ground is waterlogged. The continued existence of peat depends upon its ability to retain water. Water level monitoring (Ove Arup 2003 (CD037)) suggests that much of the bog is fully saturated in winter, but water levels drop by 0.5-0.75m over the summer (see Fig 8).

Table 4-2: Hydrogeological Units

Formation / Member /Group	Description	Location	Hydrogeological Properties[1]
Peat	Varied due to complex history of the site. Some areas thin and oxidised, other areas deep and amorphous	Thin peat around the edge of Askham bog Thickens towards centre and west of the bog	Relatively Low permeability but high porosity
Lacustrine /Fen Deposits	Deposits laid down as lake transitioned to fen. Deepest deposits are lake bed clays and organic rich mud	Within the Askham bog basin. Lateral extent in some areas less than the peat, as the wetland extends beyond the original lake area	Low permeability
Alne Formation	Glaciolaustrine deposits described by the BGS as "Thinly to thickly laminated SILT and CLAY with common sand beds or laminae (saturated running sand)". Borehole logs show a Medium SAND in part of the site	Underlies the Askham Bog basin and the majority of the development site as shown in borehole logs from previous ground investigations	Variable depending upon composition Moderate permeability in areas where sand dominates
Till (Vale of York Formation)	Site investigations show it to comprise in the main gravelly CLAY with sand layers	On high ground of the site and below the Alne Formation	Variable depending upon composition
York Moraine	Gravelly, Sands and clays with boulders	Forms the ridge that lies to the south and west of Askham Bog	Highly permeable where dominated by sands and gravels
Sherwood Sandstone Group	Sandstone	At depth and not exposed at the ground surface	Highly Permeable
1 - Based on BGS Mapping, Appellant’s Site Investigation (CD040), Ove Arup (2003) (CD037), BGS (2003) (CD038)., and desk-based sources (see Fig 19)			

Hydrogeology of the Alne Formation and interaction with Askham Bog Drain

4.15 This section focuses on the area shown in Map 3 and Map 4, where the valley floor of the site contains thick sand deposits which form part of a geological strata known as the Alne Formation adjacent to the bog.

4.16 The ES chapter (Paragraph 11.50) (ESD013) describes the superficial deposits of the site as follows: "The natural deposits were typically described as sandy slightly gravelly clay with occasional silt, sand and peat layers". This interpretation is based on "previous ground investigation". In Appendix 11 of the ES (ESD013) the following is also added. " In the south-eastern corner of the site, there was between 4m and >7m of sand present, beneath the Made Ground."

4.17 The British Geological Society (BGS) report[4] (CD038) provides the following description of the Alne Formation "Thinly to thickly laminated SILT and CLAY with common sand beds or laminae (saturated "running sand")". The table below provides a review of the sand deposits within what are interpreted to be the Alne Formation in the borehole logs and a number of key locations from other sources used within cross-section presented in Fig 10 and Fig 11. It demonstrates clearly that sand deposits of varying thickness are extensive within the Alne Formation beneath the proposed development site. It also indicates that in the valley bottom the sand deposits are relatively thick (see Map 3 and Map 4 and Fig 7).

Table 4-3: Sand Deposits in the Alne Formation

Name	Thickness	Source
BH14/07	4.2	Wardell Armstrong 2014 - ES Appendix 10.1
BH14/08	7+	Wardell Armstrong 2014 - ES Appendix 10.1
BH14/10	0.5	Wardell Armstrong 2014 - ES Appendix 10.1
TP14/04	0.7+ (two bands)	Wardell Armstrong 2014 - ES Appendix 10.1
TP14/05A	1.5+	Wardell Armstrong 2014 - ES Appendix 10.1
TP14/06a	2.05+	Wardell Armstrong 2014 - ES Appendix 10.1
BH04/06	1	Wardell Armstrong 2014 - ES Appendix 10.1
BAR5	1.3+	WWT 2013
BAR1	1.2	WWT 2013
BAR7	0.7	WWT 2013
BAR2	0.6	WWT 2013
BAR16	0.3	WWT 2013
DW207	1.5	Ove Arup 2003

4.18 Fig 9 is a composite hydrograph based on data presented in Peter Brett Associates (PBA) technical note (29/10/2015) in Appendix 12 of the ES (CD042). It presents a record of groundwater levels at BH14/07 situated between the planned attenuation basin and the boundary drain against the nearest gauge board in Askham Bog Drain (which records corresponding surface water levels) with a significant number of monitoring records. There is a strong correlation between groundwater levels in the Alne Formation and surface water in the drain as they have a very similar pattern of rising and falling behaviour over time. This demonstrates that groundwater in the Alne Formation in the valley floor and surface water within the boundary drain have good hydraulic connectivity, i.e. there is a strong interconnection between groundwater and surface water. This conclusion differs from the PBA technical note (29/10/2015) in Appendix 12 of the ES, which states:

> *When the water level data between adjacent groundwater monitoring boreholes and surface water monitoring locations is compared, the pattern of the data does not indicate that there is direct hydraulic continuity between the surface water and groundwater across the site.*

4.19 In my opinion, this conclusion is not supported by the evidence presented above, which clearly shows direct hydraulic continuity at BH14/07. Nor does it take into account the presence of thick deposits of sand in the base of the valley (which I interpret as representing the Alne Formation) as shown in borehole log records.

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4 BGS (2003), Vale of York 3-D Borehole Interpretation and Cross-sections Study, Lands and Resources, Integrated Geological Surveys South Commercial Report CR/03/251 N available at http://nora.nerc.ac.uk/id/eprint/509481/1/CR03251N.pdf

The Role of the Alne Formation in Supporting Groundwater Levels within Askham Bog

4.20 The detailed geological cross-sections presented in Fig 10 and Fig 11 are based on sources detailed in the table below and the line of the cross-sections are shown in Map 3 and Map 4.

Table 4-4: Sources of Cross Section Information

Source	Location
Wardell Armstrong 2014 - ES Appendix 10.1	BH14/07
	BH14/08
	BH14/10
	TP14/04
	TP14/05A
	TP14/06a
	BH04/06
	BH14/05
Headland Archaeology - ES Appendix 10.1	TR61
WWT 2013	BAR5
	BAR1
	BAR7
	BAR2
	BAR16
Ove Arup 2003	19-50N
	19-100N
	DW217
	DW207

4.21 The cross-sections can be used to illustrate two conditions where the groundwater levels in the Alne Formation and surface water in the boundary ditch (i.e. Askham Bog Drain) (which have been shown to be connected) support groundwater levels in the peat bog, namely:

1 The first cross-section shows that, where the peat body is contained within lake bed deposits, a high groundwater table in the Alne Formation and boundary drain limits the rate of lateral groundwater movement through the lake deposits.

2 The second cross-section shows where peat or thinner peaty soils, lie directly on the Alne Formation. In this situation high groundwater levels in the Alne Formation will limit the vertical loss, or drainage of water from the peat deposits.

4.22 The role of the Alne Formation in supporting water levels in Askham Bog along the shared border with the proposed development is also commented on in Ove Arup (2003) (CD037). Section 14.2 of that report states (note Fig 17 replicates the dipwell water level records at the locations referenced):

> *"Records from dipwells 217 and 220 support the hypothesis that there is groundwater movement towards the Beck in the summer, but that the combination of reduced evaporation and flooding from the Beck sets up a horizontal water level in winter. In the dry winter of 2001/2002 Beck water levels did not rise high enough for overbank flow, and water levels in the logged dipwell were significantly lower than those in the other dipwells. This shows that outside the transpiration season the logged dipwell is influenced by Beck water levels,* ***and that the zone of***

significant lateral groundwater movement to and from the Beck is at least 20m wide in this part of the site."

4.23 Fig 17 also presents the borehole logs from Ove Arup (2003). No borehole log was available for the "logged dipwell", however the log for DW216 is presented 30m to the east. DW216 shows that the deposits at this location consist of peat lying directly on sand, whereas DW217 and DW220 are underlain by silt clay. The likely reason that the "*water levels in the logged dipwell were significantly lower than those in the other dipwells*" is that the peat here lies directly on the Alne Formation, whereas the others are underlain by lower permeability lake deposits. Together this dataset supports the two conditions identified above where the Alne Formation supports the water levels in the peat.

Eco-hydrological Conditions

4.24 Ecohydrology is concerned with the effects of hydrological processes on the distribution, structure, and function of ecosystems. Specific hydrogeological and landscape contexts of different wetland result in "some habitats and vegetation types are intrinsically rare and confined to specific locations[5]" (CD067).

4.25 Through my review, I have identified four main eco-hydrological conditions that occur on-site:

1. Rainfall fed areas of higher ground above flood levels where nutrient levels are generally lower and where acidic habitats are present.
2. Habitat affected by flooding and surface water inputs from the catchment where the quality of flood waters influences the habitat.
3. Habitat affected by flooding where the peat is thin and lies directly on the Alne Formation and where water quality is influenced by groundwater from this Formation.
4. Groundwater seepage from the glacial deposits along the southern boundary of the site away from the proposed development footprint.

4.26 The boundary between the first two areas is illustrated in Fig 13, which shows flood extents and soil pH as an indicator of a changing environment. These are also reflected in the National Vegetation Community mapping shown in Fig 12 which shows habitats such as *W4a Betula pubescens-Molinia caerulea* woodland and *M25 Molinia caerulea-Potentilla erecta* mire are limited to areas which do not regularly flood.

4.27 "Rainfall fed" or "Habitat affected by flooding" are descriptions related to the controls on the water quality in the upper soil layers that control which type of habitat is present. It does not consider that the high position of the water table is dependent on the support of the water table in the surrounding Alne Formation and boundary drains.

Ecohydrological Conceptual Model of Askham Bog

4.28 Based on the baseline description developed above, an ecohydrological conceptual model of Askham Bog is shown in Fig 14 and has the following features:

- The bog lies in a depression surrounded by boundary drains and is underlain by strata including clays, muds, and peat.
- These deposits upon which the wetland has formed are surrounded by a geological formation known as the Alne Formation. In the base of the valley this formation comprises of a relatively thick layer of sand deposits as evidenced by borehole logs.

[5] Environment Agency (2009), A wetland framework for impact assessment at statutory sites in England and Wales (Science Report: SC030232/SR1)

- In the valley bottom and along the SSSI boundary with the proposed development, water level monitoring clearly demonstrates that the Alne Formation and boundary drain are hydraulically connected.
- Water levels in the peat body are supported by water levels in the boundary drains and Alne Formation by two mechanisms; (1) Where the peat body is contained within lake bed deposits, a high groundwater table in the Alne Formation limits the rate of lateral groundwater movement (or leakage) through the lake deposits; and, (2) Where peat or peaty deposits (and especially thin deposits) lie directly on the Alne Formation, high groundwater levels in the Alne Formation prevent the vertical loss of water out of the peat deposits.
- On higher areas, the bog is also supported by direct precipitation inputs. This results in lower nutrient conditions.
- On the lower-lying areas of the bog, water derived from the boundary drains and/or groundwater inputs from the Alne Formation bring nutrients and minerals into the area, which support the habitat types present in there.

5 Assessment of Effects with Respect to Reasons for Refusal

5.1 I will now consider the effects on Askham Bog SSSI with specific reference to the reason outlined in the refusal. The particular reason for refusal given in Section 2.

Fig 15 presents my conceptual model of the SSSI showing potential development related impact mechanisms on Askham Bog. Each show how the attenuation basin which is currently proposed (see

5.2 Map 1 for the footprint) as part of the surface water management system in the full planning application may affect the water supply mechanisms that support the bog. These are discussed in more detail below.

Identifying the sensitivity to change

5.3 Key to understanding the severity of potential impacts that the development may have on the SSSI is to understand the water level conditions that the habitats rely upon. The following passage is from Natural England (2011), A review of techniques for monitoring the success of peatland restoration[6](Appendix E):

> *A properly planned restoration project attempts to fulfil clearly stated goals that reflect important attributes of the reference ecosystem (SER, 2004). Goals are attained by pursuing specific objectives. The goals are ideals and the objectives are the desired results of actions taken to attain those goals. In the case of peatlands, Quinty & Rochefort (2003) state that the goal of current restoration is often to re-establish self-regulatory mechanisms that will lead back to functional peat accumulating ecosystems. Peat will not accumulate during the short-term period of restoration. However, the objective in the short-term is to establish plant communities which will eventually in the long-term (10-100 years) produce debris that will accumulate and become peat. Dead plant parts will accumulate only if the water table is high enough throughout the year to impede decomposition, and a restoration target identified some years ago for important peatland sites was to retain rainwater within 10 cm of the peat surface for ombrotrophic peatlands, and reduce seasonal fluctuations (Johnson, 1997).*

5.4 This passage indicates that the main aim of managing and restoring rainfall fed or "ombrotrophic" areas within the bog is to produce conditions for peat to form. To do so requires that the water levels are maintained to within 10 centimetres of the surface, with limited seasonal fluctuations. Paragraph 4.14 provides site-specific details showing that much of the bog is fully saturated in winter, but water levels drop by 0.5-0.75m over the summer.

5.5 The requirement to maintain a state of near saturation so close to surface means that slight changes (i.e. reductions) in water table levels can have an adverse effect on the habitats present on the site.

5.6 Morgan et al (2003)(CD068)[7] states There is a specific relationship between the level of water around a bog and that at it's centre. Take away the water from around its edge, and the centre suffers." The International Union for Conservation of Nature (IUCN), Briefing Note No 3 – Impacts on Artificial Drainage on Peatlands[8](Appendix F), provides reasons why this is the case. It states that the main damage that results from drains on peatland is not the immediate drawdown of the water table but surface subsidence. A high proportion of peat is formed from water. So as the water is drawn out of it by a structure such as a drain, the peat shrinks and collapses (this is termed primary consolidation). The shrunken and collapsed peat, which previously was relatively buoyant,

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6 Natural England (2011), A review of techniques for monitoring the success of peatland restoration NECR086

7 Morgan-Jones, W., Poole, J. S. and Goodall, R. (2005), Characterisation of Hydrological Protection Zones at the Margins of Designated Lowland Raised Peat Bog Sites, JNCC Report No.365

8 Lindsay R., Birnie R., and Clough J. (2014), Programme Briefing Note No3, Impacts of Artificial Drainage on Peatlands, IUCN UK Committee Peatland

now presses down on the deeper saturated peat, squeezing water out, leading to secondary consolidation. The last process is peat oxidation. The dried shrunken, collapsed peat, is now more prone to oxidation and therefore wastes away. Together these three processes can proliferate away from the drain edge, and the impact can be measured over several hundred metres.

5.7 The Proof of Evidence to this inquiry by Professor Fitter provides more detail on the requirements for future restoration, and control of boundary drains, to raise the current status of the SSSI from unfavourable recovering

5.8 Overall, the designated habitats of the SSSI could be affected by relatively small changes in the hydrological and hydrogeological conditions that support them. The following section highlights how the current development proposals may affect water supply mechanisms to the SSSI, specifically in relation to the proposed use of an attenuation basin situated to the north-east of the SSSI.

Flooding of the Bog

5.9 Periodic flooding is critical to maintaining the low-lying habitats of the bog (see Paragraph 4.25) and therefore a reduction in the rates of run-off from the development site could lead to an adverse impact. A 3.1 l/s/ha QBAR greenfield run-off rate (the run-off rate that has been calculated to be equalled or exceeded each year) from the site is presented in the FRA (Appendix 13.1 of the ES) (ESD013). The peak run-off rate from the attenuation basin is however "limited to 1.4l/s/ha". This is described as having the following impact in the FRA:

> "Proposed surface water management strategy represents betterment through reducing the peak discharge rates into the receiving system"

5.10 The SSSI is dependent on maintaining, regular flooding of some habitats. Reducing the rate of run-off from the site will reduce flooding to the bog, especially affecting lower magnitude events. For those habitats, reducing flood frequency will not be a "betterment", and in fact would be a negative impact.

Surface Water Supply to the Boundary Drain

5.11 When water levels drop below the "normal level" in the attenuation basin, run-off from the development site to the boundary drain will cease as water would drop below the outfall. This may have significant impact on the quality and pattern of run-off entering the Askham Bog Drain which I have demonstrated earlier is important in supporting water levels on the Bog through the Alne Formation. For example, if the attenuation basin dries out in a dry period, no run-off from the site will enter Askham Bog Drain, until the "normal level" is reached and water can flow into the drain. This would exacerbate the effect of periods of low rainfall on the bog by reducing levels in Askham Bog Drain.

5.12 An attenuation basin will prevent run-off entering Askham Bog Drain when water levels in the basin are low. Paragraphs 6.17 to 6.22 below provides an assessment of the water budget that has been presented by the Appellant, and demonstrates that it does not provide evidence as to how often the attenuation basin would dry out. This means that there is significant uncertainty in the understanding of how water supplied to the boundary drain will be affected during drier periods.

Induced changes in Groundwater Levels

5.13 Site investigation data indicates that the eastern part of the attenuation basin system will cut through the thick sand deposits of the Alne Formation. The base of the attenuation basin is currently designed to lie at an elevation of 10.92mAOD. The cross-section in Fig 16 shows the relative level of groundwater at BH14/07 near to the attenuation basin. Groundwater level records for BH14/07 (see Fig 9) show a minimum groundwater level of circa 10.9mAOD. Met office anomaly data indicates that the summers of 2014 and 2015 were relatively dry[9], however, there is no reason to assume this minimum level would not be frequently reached in the future.

5.14 If the attenuation basin was not lined, then it is likely that it would reflect the groundwater levels in the area. This means the attenuation basin would be prone to drying out, as the minimum recorded groundwater levels are at the base of the attenuation basin. Also, if the basins are not lined, they will be directly connected to the water table. The increase in evaporation across the footprint of the basin may generally lower the water table in the area, and water levels in the boundary drain.

5.15 Conversely, if the basin is lined, the groundwater storage capacity of the Alne Formation will be reduced leading to reduced baseflow inputs into the drain.

Marrying the Requirements of a SUDs Scheme with Replicating the Water Supply to the SSSI

5.16 The attenuation basin is integral to the SUDs design and the proposed functioning of the Ecological Protection and Enhancement Zone (EPEZ) and therefore it has two main objectives, which in my opinion are not mutually compatible. It is designed to; temporarily store and attenuate surface water flows so that there is a reduction in run-off rates below the current situation, and; replicate or improve the water supply mechanisms to the SSSI. If the SUDs function was excluded the design of the EPEZ could focus on replicating or improving the water supply to the bog, and potentially create some of the function of the lagg area highlighted in Proffesor Fitter's Proof of Evidence. However, the SUDs requirements for reduction in flows do not align with improvement to, or mimicry of, the current supplies of water to the bog.

Conclusions

5.17 Within the conceptual model of water supply to Askham Bog which is based upon relevant background information and data which has been collected at the site, I have identified the key water supply mechanisms which maintain water levels on the SSSI and also highlighted the impact of changing water levels. I am of the opinion that the Appellant has not considered these issues in sufficient detail within their proposed strategy for management of surface water run-off from the development site. Therefore, there is significant uncertainty that the development will not result in adverse impacts to the SSSI.

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9 https://www.metoffice.gov.uk/climate/uk/summaries/anomacts

6 Review of Appellant's Assessment of Effects

Review of Appellant's Interpretation of the Hydrological Interaction Between the Proposed Development and Askham Bog

6.1 The ecohydrological conceptual model developed in this Proof of Evidence shows how Askham Bog is supported and highlights the role of the Alne Formation and the boundary drain in supporting those conditions. The Appellant's assessment presents a different understanding.

6.2 Paragraph 12.30 of the ES (ESD013) states the following:

> *Previous studies include the 'Eco-hydrological Assessment of the Moor Lane Site on the Adjacent SSSI', WWT Consulting (2013 and the 'Yorkshire Wildlife Trust Askham Bog Restoration Project Technical Report' (Ove Arup, 2003). Both make the conclusion that Askham Bogs is critically dependent on precipitation for water supply rather than surface water runoff or groundwater inputs.*

6.3 The last statement "Askham Bog is critically dependent on precipitation for water supply rather than surface water runoff or groundwater inputs" is overly simplistic in my opinion. It is conceded that the quality of shallow groundwater across much of the site, is influenced by precipitation as on higher parts of the site it is low in nutrients, as it is derived from direct precipitation. However, water levels in the Alne Formation and boundary ditch also play a crucial role in supporting the high groundwater levels within the peat. If these are not maintained, the peat will drain faster and water levels in the peat will drop and consequently there will be an impact upon the SSSI.

Askham Bog and the Alne Formation

6.4 The ES chapter summarises the conclusion of the Ove Arup (2003) (CD037) and WWT Consulting (2013) (CD039) reports, and states that "***Both make the conclusion that Askham Bogs is critically dependent on precipitation for water supply rather than surface water runoff or groundwater inputs***." This is used within the assessment to rule out impact mechanisms affecting the bog (see Paragraph 6.15). This summary is, however, an oversimplification of the conclusions of the report. For example, the conclusion of WWT (2013)[10] also notes:

> *"Although surface and sub-surface hydrological inputs from the land to the north of Askham Bog are not the primary hydrological input to the Bog they do play a role in maintaining water levels within the Beck. Any development on the land to the north of Askham Bog should ensure drainage designs do not have any detrimental impacts on the Holgate Beck and therefore Askham Bog.* ***To avoid this, water levels in the Holgate Beck and surrounding ditches should be maintained at their current levels by designing sustainable drainage features that mimic the current drainage network and current infiltration processes occurring across the site.****"*

6.5 Ove Arup (2003) provides further information on the role of Askham Bog Drain. In section 14.2 of that report, the following is stated (note this is the same quote as in paragraph 4.22 and repeated here for ease):

> *"Records from dipwells 217 and 220 support the hypothesis that there is groundwater movement towards the Beck in the summer, but that the combination of reduced evaporation and flooding from the Beck sets up a horizontal water level in winter. In the dry winter of 2001/2002 Beck water levels did not rise high enough for overbank flow, and water levels in the logged dipwell were significantly lower than those in the other dipwells. This shows that outside the transpiration season the logged dipwell is influenced by Beck water levels,* ***and that the zone of significant lateral groundwater movement to and from the Beck is at least 20m wide in this part of the site****."*

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10 The WWT 2013 report was provided to the Yorkshire Wildlife Trust during an earlier round of consultation

Fig 17 replicates the records from the dipwells and their location) and Section 15.2 states:

> *"The Holgate Beck also seems to be a relatively unimportant source of water to the mire, as at current levels it functions mainly as a potential drain rather than as a source of supply. It does sometimes supply the site in periods of flood (generally in winter), but this appears to be more of nuisance value (by maintaining excessively wet conditions and helping to enrich the mire with nutrients) than a useful mechanism for augmenting the summer water table of the mire. Thus, whilst* ***the invert level of the Beck (itself maintained by a pumping station downstream) may possibly help to regulate the mire water table****, it is not an important water source."*

6.6 In these sections, the role of the boundary drain in maintaining conditions on the bog is stressed. Although it does not identify the conditions where the peat lies directly on the Alne Formation and supplies the SSSI, it does identify that it supports groundwater levels in the bog. This understanding is lost through the assessments of the Appellant. The conclusions of the PBA Technical Note 29th October 2015 (CD042) identified a connection in some conditions:

> *"The baseline groundwater and surface water monitoring data collected between July 2014 and September 2015 supports the conclusion of the Hydrogeological Review that the wetland system in the Askham Bog is fed, supported and maintained predominantly by direct precipitation, and not from the groundwater and surface waters across the wider Moor Lane site. The data suggests that the degree of hydraulic continuity between groundwater and the surface water features is low or very low, and also that there is* ***normally limited hydraulic continuity*** *between the Holgate Beck and the Askham Beck (unless active water level management takes place via the sluices present). It is recommended that this data and these conclusions be used to define the drainage strategy such that the proposed development does not have any adverse impact on the Askham Bog."*

However, the PBA Technical Note 19th June 2019 which presents a Water budget states:

> *"there is no groundwater connectivity from the site to the SSSI, any change in groundwater due to development of the site will not affect the SSSI"*

And Paragraph 12.87 of the ES states:

> *"Monitoring work has proven that there is no groundwater connectivity between the Site and the SSSI"*

6.7 These conclusions are not supported by the conceptual model I have presented in this Proof of Evidence. In paragraph 4.18 and Fig 9, I outline the basis of my rationale for demonstrating that groundwater has an important role in maintaining water levels in the Bog.

Implications of Not Understanding the Role of the Boundary Drain and Alne Formation

6.8 Without a conceptual model that accounts for the role of the Alne Formation and the boundary drains (e.g. Askham Bog Drain) in maintaining water levels, in my opinion, the Appellant has not fully assessed how development may alter the water supply mechanisms that support the bog.

6.9 In my opinion, a robust assessment should have addressed the following aspects:

- How will the development affect groundwater levels in the sands of the Alne Formation in the valley bottom?
- Will the development affect water levels in the boundary drain (either through changes in run-off, or by lowering of groundwater levels in the Alne Formation)?
- Will the development change the nature and regularity of inputs by flooding onto the bog surface?

As a result, none of these have been answered in the Appellant's assessments.

Appellant's Assessment Methodology

6.10 This section considers how the assessment of hydrological and hydrogeological issues have been presented in the Appellant's application. This critique stands alongside the consideration that the assessments did not correctly identify potential impact mechanisms from the site to the bog. This occurred by not firstly understanding the eco-hydrological conditions supporting the SSSI (see Paragraph 4.28).

Document Structure

6.11 Consideration of the eco-hydrological impacts on Askham Bog are not well presented in the application. Elements of the impact assessment are spread across several documents including:

- Appendix 12.1 of the ES presents a short Hydrogeological Review from 2014 (ESD013).
- Appendix 12.2 of the ES presents a technical note on groundwater and surface water monitoring (CD042).
- The main hydrogeological impact assessment is presented in Chapter 12 of the ES (ESD013).

6.12 Each document acts as an addendum to the last, with no one document presenting the applicant's full understanding in a coherent way. It would have been preferable for the appendices to contain a full hydrogeological risk assessment outlining all the pertinent baseline information and the risk assessment process (see Paragraph 6.13 to 6.14). This could have then been synthesised in the main ES chapter. By presenting information in this way, the assumptions used in the various assessments are not always clear. This issue has not been resolved through the additional hydrogeology documents supplied by the Appellant for the appeal.

Hydrogeological Risk Assessment and Use of a Conceptual Model

6.13 The assessment of impacts within the ES should, in my opinion, have been based upon the use of a single Hydrogeological Risk Assessment (HRA). Hydrogeological risk assessments are based on the development of a detailed conceptual model, which can be defined as "a synthesis of the current understanding of how the real system behaves, based on both qualitative and quantitative analysis of the field data"[11](Appendix B). A limited conceptual model is presented in the hydrogeological review in Appendix 12.1 of the ES, with no conceptual cross-section provided. In Appendix 12.2 the monitoring is used to update the conceptual model, but this is done in a limited way.

6.14 Environment Agency guidance[11] (Appendix B) states that a Hydrogeological Impact Assessment (HIA)"*must:*

- *be risk-based; that is, the effort and resources used to assess the impacts should be matched to the level of risk of environmental damage.*
- *emphasise the importance of developing a robust conceptual model of the site that is continually reviewed and updated as new information is collected.*
- *be able to distinguish between impacts caused by changes in flow, and those caused by changes in water level, and deal with them appropriately.*

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11 Environment Agency (2007) Hydrogeological impact appraisal for dewatering abstractions

- *result in an appropriate level of on-going monitoring, targeted at the issues of real concern.*
- *if relevant, take into account the mitigation of impacts by the return of water to the groundwater or surface water system.*
- *be able to cope with a variety of spatial scales (regional and local, for example)."*

In contrast to the guidance above, the assessments provided by the Appellant are limited in their scope and poorly structured over several documents. By not continually developing the conceptual model within the three main documents presented, the rationale behind the assessments is not formally laid out or validated.

ES Chapter 12 Assessment Methodology

6.15 Chapter 12 of the ES (ESD013) sets out the impact significance criteria. However, it is not shown how sensitivity and magnitude are combined to produce significance of impact. It can only be inferred by the significance criteria examples presented in Table 12.2 of Chapter 12. However, none of the examples relate to ecological features of interest and no criteria for the sensitivity classification are presented in the assessment. The sensitivity of Askham Bog has been ascribed as 'medium' within the "Residual Effects Summary" table (Table 12.3). However, Askham Bog is not identified as a separate receptor. Instead, paragraph 12.22 states that it has been included with a receptor called "Waterbodies and Surface Water (Askham Bogs, Askham Bog Drain, Pike Hill Drain, Marsh Farm Drain and other IDB watercourses within the site". Given that Askham Bog SSSI is a national designation it is not clear why it has only been given a medium sensitivity. Table 2.5 of the ES Approach chapter defines High Sensitivity receptors as "High importance and rarity, national scale, and limited potential for substitution" and Table 9.6 of the Ecology and Nature Conservation chapter identifies the bog as having "National" conservation importance. On this basis a sensitivity of at least "high" would be suitable.

6.16 Overall, in my opinion, there are a number of shortcomings in Chapter 12 of the ES which lead to an incorrect assessment of impact significance for the following reasons:

- A justification for the sensitivity of Askham Bog is not given. In my opinion, it should have been assigned a high sensitivity, in line with the definitions of sensitivity provided in Table 2-5 of the ES;
- Askham Bog is not treated as a separate receptor. In my opinion, it is distinct from other surface water bodies in terms of its functioning and unique characteristics because of its designation; and,
- How sensitivity and magnitude have been combined to produce an assessment of impact significance is not stated.

Appendix 3 of the ES Addendum - Water Budget

6.17 Appendix 3 of the ES Addendum presents a technical note by PBA on a water budget produced. The technical note states that the water budget which is presented shows:

> "Under drought conditions (less than once every 5 years), there is a net loss during June and July, which may reduce the water levels in the ponds. This confirms the statement of the WWT Consulting Report (April 2019) that "only in highly unusual, extreme drought conditions the attenuation basins would dry out".

6.18 Before commenting on the technical aspects of the water budget which has been developed by PBA, less than once every 5 years, is a relatively regular occurrence and not "a highly unusual, extreme drought" as suggested by PBA.

6.19 My main concern with the approach used for the water budget is that it considers overall annual changes in water budget for the site, rather than assessing through the year on a month by month, or seasonal basis the mass balance of the attenuation basin (i.e. how water levels in the attenuation basin will vary between wetter and drier periods). This means that no information is presented on how water levels in the attenuation basin will lie during dry periods.

6.20 Calculations presented by the Appellant indicate that the development will change the water budget in dry years from a deficit to a positive budget, which will provide run off to the attenuation basin. The difference is explained by the change in land use, leading to a reduction in evapotranspiration rates. However, the calculations are based on the main development footprint and not on the whole attenuation basin catchment (see Fig 18 for a comparison of the water budget catchment and the attenuation basin catchment). It is assumed that the underdeveloped part of the catchment would continue to have a water deficit in dry years, and no evidence is provided to show that this deficit would be made up by the additional run-off from the attenuation basin.

6.21 In addition to the above shortcomings, the methodology for the water balance has a series of limitations:

- The wet and dry scenarios use the same averaged evapotranspiration rates from MORECS[12] data from 1981 to 2010 as the mean water budget. In reality, in dry years, evaporation rates from the ponds will be higher than the average. Therefore, the dry year scenario may underestimate levels of evaporation and therefore impacts upon the Bog.
- MORECS data for open water has not been used. Instead, a conversion factor has been used from the grassland figures. No reason is given why MORECS for open water was not used.
- Infiltration to ground is has been discounted as a significant output from in the water budget. It states "In reality, instantaneous rainfall rates will often exceed 3.6 mm/hr and lead to surface water run-off from the catchments, and therefore only a small proportion of event rainfall will infiltrate to groundwater.". This may be true of the main development footprint, but once water is stored in the attenuation basin, which partly cuts into the underlying sand (see Fig 16), losses to ground may be significant.

6.22 Overall, the water budget has a number of technical limitations which means the conclusions are not supported. Even if these technical limitations are solved, the outputs are of limited use as the water budget fails to relate back to the water supply mechanisms that support the bog, for example how will surface water levels in the boundary drain and groundwater in the Alne Formation be affected. As a result, it provides little useful information in assessing the impacts of the development on Askham Bog.

Appendix 3 of the ES Addendum WWT Review

6.23 The names of the authors of WWT review in Appendix 3 of the ES addendum are not given within the document, nor are their technical expertise outlined with respect to hydrology and hydrogeology. The stated aim of the WWT review is:

> *The aim of the review was to critically assess the consultee responses, related to the proposed Moor Lane development, in terms of hydrological aspects, and in particular to assess discussions related to any potential impacts on Askham Bog Site of Special Scientific Interest (SSSI). This was achieved by fulfilling the following objectives:*
>
> *• To review consultee responses and subsequent technical note responses; and*

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12 Meteorological Office Rainfall and Evaporation Calculation System

> • *To produce an independent evaluation of the submitted application and the comments made on the application in respect to potential impacts on Askham Bog SSSI and its hydrology.*

6.24 The document draws up a list of documents reviewed but does not replicate them within the appendices, nor are a number of them reproduced elsewhere in the planning documents nor within the core documents; notable EDP Technical Note 'edp2165_r032(B)' (April 2019). According to WWT, these technical notes "provide clarification" on concerns raised by JBA Consulting, Natural England, Mott MacDonald and the CYC Flood Risk Manager. Without supplying all these documents for review, the many conclusions of WWT cannot be verified.

6.25 In the evaluation section the following passage is of note:

> *"PBA clearly demonstrate that surface water, under non-flood conditions, and shallow, sub-surface groundwater do not directly flow into Askham Bog SSSI as these inputs from the proposed development site are below the hydraulic levels of Askham Bog SSSI. However, JBA Consulting and Mott MacDonald argue that inputs into the surface water drainage network and groundwater from the site maintain the groundwater aquifer under Askham Bog SSSI which in turn maintains water levels within the SSSI primarily fed by precipitation. In the opinion of the authors, as discussed above, if this mechanism does exist then the input from the proposed development site is likely to be minimal in comparison to regional groundwater but* ***it is impossible to assess the full significance on the ecology of the SSSI without further study.*** *However, in the opinion of the authors this argument is a distraction and missing the point.* ***If the drainage strategy design for the proposed development site mimics existing infiltration volumes to ground and existing surface runoff volumes then the mechanisms supporting Askham Bog SSSI would not be altered.*** *The authors feel that there is no reason why this cannot be achieved within the detailed design of the SuDS features and that modelling of volumes, following design, would be able to demonstrate this. The authors also support the argument that suitably designed SuDS features could reduce the nutrient pollution loads currently entering the Askham Bog Drain from agricultural fields and certainly adequately treat the runoff from the proposed development. "*

6.26 It concludes that the role of groundwater in supporting the SSSI would require further study to understand the relationship between the two. It also concludes that "If the drainage strategy design for the proposed development site mimics existing infiltration volumes to ground and existing surface runoff volumes then the mechanisms supporting Askham Bog SSSI would not be altered". I am in agreement with this conclusion. However, in my opinion for the reasons presented above, I am concerned that the drainage strategy does not fully assess the impact of the development proposals. In particular there is insufficient information presented to demonstrate with confidence that the water supply mechanisms to the Bog which are presented in Section 4 of my Proof of Evidence, have been fully considered within the assessments. For this reason, I am of the opinion that there are a number of ways in which the drainage strategy as currently presented will not mimic the existing situation and that this will lead to adverse impacts upon the SSSI.

Review of PBA Technical Note (29.03.19)

6.27 PBA Technical Note (29.03.19) provides a response to CYC, Natural England, YWT and JBA Consulting comments submitted with the original application and forms one of the documents reviewed by WWT (2019) (CD039). This section focuses just on the responses to JBA's original review of the application, which is similar in many regards to my Proof of Evidence.

6.28 The Note states:

> *"There is no evidence that this pocket of sand is continuous and in any case the location is down hydraulic gradient of the Proposed Development and the Bog. In*

another borehole (BH14/07) also at the eastern end of the Bog, a thickness of 0.9m of silty sand was encountered overlying 3.3m of fine to medium sand, overlying slightly sandy slightly gravelly Clay to 8.5m depth. There is no evidence that the lense/pocket of sand encountered at this location is laterally extensive, although it may be connected to the sand in BH14/08, however these are both down hydraulic gradient of almost the entire Bog."

As evidence that the sand between BH14/07 and BH14/08 may be connected is provided in a cross-section (reproduced in Fig 20).

Cross sections based on the GI undertaken in 2014 are provided in Appendix 2 and indicate the actual material encountered in the exploratory holes"

The section states "these are both down hydraulic gradient of almost the entire bog", which therefore means it is up-gradient of some of the bog, and therefore groundwater from this sand area will flow towards the bog. This is because both of these boreholes lie in the hollow containing Askham Bog, and the ground slopes towards it.

6.29 On groundwater levels the note states:

"The 'Eco-hydrological conceptual model of Askham Bog' provided in the JBA report, clearly indicates that in both summer and winter, there is a groundwater mound in the bog, and then lower groundwater tables in the surrounding deposits (Alne) with even lower levels in the Askham Bog Drain/Holdgate Beck. Assuming the permeability and connectivity that YWT and JBA are purporting, and assuming the widely accepted principle of groundwater flow – if their own model was correct, groundwater would always be coming out of the Bog, draining it. Water does not flow up the hydraulic gradient – by their own model, they are indicating that there is no significant influence on the Bog by groundwater levels in the surrounding deposits, and surface water levels in the adjacent drain. Very simply, the fact the Bog hasn't drained into the Askham Bog Drain/Holdgate Beck indicates the low hydraulic continuity between the two."

6.30 This section does not recognise how JBA in their report, and repeated in this Proof of Evidence, have shown specific mechanisms where water levels on Askham bog are supported by levels in the Alne Formation, limiting the rate of drainage, and how groundwater is directly supplied where the peat lies directly on it. The last sentence, which states "*Very simply, the fact the Bog hasn't drained into the Askham Bog Drain/Holdgate Beck indicates the low hydraulic continuity between the two.*", indicates a lack of appreciation of the ecohydrological conditions that Askham Bog is dependent upon and the effect of the boundary drains in lowering water levels on a seasonal timescale which I have detailed in my Proof of Evidence.

6.31 Overall, the note is a reiteration of the PBA assessment that " that precipitation is the primary hydrological input to Askham Bog and the other hydrological inputs from overtopping/flooding provide a supporting role" but does not directly address the water supply mechanisms that support the bog identified in the JBA assessment.

7 Conclusions

7.1 The reasons given for refusal of planning permission by York City Council is in part based on their assertion that "*The proposed drainage scheme and Environmental Protection and Enhancement Zone associated with the residential development are considered to have an adverse impact on Askham Bog Site of Special Scientific Interest as a result of changes likely to occur to the hydrological/ hydro-geological interaction between the development site and the Bog. The proposals are considered contrary to paragraph 175 of the National Planning Policy Framework and policies DP2 Sustainable Development, DP3 Sustainable Communities, GI2 Biodiversity and access to nature and GI3 Green Infrastructure Network of the emerging Local Plan.*"

7.2 Askham Bog is a SSSI and the lowland fen habitats within it are defined as "*irreplaceable*" under the NPPF (CD015)[13]. In accordance with Paragraph 175 of the NPPF, all development proposals must identify adverse effects upon SSSIs and should "*normally not be permitted*" if they are identified. In addition, developments should not result "*in the loss or deterioration of irreplaceable habitats"*, and "*…should be refused, unless there are wholly exceptional reasons"*.

7.3 I acknowledge that the Appellant has considered whether the development will create hydrological and hydrogeological impact mechanisms that could affect Askham Bog SSSI. However, based on the information I have reviewed, I have identified a number of shortcomings in the Appellant's understanding of how Askham Bog SSSI is supported and the level of assessment that has been applied to assess impacts. I am of the opinion that the Appellant has failed to identify key potential impact mechanisms associated with the proposed drainage scheme, that could affect the SSSI and the irreplaceable habitats within it. As a result, the Appellant has not been able to develop effective proposals for avoidance, mitigation or compensation of these impacts which is contrary to NPPF Paragraph 175.

7.4 Underlying the issues with the proposed scheme (or potential variants) is the difficulty, and potential contradictions, of requiring the Ecological Protection and Enhancement Zone (EPEZ) to store and attenuate water in line with the requirements of the drainage strategy, while replicating or improving upon the water supply mechanisms to the SSSI. Combining the two objectives within the same space will likely lead to compromise in any design achieving both those objectives.

---

[13] **Irreplacebale Habitat** - Habitats which would be technically very difficult (or take a very significant time) to restore, recreate or replace once destroyed, taking into account their age, uniqueness, species diversity or rarity. They include ancient woodland, ancient and veteran trees, blanket bog, limestone pavement, sand dunes, salt marsh and lowland fen.

Appendices

A Maps and Figures

Map 1: LIDAR Topography

Map 2: Superficial Geology

Map 3: Cross Section Lines and Geology

Map 4: Cross Section Lines and Topography

Fig 1: Figure 2.1 from the FRA (PBA 2018)

Fig 2: Schematic Model of the Creation of the York Moraine and Alne Formation (From BGS 1999)

Fig 3: Fitter and Smith (1979) Cross Section through Askham Bog (from Ove Arup 2003)

Fig 4: Selected Stratigraphy Data from Ove Arup 2003 (1 of 2)

Fig 5: Selected Stratigraphy Data from Ove Arup 2003 (2 of 2)

Fig 6: Diagram showing the Bog Development

Fig 7: Borehole Log BH14/07

Fig 8: Water Level Monitoring from Near Wood (Ove 2003)

Fig 9: Hydrograph of BH14/07 and GB14/09

Fig 10: Western Geological Cross Sections with Water levels

Fig 11: Eastern Geological Cross Sections with Water levels

Fig 12: NVC Survey (Ecological Surveys 2011)

Fig 13: 20yrs Return Period Flood Modelled Extent from Askham Bog Drain (from Appendix 13 of the ES) and Hogg et al. 1993 Soil pH in Far Wood

Fig 14: Eco-hydrological Conceptual Model of Askham Bog

Fig 15: Impact Conceptual Model

Fig 16: Geological Cross Section with Monitored Water levels and the Bund and Attenuation Basin Design

Fig 17: Water levels in Near Wood and location of monitoring from Ove (2003)

Fig 18: Water Budget Catchments and Attenuation Basin Catchment

Fig 19: Hydraulic Properties of Aquifers

Fig 20: PBA Cross Section From 29/03/2019 Technical Note

LEGEND

Basin
SSSI
Site Boundary

LIDAR

mAOD

- < 11.5
- 11.51 - 11.75
- 11.76 - 12
- 12.01 - 12.25
- 12.26 - 12.5
- 12.51 - 13
- 13.01 - 13.5
- 13.51 - 14
- >14.01

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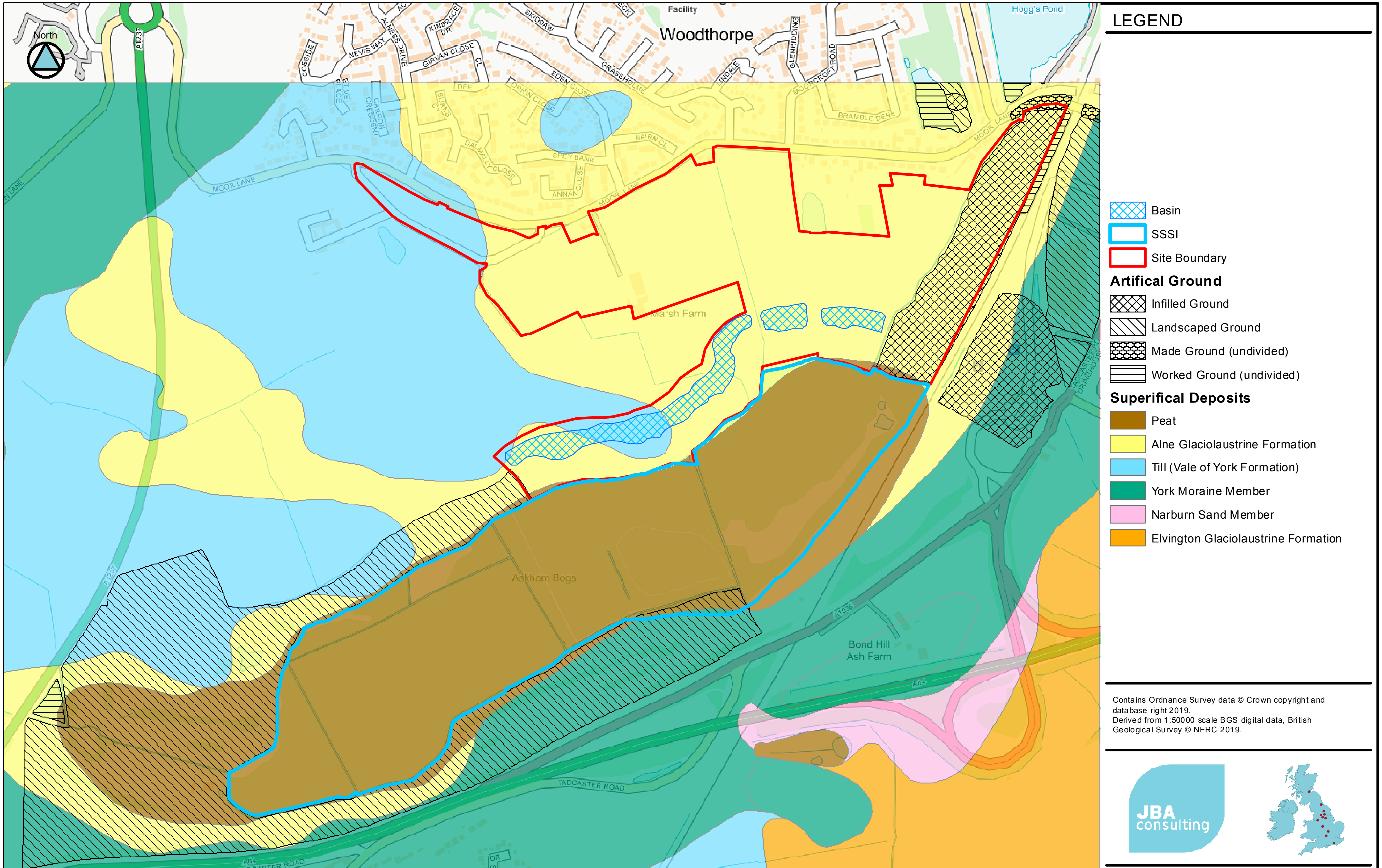
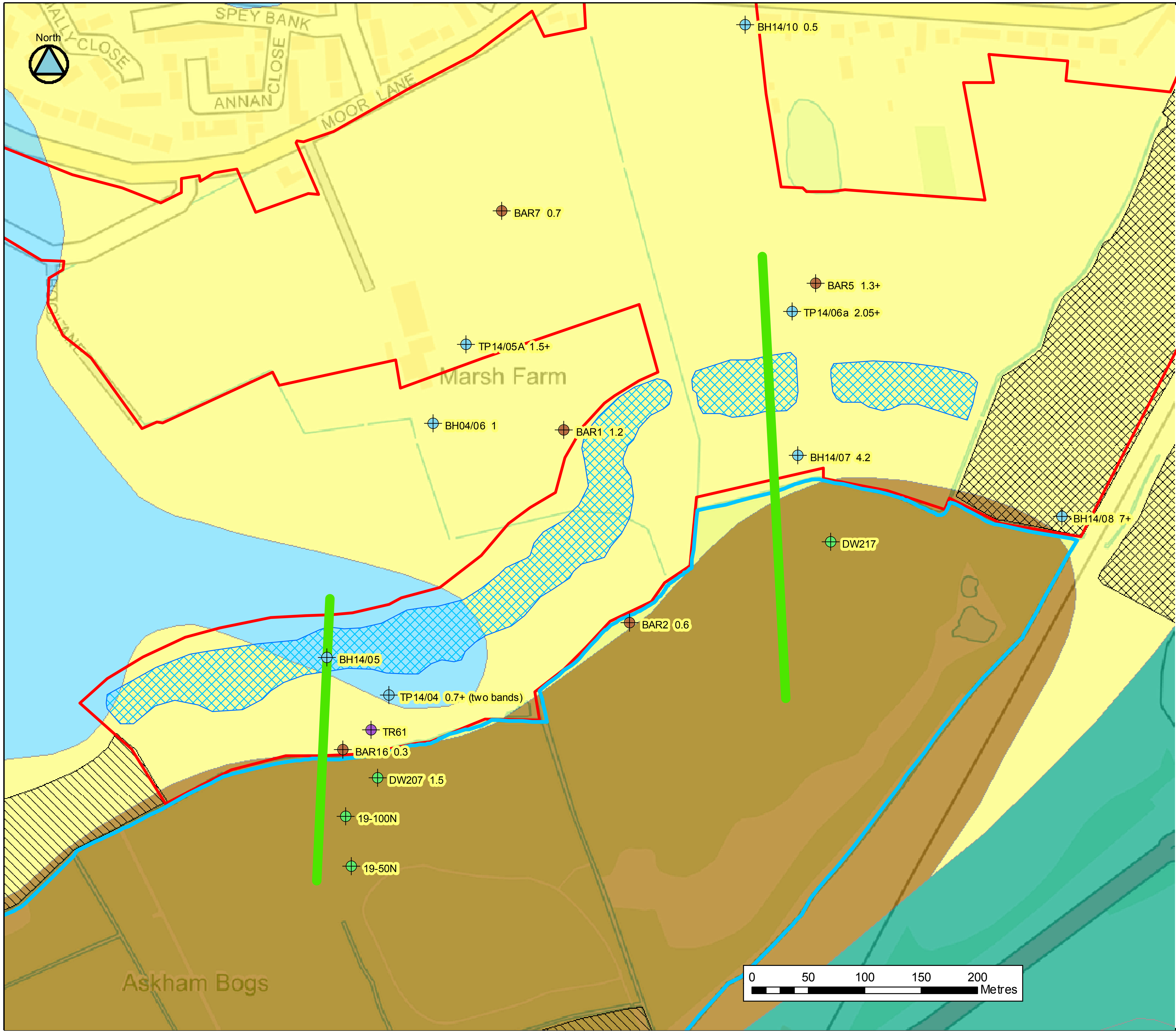
MAP 1

LIDAR Topography



MAP 2

Superficial Geology



LEGEND

SI Sources

- Headland Archaeology - ES App 10.1
- Ove 2003
- WWT 2013
- Wardell Armstrong 2014 - ES App 10.1
- XS Line
- Basin
- SSSI
- Site Boundary

Artifical Ground

- Infilled Ground
- Landscaped Ground
- Made Ground (undivided)
- Worked Ground (undivided)

Superifical Deposits

- Peat
- Alne Glaciolaustrine Formation
- Till (Vale of York Formation)
- York Moraine Member
- Narburn Sand Member
- Elvington Glaciolaustrine Formation

Labels
Exploratory Location Name - Sand Depth m

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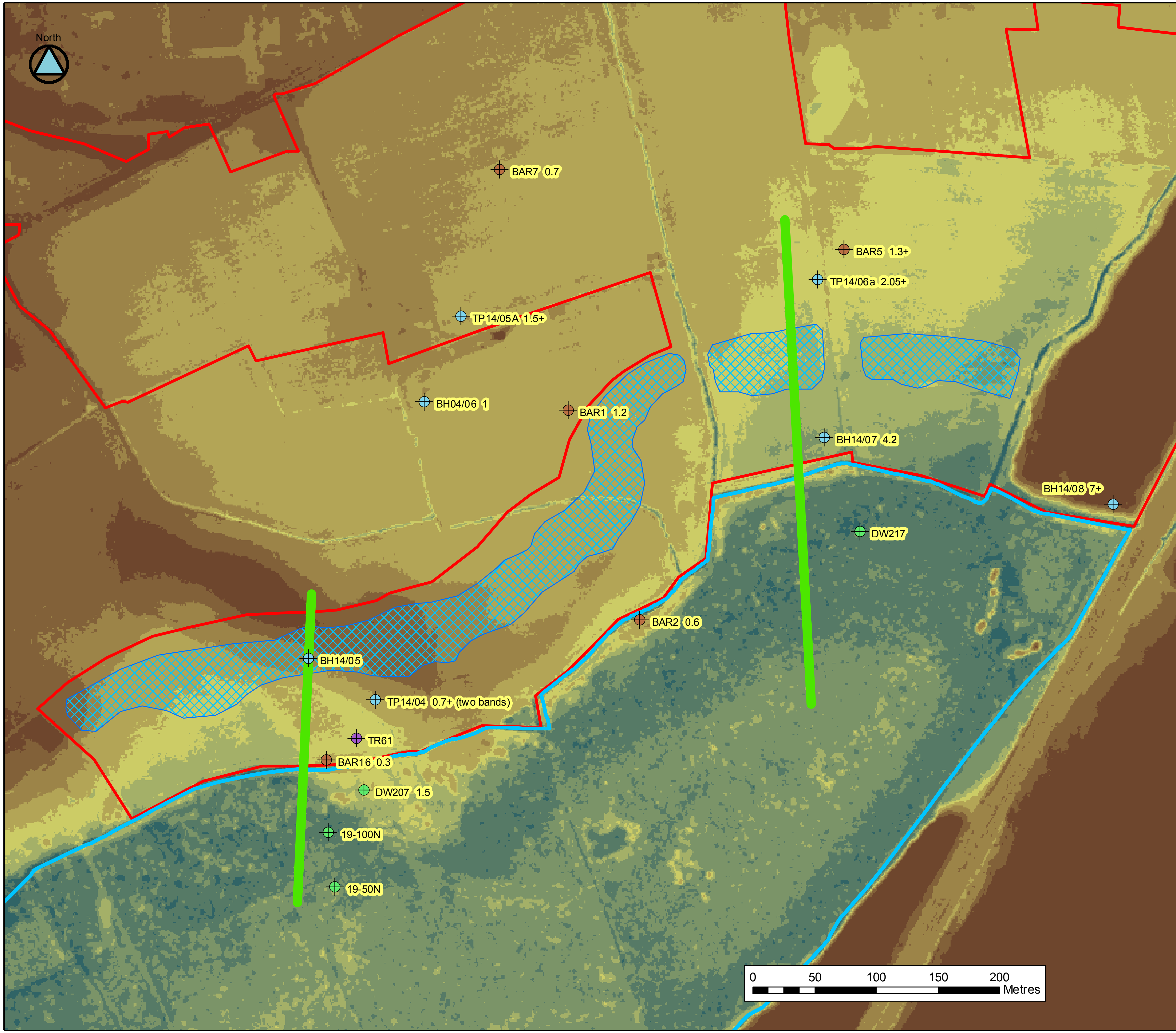
MAP 3

Cross Section Lines and Geology



LEGEND

SI Sources

- Headland Archaeology - ES App 10.1
- Ove 2003
- WWT 2013
- Wardell Armstrong 2014 - ES App 10.1

XS Line

Basin

SSSI

Site Boundary

LIDAR

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- >14.01

Labels
Exploratory Location Name - Sand Depth m

JBA consulting

MAP 4

Cross Section Lines and Topography

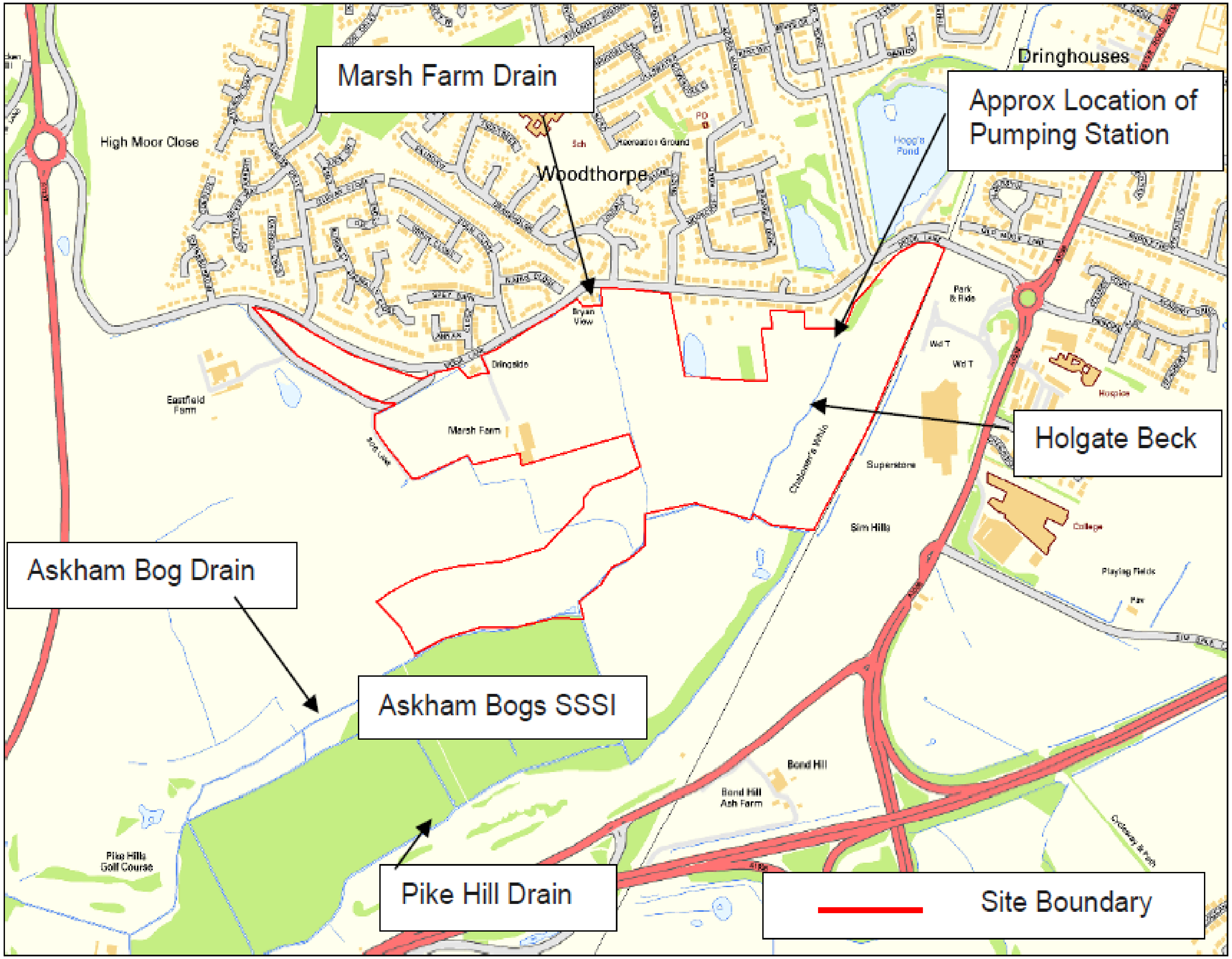

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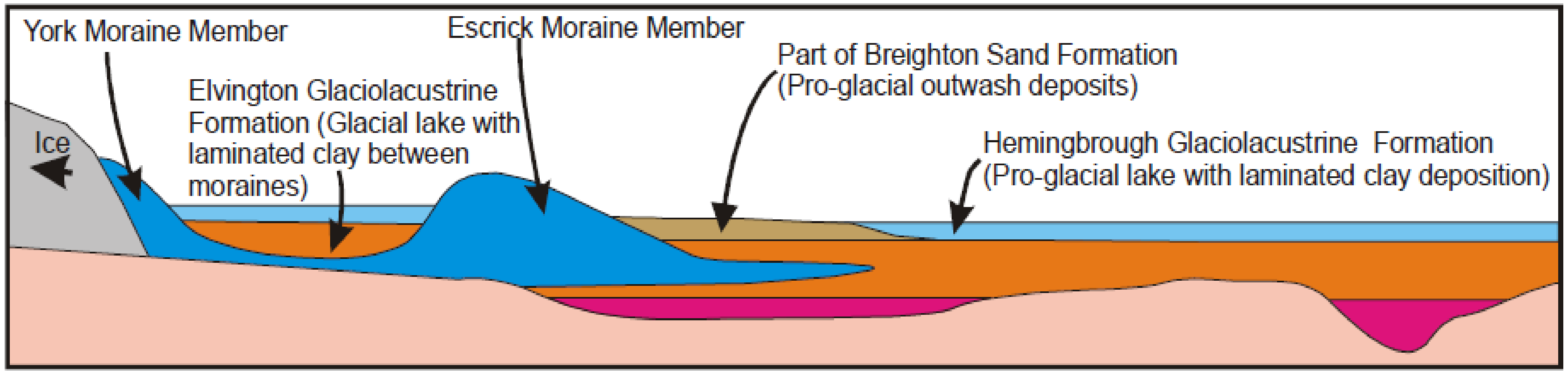
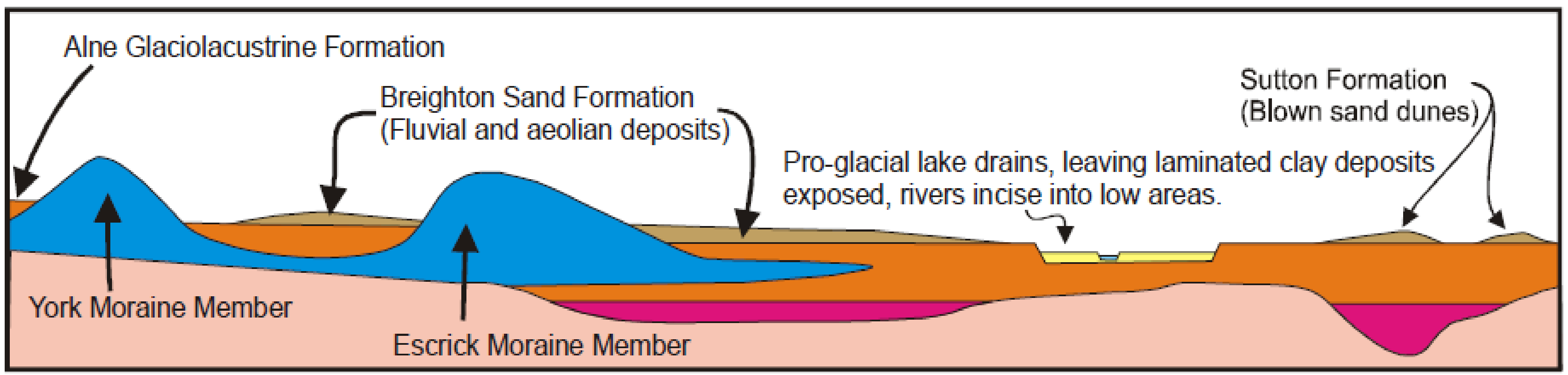
Fig 1: Figure 2.1 from the FRA (PBA 2018)



5. Ice retreats further north and a new pro-glacial lake develops between the Escrick Moraine and the new moraine formed at York. Laminated clay lake deposits (Elvington Glaciolacustrine Formation) develop between the moraines and the Hemingbrough Glaciolacustrine Formation continues to be deposited in front of the Escrick Moraine Member.



JBA consulting

Fig 2: Schematic Model of the Creation of the York
Moraine and Alne Formation (From BGS 1999)

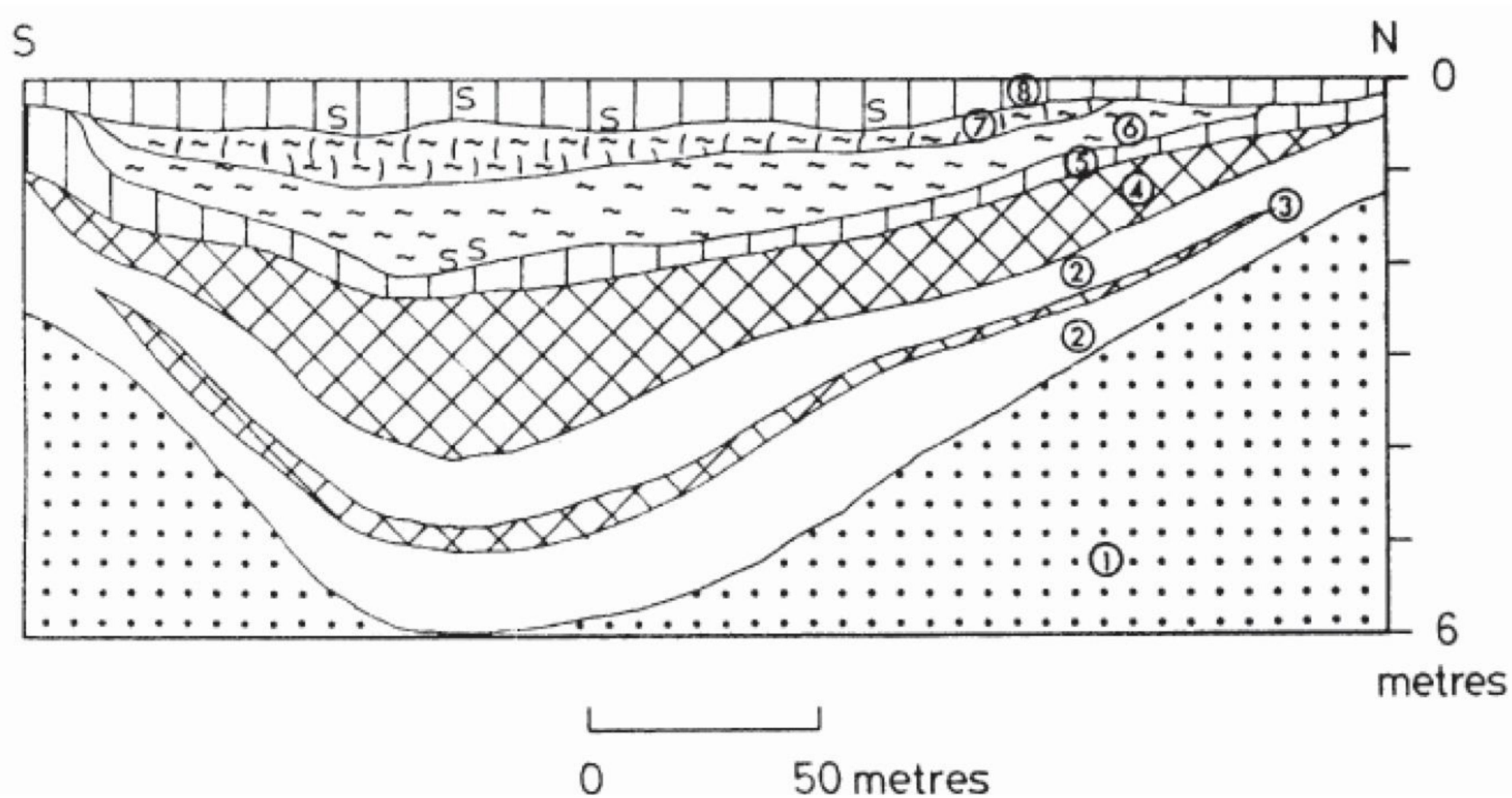


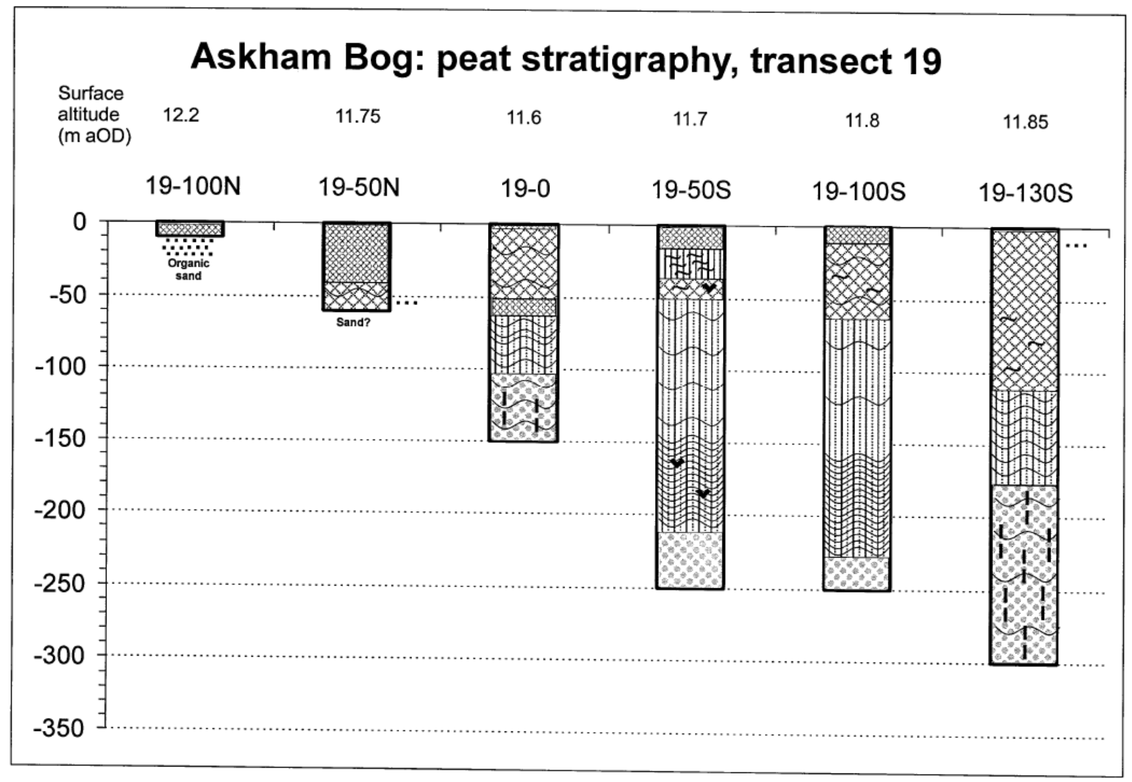
Fig 3: Fitter and Smith (1979) Cross Section through Askham Bog (from Ove Arup 2003)

Askham Peat Stratigraphy:

Key to diagrams

- Amorphous peat
- Black, oxidised peat
- Monocots (fen/swamp)
- Rootmat
- Fibrous peat (mainly monocot - probably Eriophorum sp.)
- Gyttja
- Silt / clay
- Silty sand
- Sphagnum (density of lines indicates relative number of leaves seen)
- Cannabis seeds
- Woody fragments (may include Calluna)
- Brown moss (mainly Scorpidium)
- Monocot. remains
- Mineral grains

Notes:
1. altitude given is that of the ground surface, estimated from the topographical survey maps (2000)
2. Cores were examined to a depth of 150cm or 300cm. Where mineral material was reached, this is indicated in the diagrams



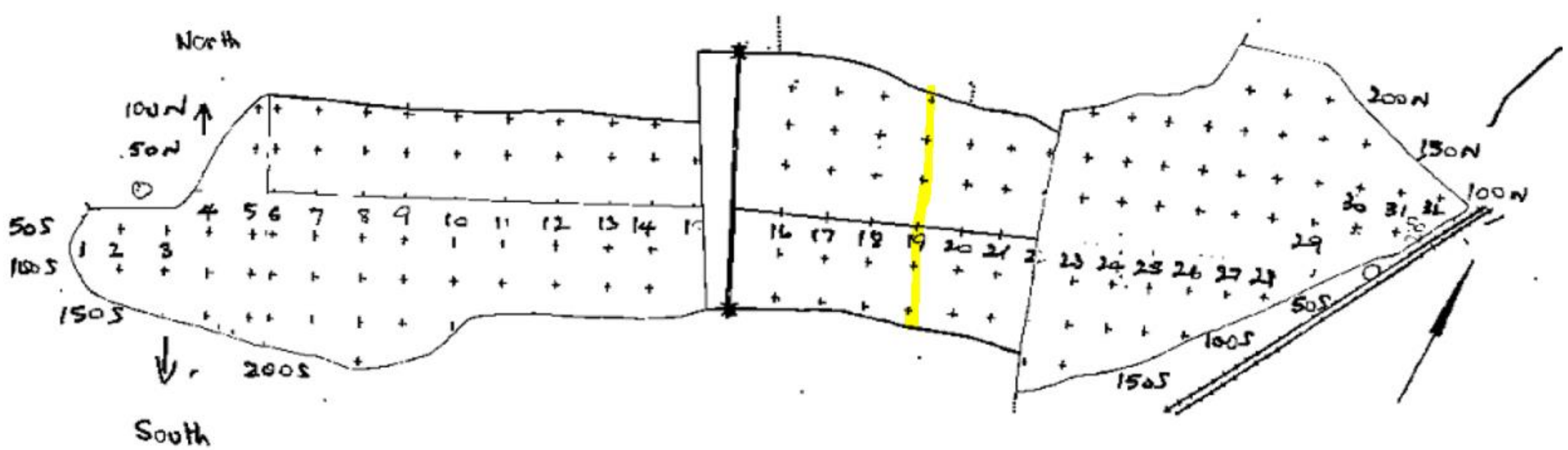
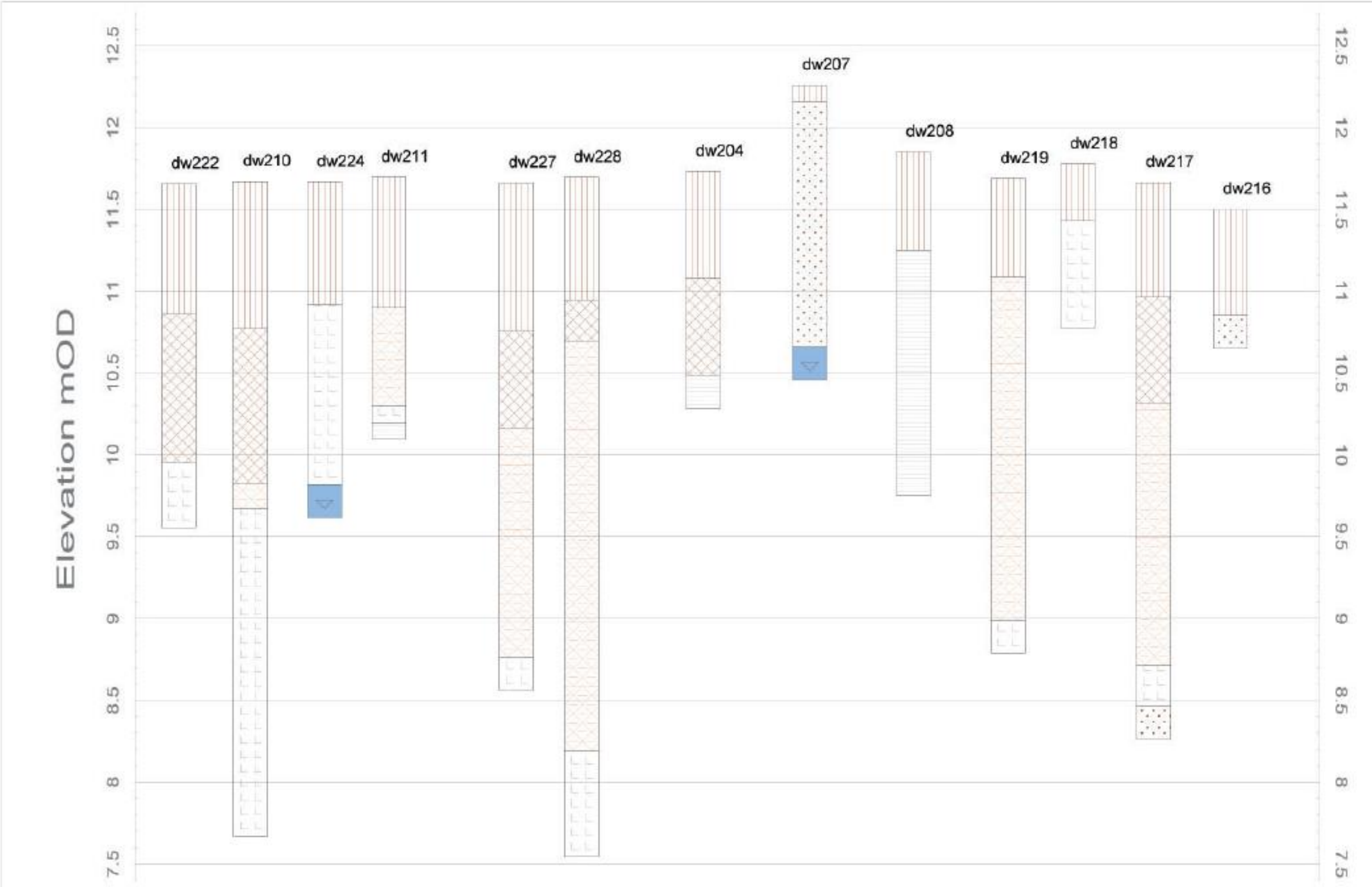


Fig 4: Selected Stratigraphy Data from Ove Arup 2003 (1 of 2)



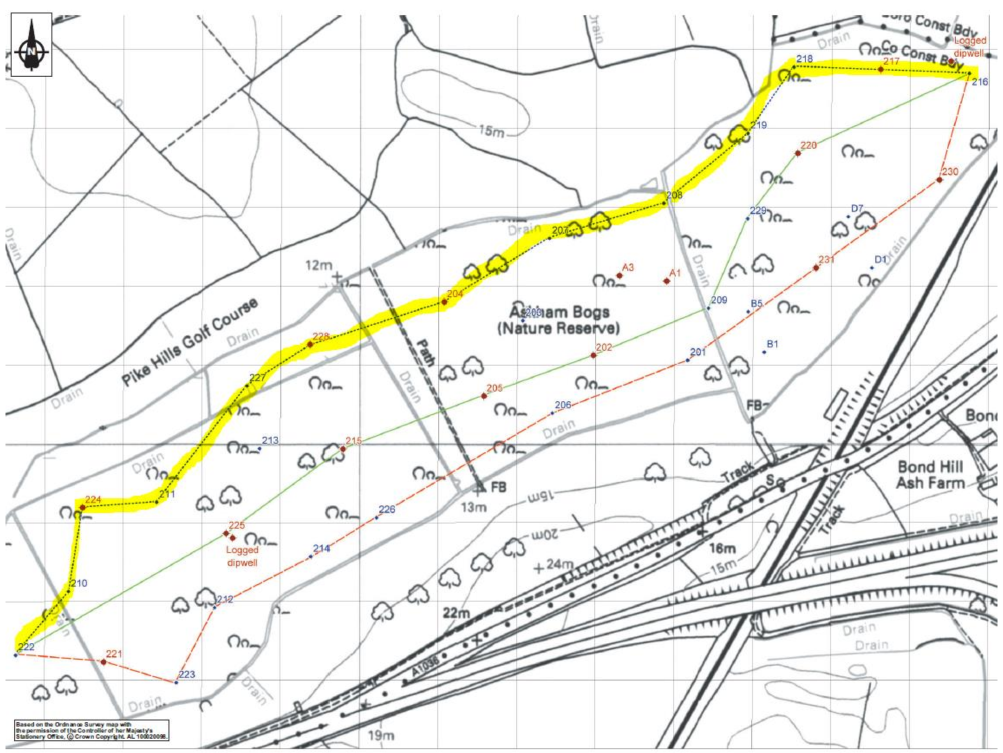


Fig 5: Selected Stratigraphy Data from Ove Arup 2003 (2 of 2)

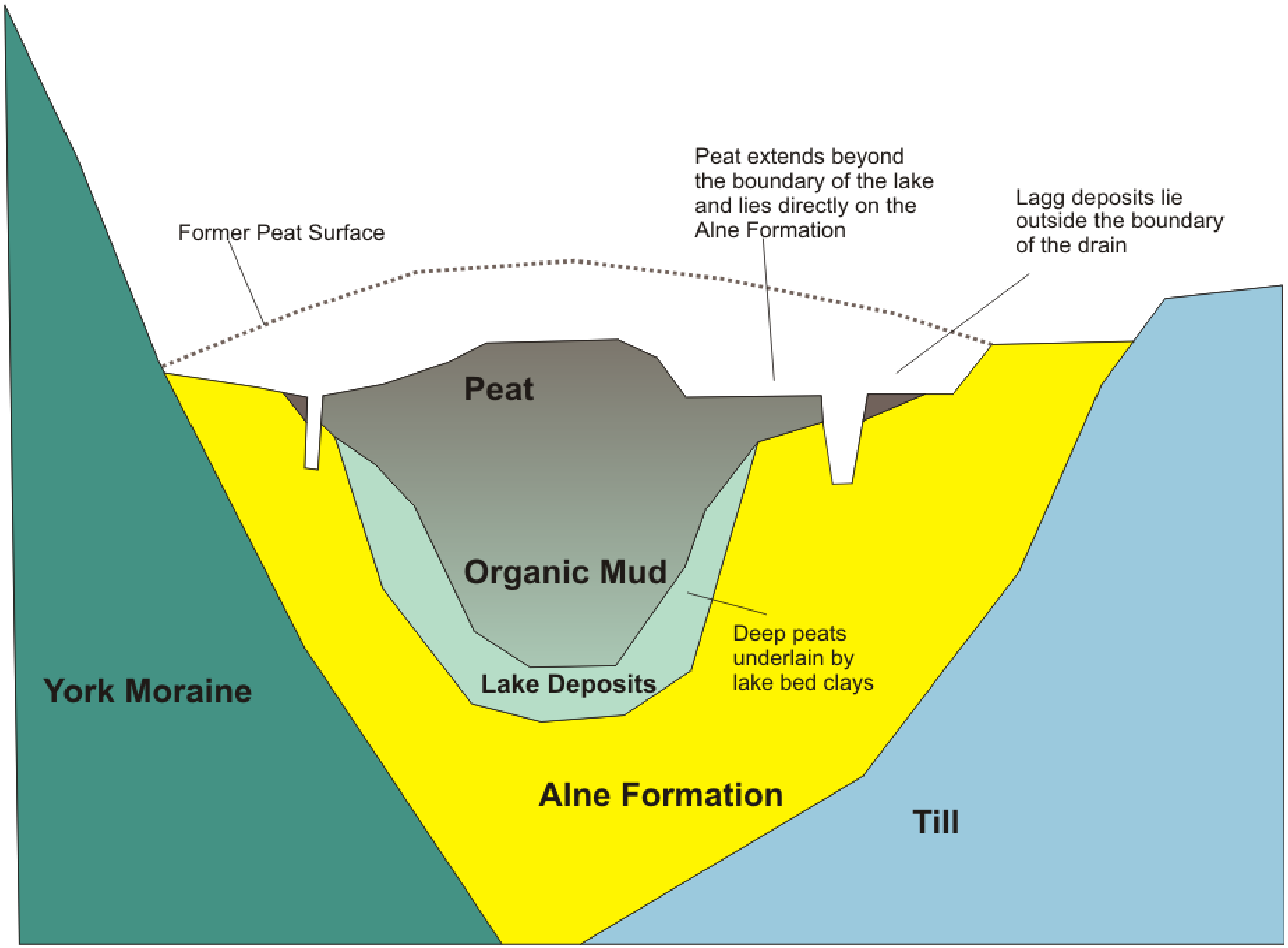


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Fig 6: Diagram showing the Bog Development

Borehole Log

wardell armstrong

Project Name: Land at Moor Lane, York	Project No. CP11005	Co-ords: 457624.87 - 448553.21	Borehole No. **BH14/07** Sheet 1 of 1
Location: York		Level: 12.11	Hole Type CP
Client: EDP		Dates: -	Scale 1:50
			Logged By

Well	Water Strikes	Samples and In Situ Testing: Depth (m)	Type	Results	Depth (m)	Level (m)	Legend	Stratum Description
					0.30	11.81		Grass over dark brown slightly sandy clayey TOPSOIL with rootlets.
					1.20	10.91		Brown silty fine to medium SAND
					4.50	7.61		Brown fine to medium SAND
								Soft and firm slightly sandy slightly gravelly

Depth scale: 1, 2, 3, 4

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Fig 7: Borehole Log BH14/07

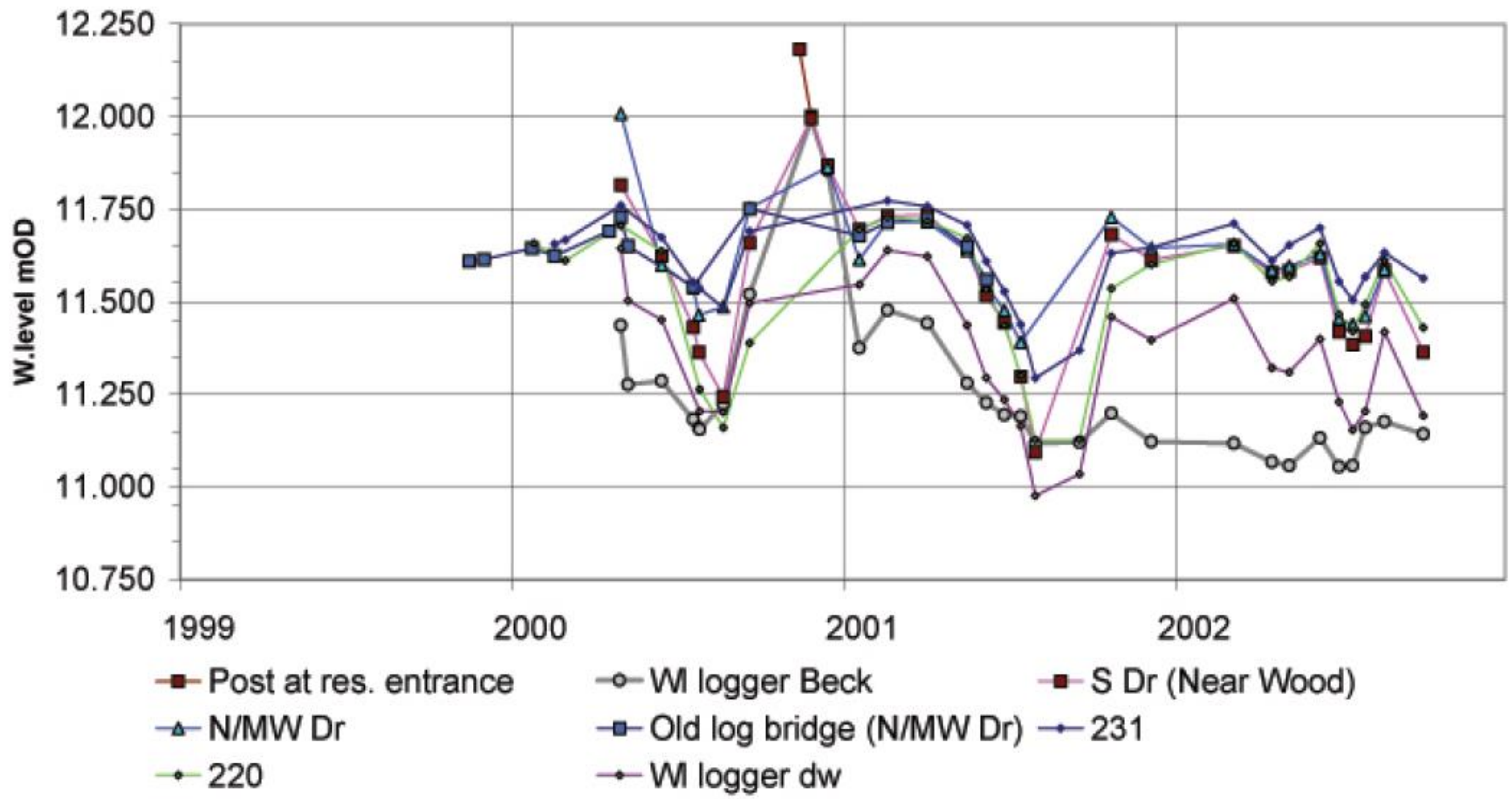

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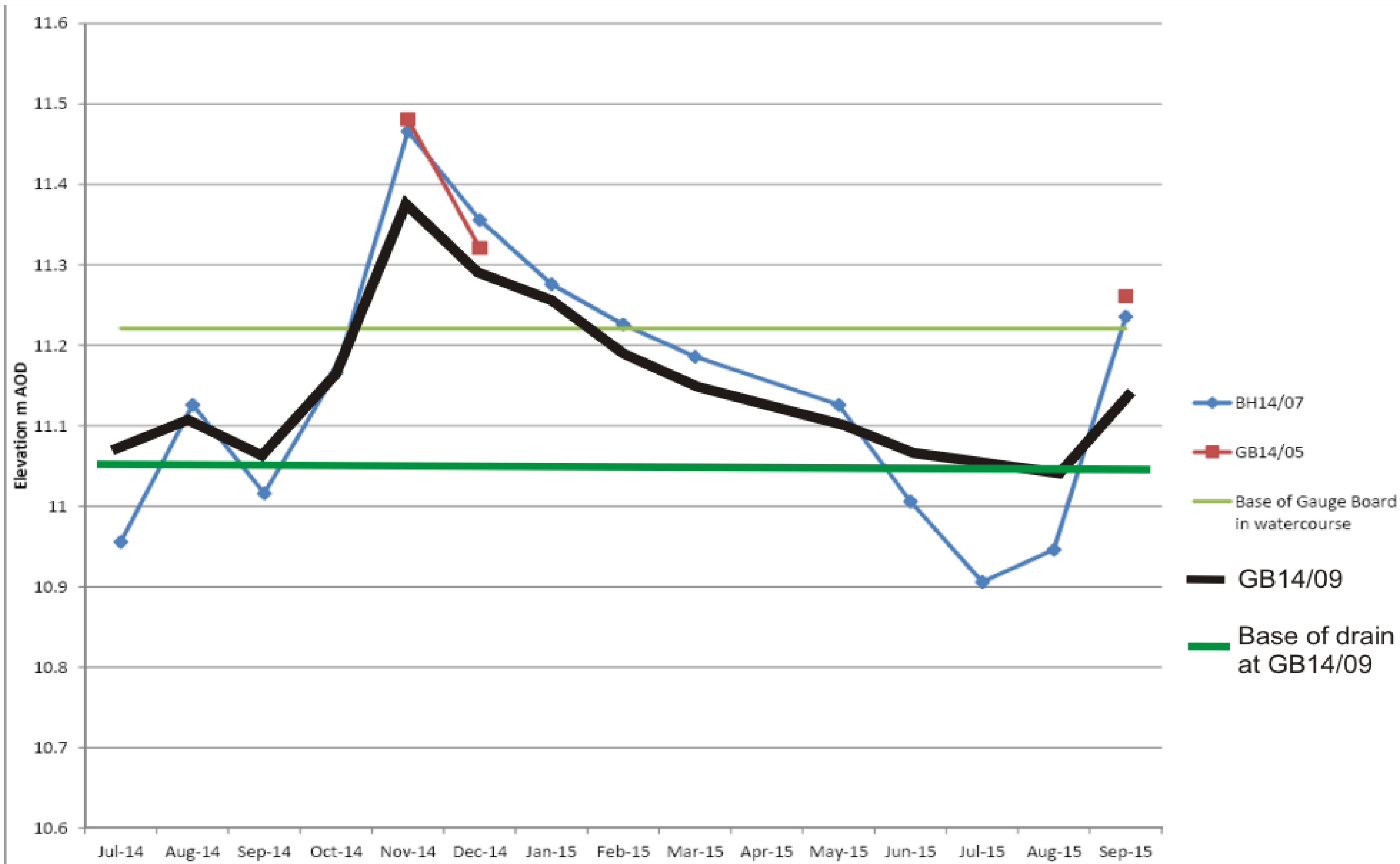
Fig 8: Water Level Monitoring from Near Wood (Ove 2003)



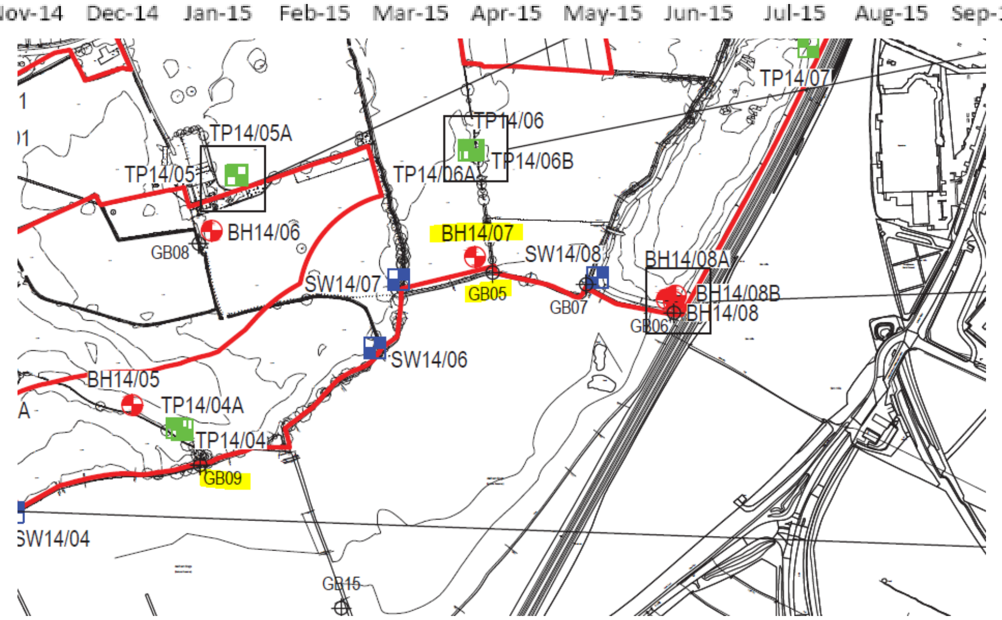
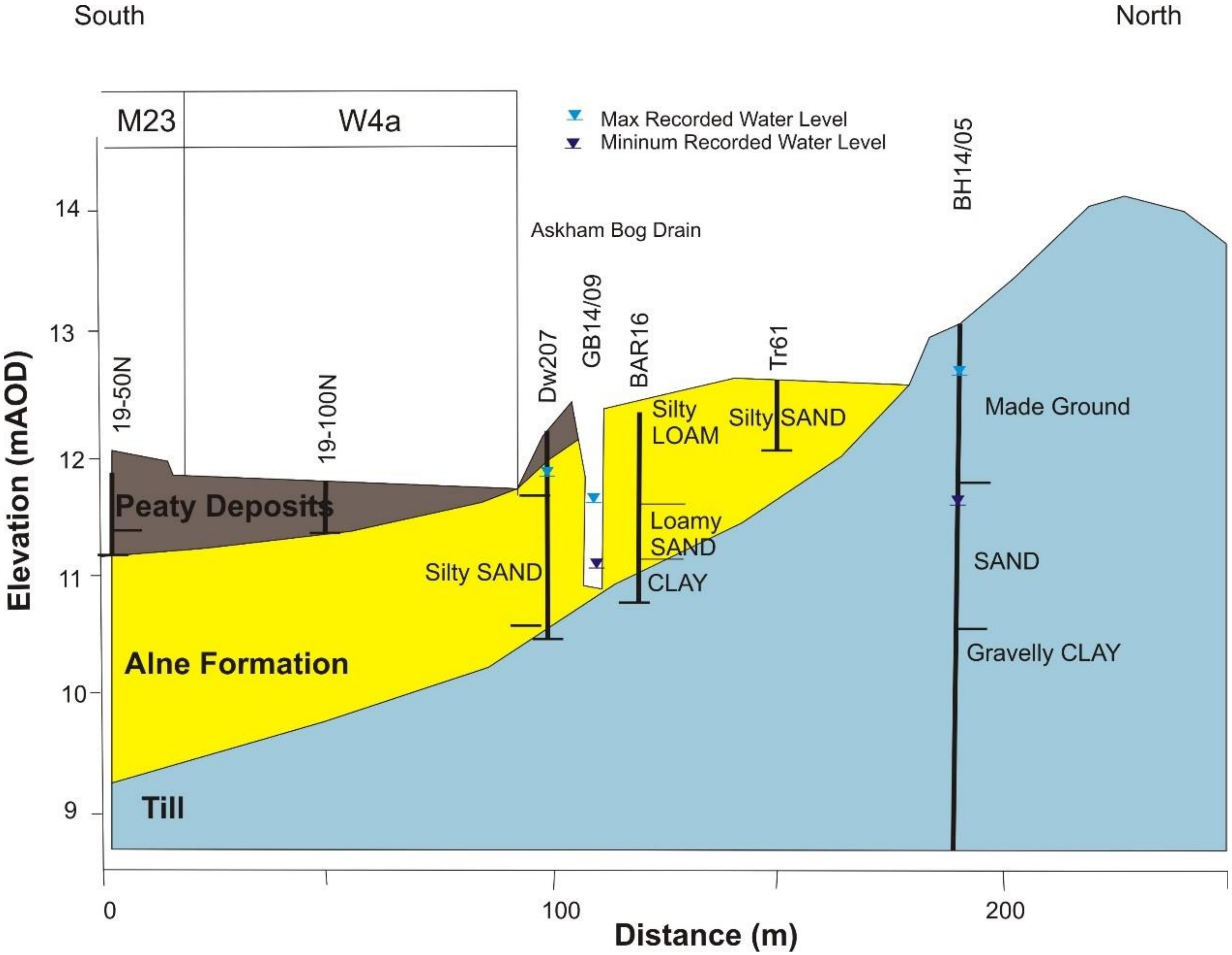


Fig 9: Hydrograph of BH14/07 and GB14/09



JBA consulting

Fig 10: Western Geological Cross Sections with Water levels

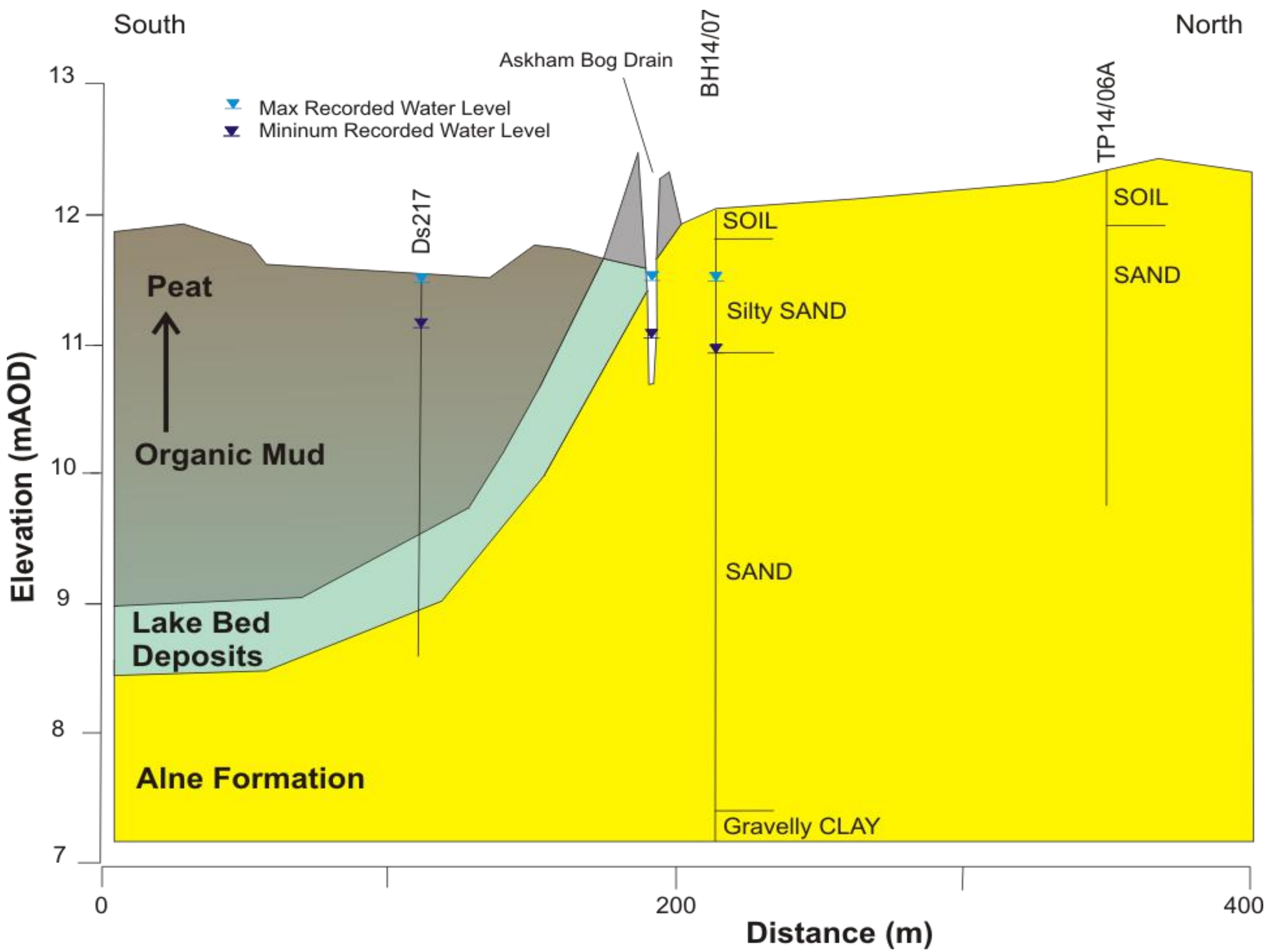


Fig 11: Eastern Geological Cross Sections with Water levels

JBA consulting

Fig 12: NVC Survey (Ecological Surveys 2011)

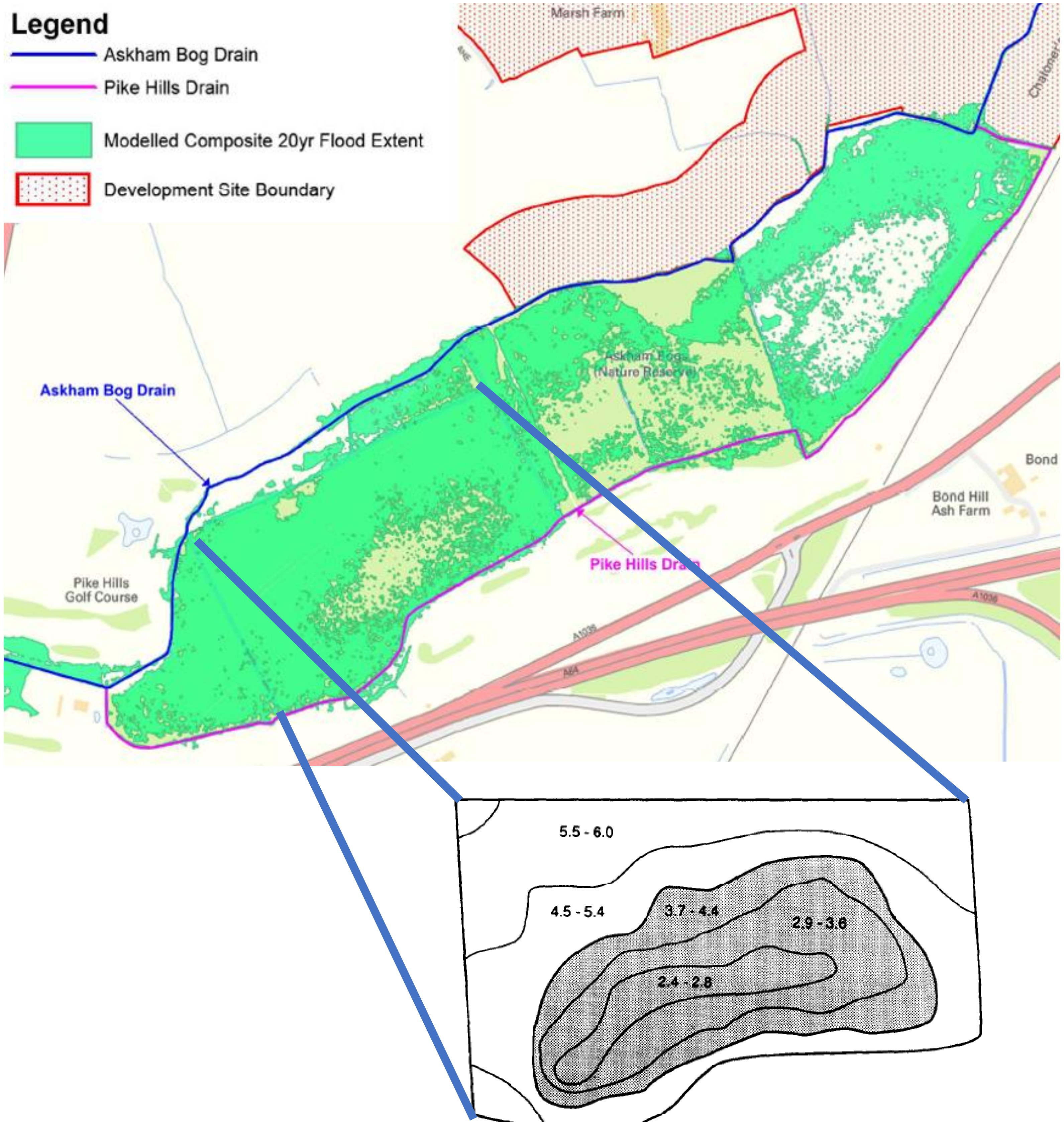


Fig 13: 20yrs Return Period Flood Modelled Extent from Askham Bog Drain (from Appendix 13 of the ES)
And Hogg et al. 1993 Showing Soil pH in Far Wood

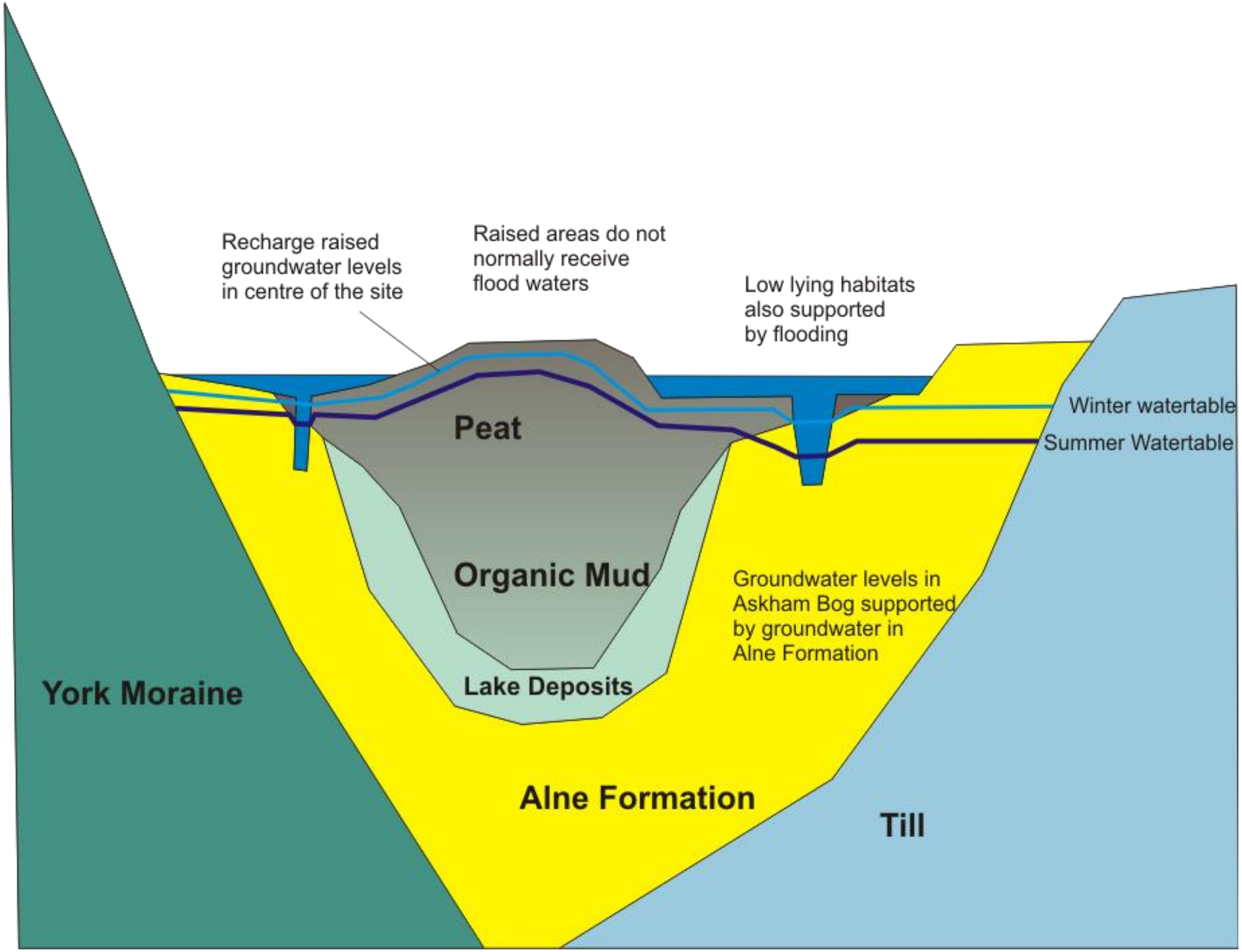


Fig 14: Eco-hydrological Conceptual Model of Askham Bog

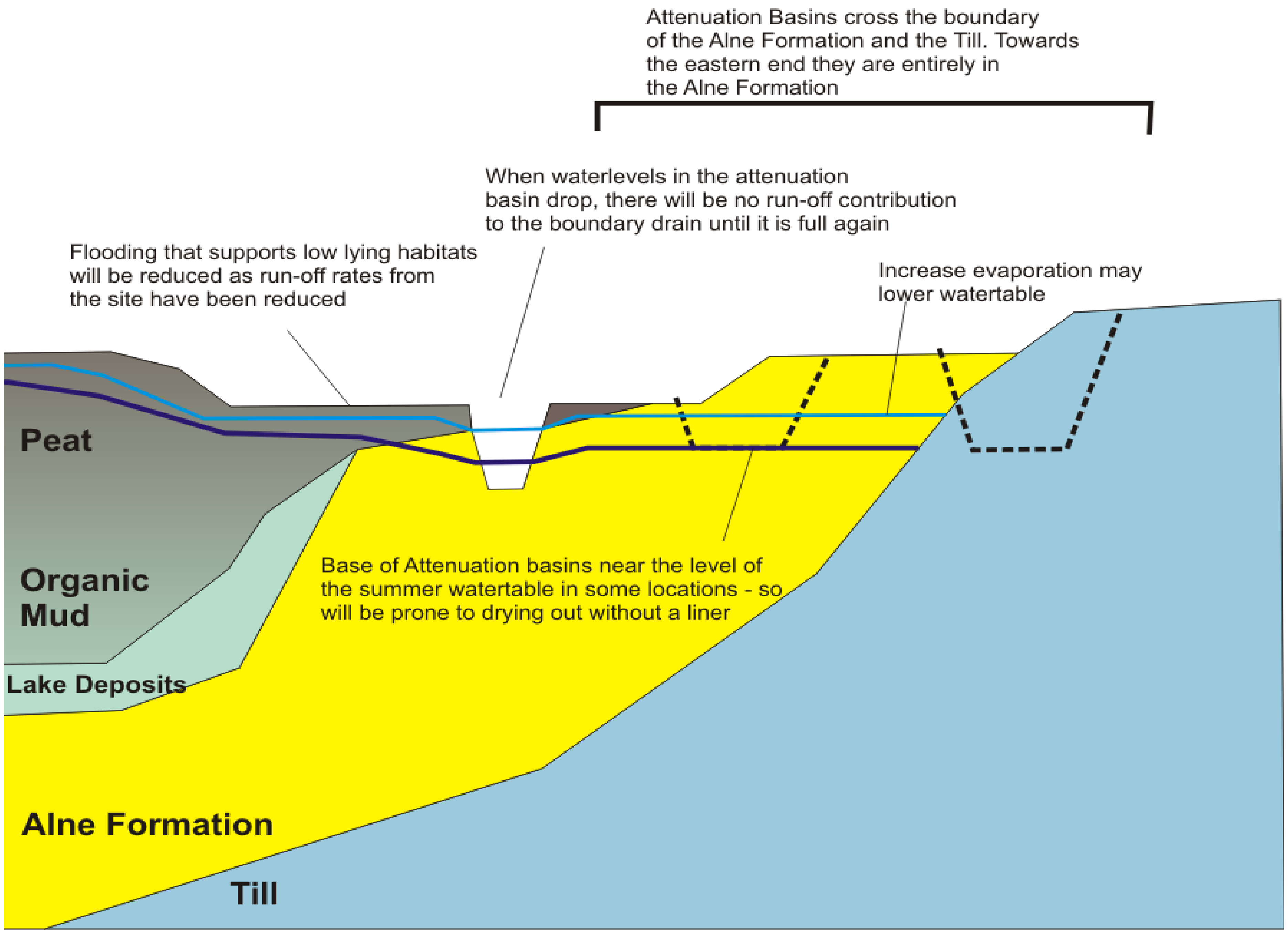


Fig 15:
Impact Conceptual Model

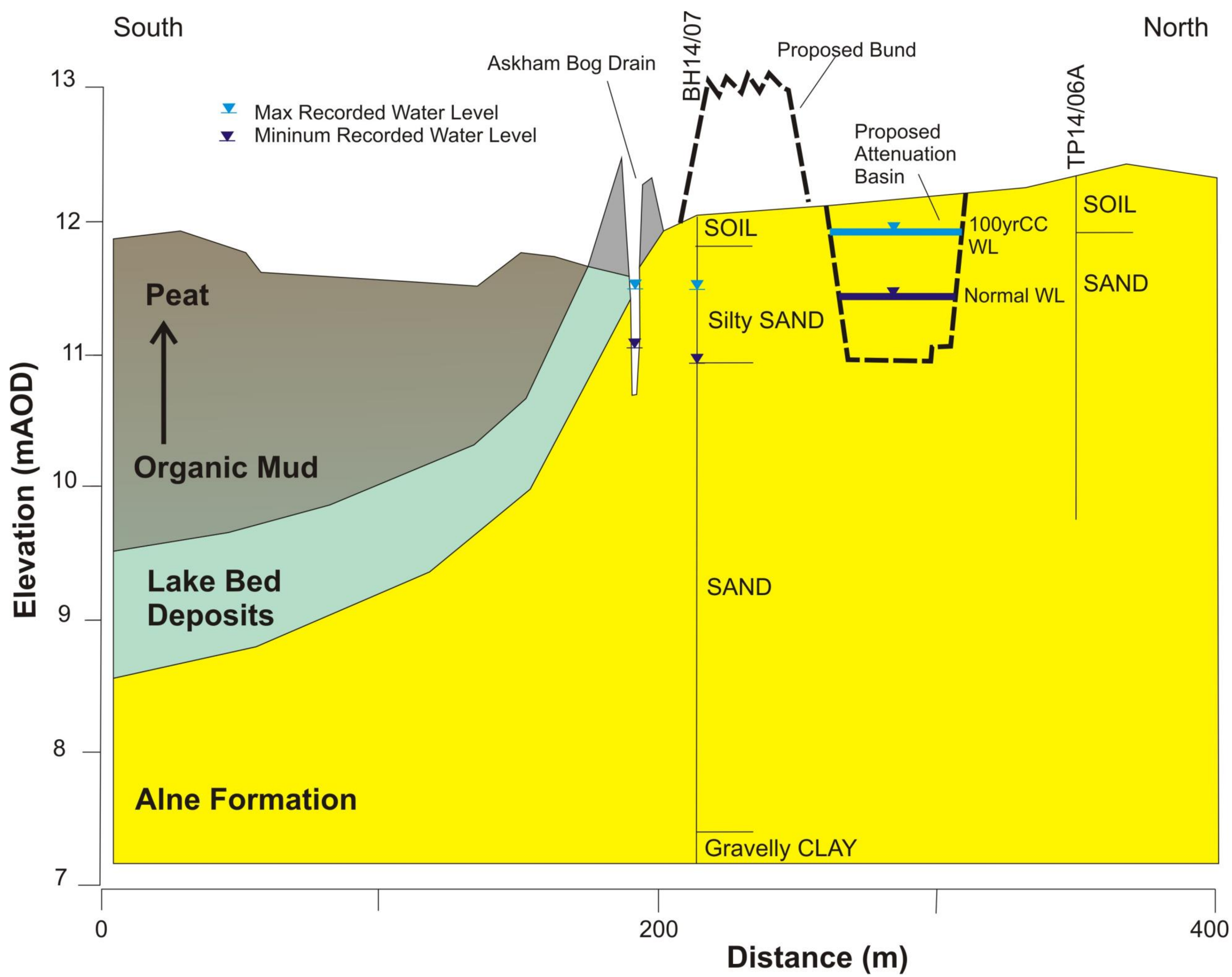
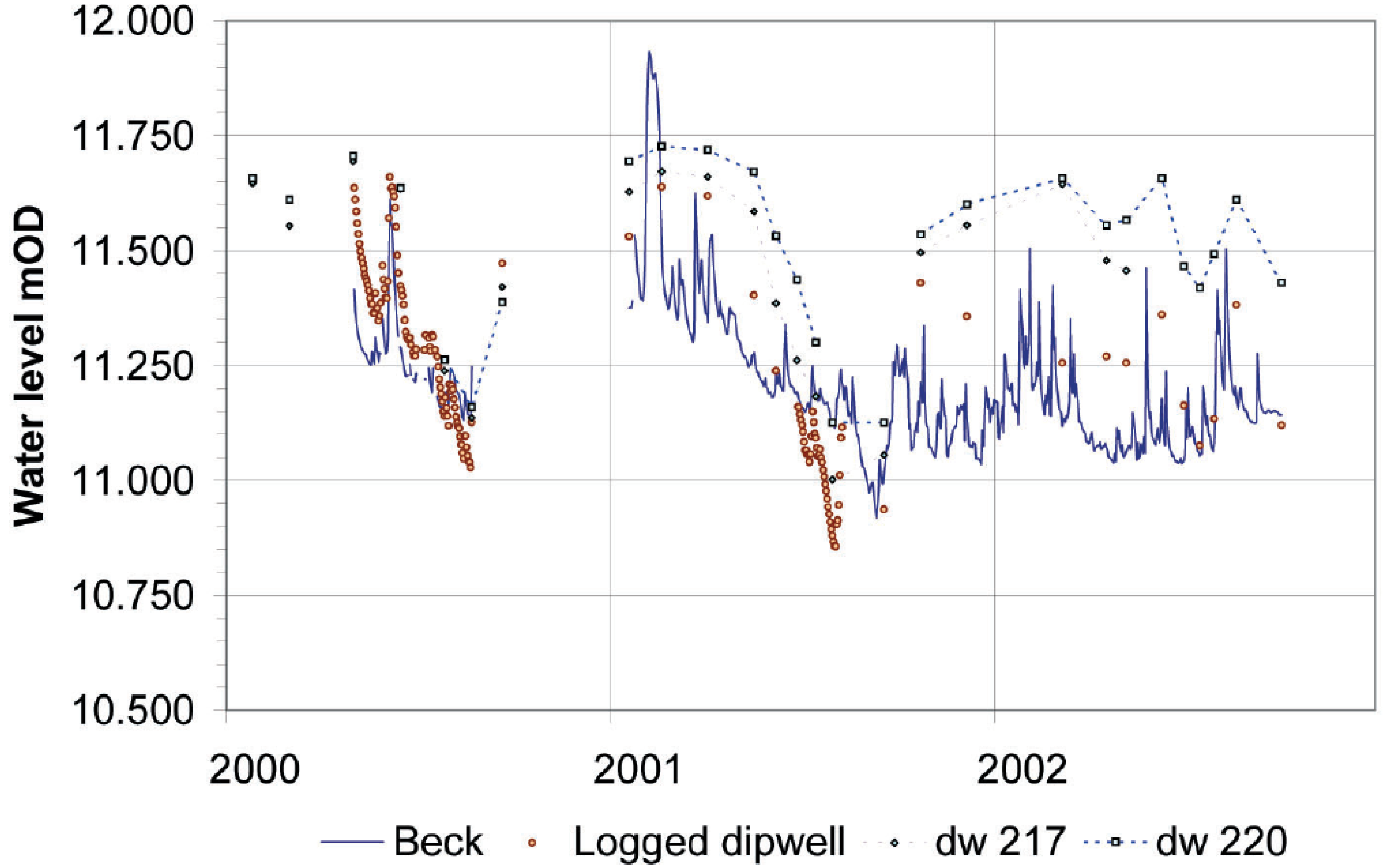
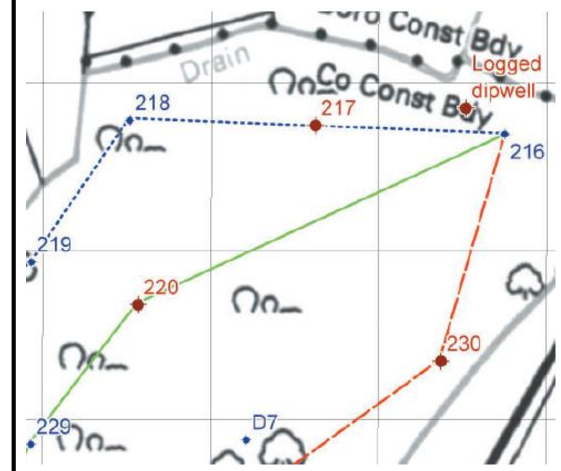


Fig 16 Geological Cross Section with Monitored Water levels and the Bund and Attenuation Basin Design





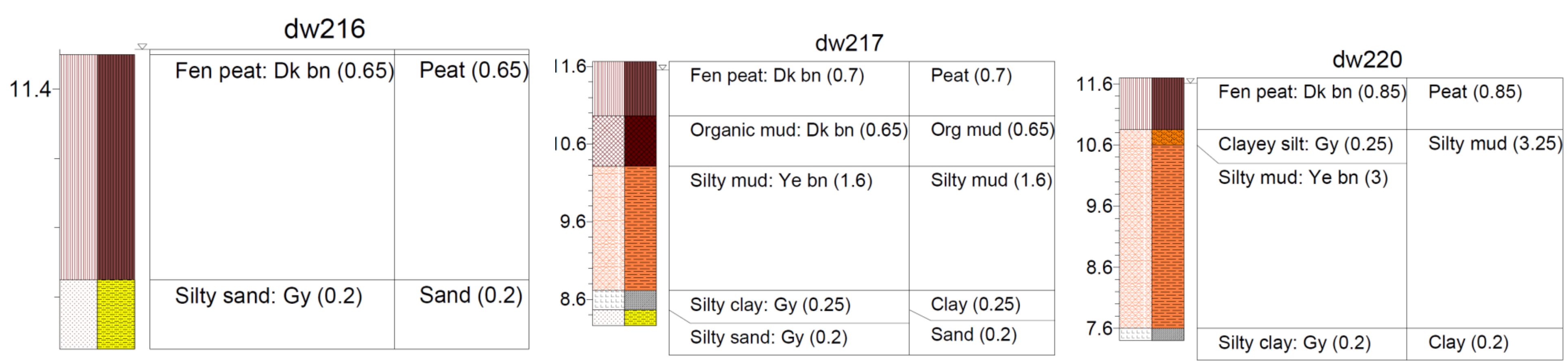


Fig 17: Water levels in Near Wood and location of monitoring from Ove Arup (2003)

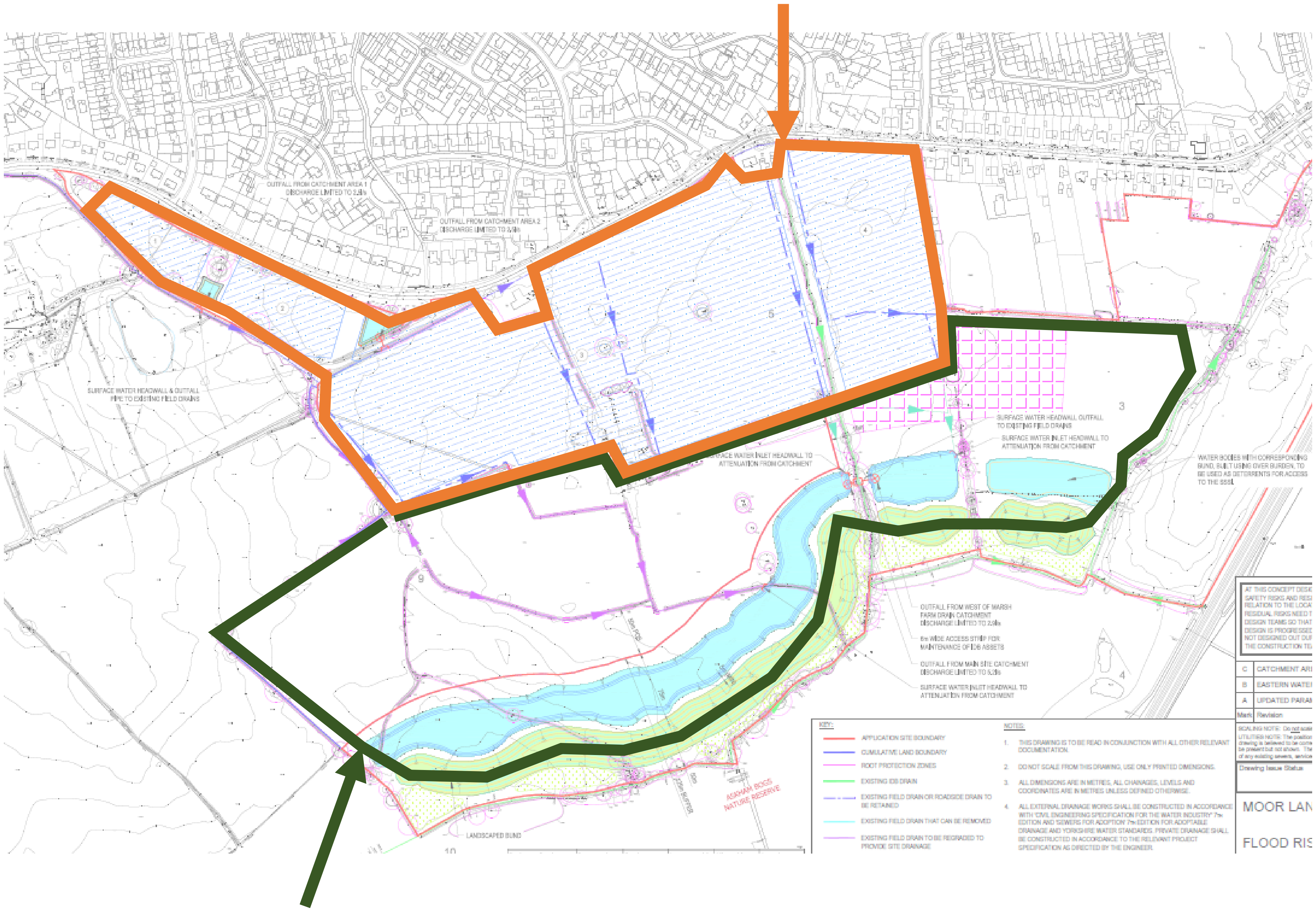


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Fig 18: Water Budget Catchments and Attenuation Basin Catchment

Table 5.4 List of indicative porosities and hydraulic conductivities for unconsolidated sediments and rocks

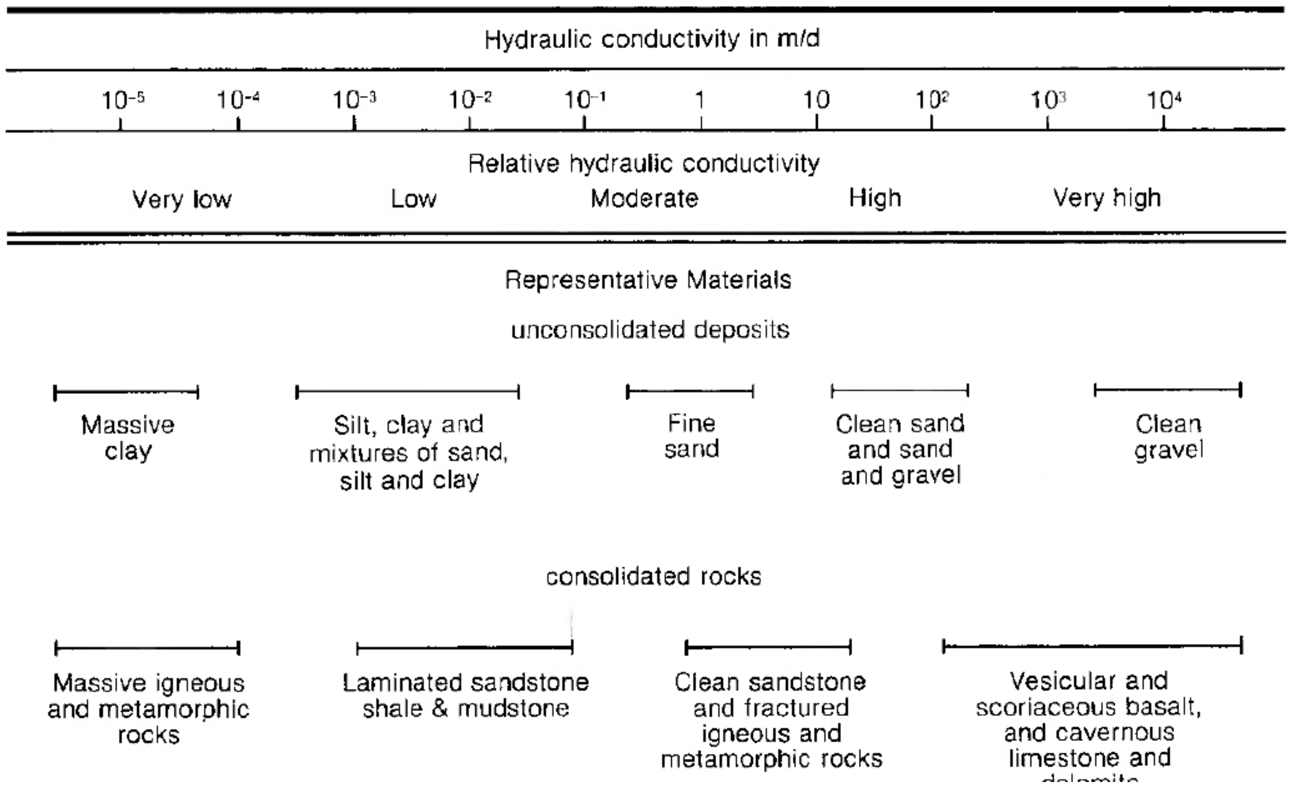


Table 5.1 Indicative values of porosity for a range of geological materials. Compare with Table 5.2

Material	*Porosity (per cent)*	*Material*	*Porosity (per cent)*
Coarse gravel	28	Loess	49
Medium gravel	32	Peat	92
Fine gravel	34	Schist	38
Coarse sand	39	Siltstone	35
Medium sand	39	Claystone	43
Fine sand	43	Shale	6
Silt	46	Till – mainly sand	31
Fine-grained sandstone	33	Till – mainly silt	34
Clay	42	Tuff	41
Medium-grained sandstone	37	Basalt	17
Limestone	30	Gabbro (weathered)	43
Dolomite	26	Granite (weathered)	45
Dune sand	45		

(Adapted from Water Supply Paper 1839-D by permission of the United States Geological Survey).

Table 5.2 Indicative values of specific yield for a range of geological materials

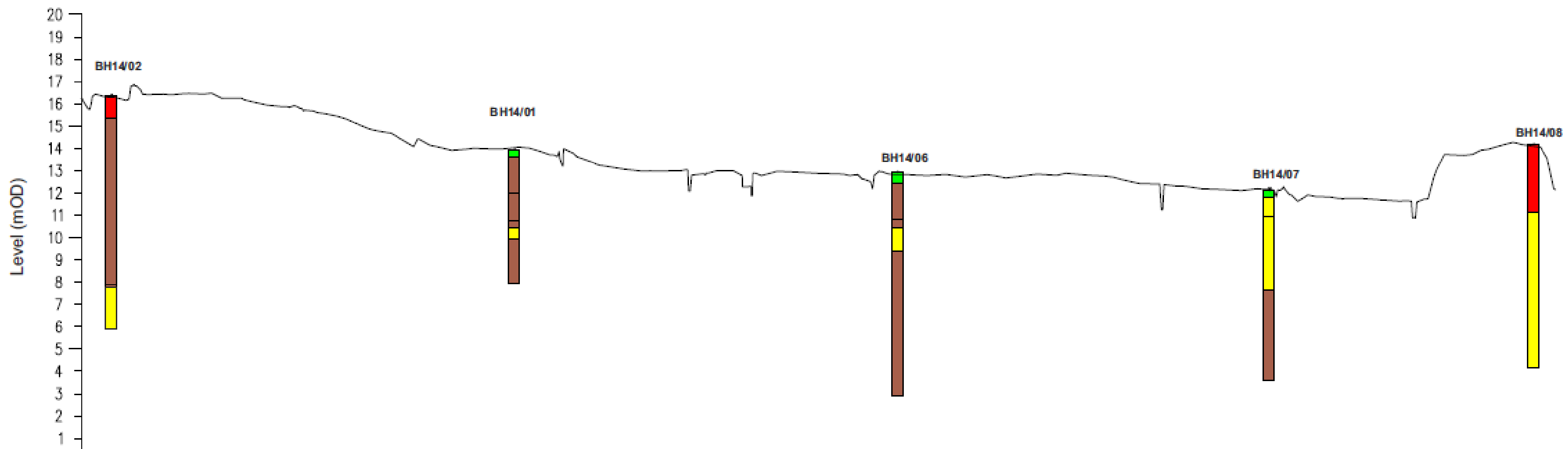
Material	*Specific yield per cent*
Coarse gravel	23
Medium gravel	24
Fine gravel	25
Coarse sand	27
Medium sand	28
Fine sand	23
Silt	8
Clay	3
Fine-grained sandstone	21
Medium-grained sandstone	27
Limestone	14
Dune sand	38
Loess	18
Peat	44
Schist	26
Siltstone	12
Till (mainly silt)	6
Till (mainly sand)	16
Till (mainly gravel)	16
Tuff	21

(Adapted from Water Supply Paper 1662-D by permission of the United States Geological Survey).

Source: R Brassington (1988), Field Hydrogeology, Geological Society of London Professional Handbook

Fig 19: Hydraulic Properties of Aquifers

CROSS SECTION A-B



Existing Levels	16.231	16.449	15.691	14.169	14.024	13.002	12.286	12.733	12.736	12.817	12.250	11.814	10.948	14.136 12.149
Chainage	00.000	100.000	200.000	300.000	400.000	500.000	600.000	700.000	800.000	900.000	1000.000	1100.000	1200.000	1300.000 1325.957

KEY

- Topsoil
- Made Ground
- Sand
- Clay

Horizontal Scale: 1:4000
Vertical Scale: 1:200

now part of Stantec
peterbrett.com

Client
Barwood Strategic Land II LLP

LAND AT MOOR LANE, WOODTHORPE, YORK

SCHEMATIC GEOLOGICAL CROSS SECTIONS

Date	18.03.2019
Scale	as shown
Drawn by	davco
Checked by	VKR
Revision	0

FIGURE B1

JBA consulting

Fig 20: PBA Cross Section From 29/03/2019 Technical Note

B Environment Agency (2007) Hydrogeological impact appraisal for dewatering abstractions

using science to
create a better place

Hydrogeological impact appraisal for groundwater abstractions

Science Report – SC040020/SR2

SCHO0407BMAH-E-P

ea/br/e/sci/v1

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency's Science Programme.

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or by telephoning 08708 506506.

Author(s):
Boak R and Johnson D

Dissemination Status:
Publicly available

Keywords:
Groundwater, abstraction, conceptual modelling, uncertainty, risk assessment, monitoring, licensing, karst

Research Contractor:
Water Management Consultants Ltd
23 Swan Hill, Shrewsbury, SY1 1NN
Tel: 01743 231793

Environment Agency's Project Manager:
Stuart Allen, Ipswich

Science Project Number:
SC040020

Product Code:
SCHO0407BMAH-E-P

Executive summary

This report provides practical guidance on how to assess the hydrogeological impact of groundwater abstractions, for those who are preparing applications to the Environment Agency for full licences. The methodology for hydrogeological impact appraisal (HIA) is designed to fit into the Environment Agency's abstraction licensing process, including the changes brought about by the Water Act 2003. It is also designed to operate within the Environment Agency's approach to environmental risk assessment, so that the effort involved in undertaking HIA in a given situation can be matched to the risk of environmental impact associated with the proposed groundwater abstraction. The HIA methodology can be summarised in terms of the following 14 steps:

Step 1: Establish the regional water resource status.

Step 2: Develop a conceptual model for the abstraction and the surrounding area.

Step 3: Identify all potential water features that are susceptible to flow impacts.

Step 4: Apportion the likely flow impacts to the water features.

Step 5: Allow for the mitigating effects of any discharges, to arrive at net flow impacts.

Step 6: Assess the significance of the net flow impacts.

Step 7: Define the search area for drawdown impacts.

Step 8: Identify all features in the search area that could be impacted by drawdown.

Step 9: For all these features, predict the likely drawdown impacts.

Step 10: Allow for the effects of measures taken to mitigate the drawdown impacts.

Step 11: Assess the significance of the net drawdown impacts.

Step 12: Assess the water quality impacts.

Step 13: If necessary, redesign the mitigation measures to minimise the impacts.

Step 14: Develop a monitoring strategy.

The steps are not intended to be prescriptive, and the level of effort expended on each step can be matched to the situation. Some steps will be a formality for many applications, but it is important that the same thought-process occurs every time, to ensure consistency. The methodology depends heavily on the development of a good conceptual model of the aquifer and the abstraction itself. The steps of the methodology are followed iteratively, within a structure with three tiers, and the procedure continues until the required level of confidence has been achieved. Advice is also given on how to undertake HIA in karstic aquifers and fractured crystalline rocks.

1 Introduction

1.1 Purpose of this report

This report describes a methodology and suite of tools for assessing the hydrogeological impact of groundwater abstraction. With the coming into force of the Water Act 2003, there are now three types of abstraction licence:

- ***Temporary licences:*** for water abstraction for any purpose over a period of less than 28 days.
- ***Transfer licences:*** for water abstraction to transfer water from one source to another without intervening use, or to transfer water within the same source for dewatering activities in connection with mining, quarrying, engineering works etc, again without intervening use.
- ***Full licences:*** for water abstraction for any other licensable use.

The main purpose of this report is to provide practical guidance on how to assess the hydrogeological impact of existing or proposed groundwater abstractions, for those who are preparing technical material to support applications to the Environment Agency for full licences. Similar guidance for those preparing applications for transfer and/or full licences in connection with dewatering operations at quarries, mines and engineering works can be found in a separate report (Boak *et al* 2006).

Both reports build on work carried out under an earlier Environment Agency R&D Project (W6-071) on risk-based decision making for water resources licensing, reported by Faulkner *et al* (2003).

1.2 The regulatory context

The Water Act 2003 has introduced significant changes to the abstraction licensing system in England and Wales. It has changed the licensing system in six key areas (Environment Agency 2003a):

i. All small abstractions, generally under 20 m^3/d, will not need a licence.

ii. Dewatering of mines, quarries and engineering works, water transfers into canals and internal drainage districts, use of water for trickle irrigation and abstractions in some areas that used to be exempt now need a licence.

iii. Administration for making applications, transferring and renewing licences will be made simpler, reducing barriers to the trading of water rights.

iv. All abstractors now have a responsibility not to let their abstraction cause damage to others. From 2012, the Environment Agency will be able to amend or revoke permanent abstraction licences without compensation if they are causing serious damage to the environment.

v. There is an increased focus on water conservation. Water companies now have duties to conserve water, and all public bodies need to consider how to conserve water supplied to their premises.

vi. Water companies must develop and publish water resources management and drought plans. The Environment Agency can encourage transfer of water resources between water companies, and recover costs associated with drought orders and permits.

Even with all these changes, several other pieces of legislation and regulatory regimes remain highly relevant to the assessment of the impacts of groundwater abstraction on water resources and the water-related environment. These include the Habitats Directive, the Water Framework Directive, and Catchment Abstraction Management Strategies (CAMS). Further information on these can be found in Appendix 1.

1.3 The abstraction licensing process

The methodology for hydrogeological impact appraisal (HIA) described in this report is designed to fit into the Environment Agency's abstraction licensing process. This process can be summarised in terms of a typical sequence of events (for new applications), as follows:

i. *Initial enquiry to the Environment Agency:* Many enquiries for new abstractions are received by the Environment Agency, and a significant number are dropped at an early stage. Enquirers are usually discouraged from submitting formal applications for licences until the Section 32(3) procedure has been carried out (see below). If there is no chance of an abstraction licence being granted (if the enquiry concerns a groundwater management unit that is already over-abstracted, for example), the enquirer is informed at this point. If necessary, the Environment Agency will give advice on the type of licence that should be applied for (temporary, transfer, or full).

ii. *Application for Section 32(3) consent:* This procedure (under Section 32(3) of the Water Resources Act 1991) is triggered by an application from the applicant. Among other things, the Environment Agency needs to know the proposed maximum daily and annual average rates of abstraction, when within the year the water will be abstracted, whether and where water will be returned to the environment, what the water is to be used for, and the proposed borehole design.

iii. *Water features survey:* The applicant then carries out a water features survey within a radius specified by the Environment Agency, looking for boreholes, wells, ponds, lakes, springs, seepages, wetlands, watercourses, etc. The findings are reported using a standard format. The applicant is usually provided with details of existing licensed abstractions within the search radius by the Environment Agency.

iv. *Section 32(3) consent issued:* Assuming that existing water users and conservation sites are adequately safeguarded, a consent is issued to construct the borehole and carry out a pumping test. The results of the water features survey are used to specify which features should be monitored during the pumping test. Conditions are also laid down on maximum pumping rates, required duration, and arrangements for discharging the water during the test.

v. *Pumping test:* The objectives of the test pumping programme include proving the yield of the borehole, and providing enough information for the effects of the abstraction on the environment and other water users to be determined (see Appendix 2 for an extended discussion of test pumping). The applicant is usually expected to analyse the data from the test, and to submit an interpretative report.

vi. *Licence application and determination:* Assuming there have been no fatal flaws in the process so far, the applicant now submits a formal licence application, to be processed by the Environment Agency. This involves (for proposals over 20 m^3/d anyway) advertising the application, consideration of any objections from the public, and consultation with statutory consultees such as water companies. As mentioned above, the Water Act 2003 has exempted all abstractions below a generic threshold of 20 m^3/d from licensing. However, this threshold may be varied up or down, depending on local conditions, provided it is technically appropriate to do so and certain legal requirements are fulfilled. Finally, the application is either rejected or the licence granted (often with conditions attached).

In practice, the actual process may vary from case to case, depending on the local circumstances. It is important to realise that at no stage until the final decision does the Environment Agency commit itself to granting a licence (or indeed refusing it). However, it is in everybody's interest for the process to be stopped as early as possible if refusal is likely to be the final outcome. In practice, the main hydrogeological work (both by the applicant and by the Environment Agency) is carried out during the Section 32(3) procedures. By the time the formal licence application is made, the process is largely concerned with legal procedures of consultation and receiving objections.

So where does the HIA methodology fit in? The exact approach will of course depend on many factors, such as the water resource availability status of the groundwater management unit, whether the application is for a new abstraction or a variation to an existing one; and whether reliable conceptual and/or numerical models of the aquifer are already available. However, generally speaking, the HIA methodology can be commenced as soon as the basic details of the proposed abstraction are known, and it will be seen that the water features survey and the pumping test play an important part. Links between these and the steps of the HIA methodology will become clear in Section 4.

2 Basic concepts

2.1 Introduction

Before delving into the detail of the HIA methodology, it is useful to discuss some basic concepts that are fundamental to HIA, namely uncertainty, risk, and conceptual modelling. This section also deals with some common misconceptions about the way in which groundwater abstractions behave. Unfortunately, there is no magic tool for assessing the hydrogeological impacts of groundwater abstraction; the emphasis is on developing good conceptual models, taking uncertainty and risk into account, and using appropriate tools and techniques to answer specific questions.

2.2 Uncertainty and risk

The Environment Agency's approach to environmental risk assessment is based on the guidelines published by the Government (DETR 2000). In these guidelines, the following definitions are given:

> ***Hazard:*** *a property or situation that in particular circumstances could lead to harm.*
>
> ***Risk:*** *a combination of the probability (or frequency) of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.*

In groundwater abstraction licensing, the hazard is the act of abstracting water, and the risk relates to potential impacts on the environment, or other impacts such as derogation of the rights of existing abstractors. In order to evaluate and use risk assessments effectively as a credible basis for decision-making, it is important to understand how different sources of uncertainty contribute to the final risk estimates. Uncertainty can affect all stages of risk assessment, and environmental scientists are increasingly being required to provide information on how certain their decisions are. Analysing the sources and magnitudes of uncertainties can help to focus discussion, identify knowledge gaps, and feed into decisions about risk management. Uncertainties generally fall into the following categories (DETR 2000):

- ***Model uncertainty:*** where models provide only an approximation of the real environment. Model uncertainty may have two components: (i) conceptual modelling uncertainty due to insufficient knowledge of the system; and (ii) mathematical model uncertainty arising from the limitations of the model selected in accurately representing reality.
- ***Sample uncertainty:*** where uncertainties arise from the accuracy of measurements or the validity of the sample (number and location of sampling points).
- ***Data uncertainty:*** where data are interpolated or extrapolated from other sources.
- ***Knowledge uncertainty:*** where there is inadequate scientific understanding of the processes involved.
- ***Environmental uncertainty:*** where the inherent variability of the natural environment leads to errors in our approximations. For groundwater

systems, this could be the variations in groundwater level and flow that occur due to natural variations in rainfall and evaporation.

Environmental uncertainty cannot be reduced, and knowledge uncertainty can only be reduced by scientific investigation. However, model, sample and data uncertainty can be reduced by the conceptual modelling process. All these types of uncertainty apply to HIA and making decisions about abstraction licences. Consider the example of deriving aquifer hydraulic parameters from pumping test results:

Model uncertainty: there may be very limited knowledge of the real configuration of the aquifer, for example, whether or not it is layered, or whether a confining layer should be regarded as leaky. In addition, the test results may be analysed using an analytical equation that is based on a very idealised model of the real situation. Sweeping assumptions (that the aquifer is of infinite extent, for example) are inherent in all analytical solutions. An aquifer that in practice contains many layers with different hydraulic properties will often be simplified in the model into one or two layers with averaged properties.

Sample: results from test pumping usually only represent a small sample in time and space of the overall behaviour of an aquifer. Depending on the length of the test, it is only sampling a limited volume of aquifer around the borehole, and there may only be results from one or two tests to work with. In addition, there may be inaccuracies in the equipment used to monitor the test (for example, the calibration of the flow meter used to measure discharge during the test).

Data: test pumping results from a 7-day or 14-day test are often extrapolated to make judgements about the long-term impacts of an abstraction. Aquifer parameters derived at specific points (boreholes) have to be interpolated to give spatially-distributed parameter values for the whole aquifer, or even one average value.

Knowledge uncertainty: there are many key scientific areas where there is still only superficial knowledge and understanding of how real systems behave. Examples from hydrogeology include river-aquifer interaction, the influence of groundwater on wetlands, the behaviour of saline-fresh water interfaces, and the behaviour of highly-layered aquifers.

Environmental uncertainty: it is recognised that aquifers are heterogeneous in practice, and that aquifer parameters such as transmissivity and storage coefficient vary spatially. In addition, hydraulic conductivity can vary in different directions (a condition known as anisotropy).

It can be seen therefore that uncertainty is involved in many ways even in a routine situation. The most important thing to realise here is that uncertainties combine to produce greater uncertainty. If a single value of transmissivity is assigned to an aquifer or groundwater management unit, then the uncertainty associated with that value is a combination of the types of uncertainty just described. This is not necessarily a problem, as long as the situation is recognised, and decisions are made taking into account the overall uncertainty.

Care should also be exercised when using average parameter values. To continue the test pumping example: imagine that two pumping tests have been conducted on different boreholes in the same aquifer; and different transmissivity values have been derived, say 200 and 600 m^2/d. In many test pumping reports this would lead to the statement that transmissivity varies from 200 to 600 m^2/d, and that an average value of 400 m^2/d is going to be used in subsequent calculations. However, this is making several assumptions: that 200 and 600 represent the extremes of the true range of transmissivities; that transmissivities can be arithmetically averaged; that the results can reasonably be applied to other parts of the aquifer; that the assumptions inherent in the analysis are appropriate, and so on. When assessing potential impacts of abstraction, all assumptions must be recognised and taken into account. It is often useful to undertake some form of sensitivity analysis in order to understand the effects of ranges in parameter values on derived quantities (see Box 2.1).

Box 2.1: Sensitivity analysis

Example of simple sensitivity analysis to illustrate the effects of ranges in parameter values on derived quantities, using the Theis equation for unsteady-state flow in confined aquifers (Kruseman and de Ridder 1990):

$$s = (Q/4\pi T).W(u)$$

where $u = r^2S/4Tt$, and W(u) is a function of u (commonly known as the well function), with s being the drawdown at a radius r from the pumping well at time t, in an aquifer of transmissivity T and storativity S, and abstraction taking place at a rate Q. Suppose that the equation is being used to predict the drawdown at a sensitive wetland, using aquifer parameters estimated from previous tests. The quantities Q, r and t are known with reasonable accuracy, and we are using estimated values of T and S to predict s. Let's say $Q = 1{,}000\ m^3/d$, r = 500 m, t = 100 days, $T = 400\ m^2/d$ and $S = 1x10^{-4}$. This gives a prediction for drawdown (s) of 1.63 m. The measured range for T might be 200 to 600 m^2/d (even ignoring the fact that the true range may be much greater), and let's say the range for S is from $5x10^{-5}$ to $5x10^{-4}$. Keeping S at the original value, using the extremes for T gives a range for s of 1.14 to 2.98 m. Keeping T at the original value, using the extremes for S gives a range for s of 1.31 to 1.77 m. However, combining the uncertainties (varying both T and S in the combinations that give the greatest extremes) results in a possible range for s of 0.93 to 3.26 m. Which drawdown turns out to be the 'true' value could have dramatic implications for the wetland.

Some types of uncertainty are easier to reduce than others. For example, drilling more observation boreholes for a pumping test, or conducting tests in several boreholes, will help to reduce the data and sample uncertainty; using a radial flow model with layers (as opposed to a simple analytical equation) to analyse the results will reduce the model uncertainty. However, reducing knowledge uncertainty may require extended scientific study; and environmental or natural uncertainty is impossible to reduce, and must just be recognised.

2.3 Conceptual modelling

Conceptual modelling is at the heart of both CAMS and the Water Framework Directive (see Appendix 1), and its importance to HIA cannot be overemphasised. In the water resources context, a conceptual model can be defined as a synthesis of the current understanding of how the real system behaves, based on both qualitative *and* quantitative analysis of the field data. Some people take the view that conceptual models are based upon a purely qualitative understanding, with quantitative assessment only coming in during subsequent analytical or numerical modelling. However, in this report, the term conceptual modelling definitely includes quantitative analysis.

A real hydrogeological system is so complex that it will never be possible to study everything in detail; a conceptual model is therefore bound to be a simplification of reality. The important question is to determine what needs to be included in the study and what can be safely ignored. In other words, what observed behaviour do we want the conceptual model to get right, and what don't we mind the model getting wrong? For example, if we are investigating the mechanisms that operate during periods of low flow in a Chalk stream, we may not mind being wrong about the mechanisms that operate during groundwater flooding events (Environment Agency 2002a). Or, when developing a regional groundwater resources model of a coastal aquifer we may choose to ignore the difference in density between fresh and saline water in order to simplify the mathematical representation. We may not mind being wrong about the exact behaviour of the fresh/saline water interface, because we are focussing on larger water resources issues.

Experience has shown that for most aquifer systems there is a small number of crucial factors that *must* be examined in detail, and if any one of these is ignored the conclusions may be seriously in error (Rushton 1998). The focus of the conceptual model should be on the identification of these crucial factors. Continuing the second example above, if the coastal model is of a small Caribbean island, then it probably *will* be important to get the relative positions of the fresh water lens and the underlying saline water right, in order to know how the fresh water can be abstracted without causing upconing of the saline water. For this purpose, relative density should definitely *not* be ignored. It is helpful to write down the purpose and specific objectives of the conceptual model, as this is invaluable for focussing effort on the right factors. With these comments in mind, the important characteristics of a conceptual model can be summarised as follows:

- It should concentrate on the crucial factors, that is, the features of the system that are important in relation to the purpose of the project.
- It is based on evidence; even though it is inevitably an approximation or simplification of reality, it must not contradict the observed evidence.
- It is a set of observations, explanations, working hypotheses and assumptions, bearing in mind that there may be more than one explanation for observed behaviour.
- It must be written down; this is a discipline that forces vague ideas to be formalised, and helps to identify weaknesses in reasoning or unjustified assumptions.
- It must be tested; this is an essential part of conceptual model development, as it forces hypotheses to be evaluated and alternatives found if necessary.

It is the last point, testing the model, where the numbers come in and the conceptual model becomes quantitative rather than just qualitative. If there is no quantitative testing, the degree to which the model represents the real system cannot be assessed. Testing with numbers also enables uncertainty to be explicitly addressed, which links conceptual modelling to risk assessment. Conceptual modelling is an iterative or cyclical process (Figure 2.1).

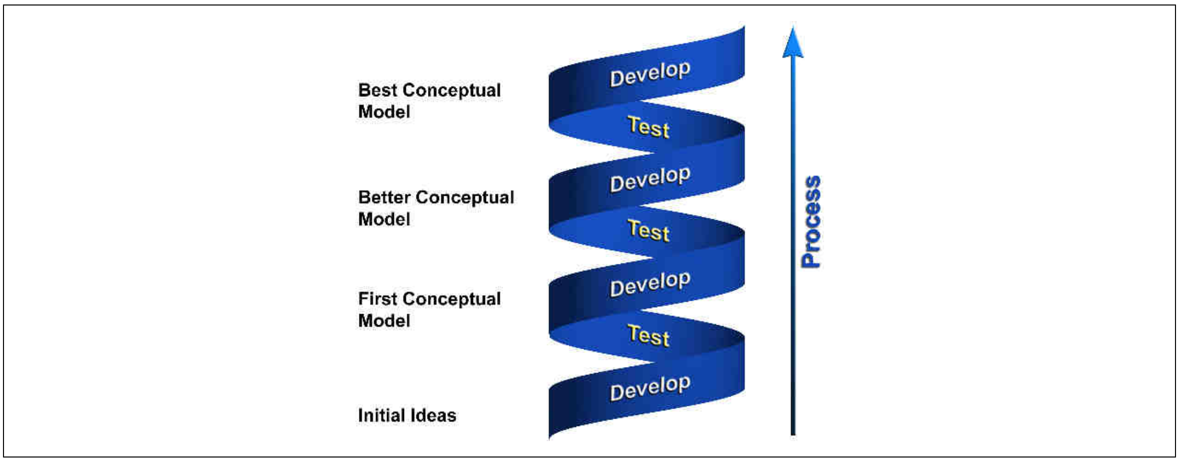


Figure 2.1 The development process for a conceptual model
(adapted from Environment Agency presentations)

The process of developing a conceptual model is as follows:

- Start with initial ideas, such as observations, hypotheses and areas of uncertainty, and write them down.
- Test the model, by for example doing some crude water balance calculations with long-term average values for the various water balance components.
- Based on the results of the testing, re-evaluate the model, rejecting some hypotheses, keeping some and developing some new ones, as necessary.
- Test the improved model, and then continue the cycle of re-evaluation and testing until the initial ideas become the best available conceptual model, as appropriate for the problem being addressed.

It is worth repeating the point that conceptual modelling is continuous and cyclical; it is a process, not a finished product. It is also important to realise that the degree of development of a conceptual model is determined by the availability of data, and the sophistication of the tools that have been used to test the model. Bredehoeft (2005) introduces the phrase 'hydrogeologic surprise', which he defines as the collection of new information that renders one's original conceptual model invalid. From limited empirical data, he estimates that such surprises occur in 20-30 per cent of model analyses. Rushton (2003) goes further, saying that it is his experience that in each modelling study at least one fundamental feature was not identified in the initial conceptual model (but became clear in subsequent modelling cycles).

Superimposed on the continuous cycle of model development and testing is a hierarchical or tiered approach, with basic, intermediate and detailed levels of model. These tiers can be described as follows:

> ***Tier 1 (Basic):*** Tested using lumped long-term average water balances and simple analytical equations, to arrive at a ‘best basic’ conceptual model.
>
> ***Tier 2 (Intermediate):*** Tested using more detailed data, such as time-variant heads and flows, and more sophisticated tools, such as seasonal or sub-catchment water balances (semi-distributed), analytical solutions (to investigate the impact of abstraction on river flows, for example), or two-dimensional steady-state groundwater models.
>
> ***Tier 3 (Detailed):*** Likely to be tested using a spatially-distributed and time-variant numerical groundwater model, calibrated and validated against historical data.

The tiered approach to conceptual modelling is illustrated in Figure 2.2, from which it can be seen that the conceptual model is refined within each tier from an initial understanding to the best available model. The diagram also illustrates that associated with each tier is an assessment of the risk involved in the decision being made.

As the investigation progresses through the tiers, the cost increases, but so does the confidence in the model. As confidence increases, so the uncertainty decreases, and the investigation should continue up the tiers until the uncertainty (and therefore the risk) has been reduced to an acceptable level. The level that is considered acceptable depends of course on what the conceptual model is being used for. Common sense must be used, and in general, decisions should be made with the simplest model possible, with refinement of the model required only if a decision cannot be made because the uncertainty is still too great.

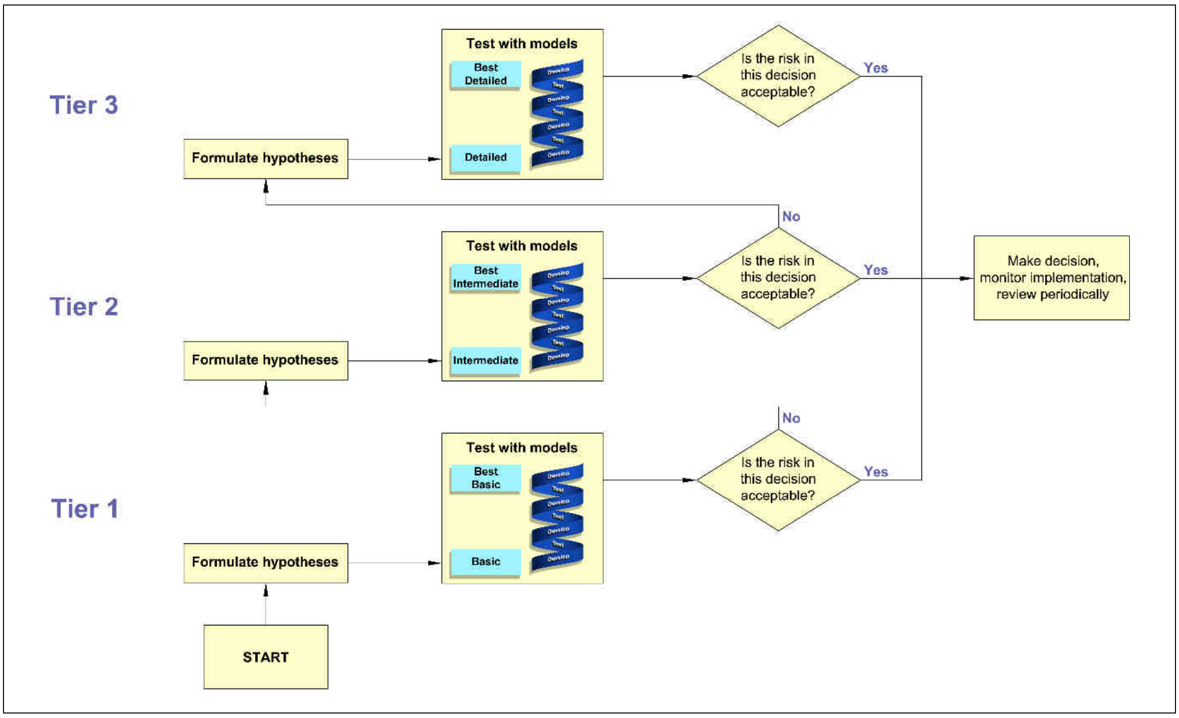


Figure 2.2 Tiered approach to conceptual modelling
(adapted from Environment Agency presentations)

2.4 Common misconceptions

It is assumed that the people undertaking HIAs have some basic hydrogeological knowledge or experience, even though they may not be specialist hydrogeologists. However, there are some common misconceptions about groundwater abstractions and the way in which they behave. Examples of such misconceptions are as follows:

- A groundwater abstraction will only have an impact, or the impact will be greater, on water features that are downstream (down the regional hydraulic gradient).
- Impacts of groundwater abstractions will be reduced or limited by recharge, or even that recharge will 'fill up' the cone of depression around a borehole.
- There will only be an impact if there is increased drawdown.
- Results from short pumping tests can safely be extrapolated in space and time.
- Faults are impermeable barriers to flow.
- The drawdown predicted by the Theis equation after 200 days represents drought conditions.

In order to counter these misconceptions, and prepare the ground for explaining the methodology for HIA, some basic principles of groundwater behaviour will now be described briefly. These are not intended to be exhaustive technical explanations, but primarily to provoke thought. Some of the ideas are admittedly counter-intuitive, but they are so important that the reader is directed to two excellent papers, Theis (1940) and Bredehoeft *et al* (1982), if they wish to know more.

3 Background to the methodology

3.1 Development criteria

In developing the HIA methodology for groundwater abstractions, certain general criteria were applied. These were that the HIA methodology must:

- be risk-based; that is, the effort and resources used to assess the impacts should be matched to the level of risk of environmental damage.
- emphasise the importance of developing a robust conceptual model of the site that is continually reviewed and updated as new information is collected.
- be able to distinguish between impacts caused by changes in flow, and those caused by changes in water level, and deal with them appropriately.
- result in an appropriate level of on-going monitoring, targeted at the issues of real concern.
- if relevant, take into account the mitigation of impacts by the return of water to the groundwater or surface water system.
- be able to cope with a variety of spatial scales (regional and local, for example).

In addition, the HIA methodology is designed to be compatible with the Government's principles of modern regulation. Five principles to be applied to any modern regulatory regime have been set out by the Better Regulation Taskforce (Environment Agency, undated). The regime must be:

Transparent, with clear rules and processes;

Accountable, leading to decisions that can be justified;

Consistent, with the same approach being applied across sectors;

Proportionate, according to the risks involved;

Targeted, with a clear environmental outcome.

Many environmental impacts arising from a groundwater abstraction will occur close to the abstraction point, especially those caused by changes in the water levels in the surrounding aquifer. However, some impacts caused by changes in flow may occur many kilometres from the abstraction, months or even years after the abstraction has commenced. Most groundwater abstractions are ultimately at the expense of surface water flows, whether they induce additional leakage from rivers or intercept water that would otherwise have discharged to them. Hydrogeological investigations are often undertaken at two scales, regional and local:

Regional scale: typically at the level of groundwater management units, such as those used in the CAMS process, or groundwater bodies as defined by the Water Framework Directive. At this scale, the impact of an individual abstraction may be of little significance, but the cumulative impact of all the abstractions may very well be significant. Impacts at a regional scale are often due to changes in flow, and the focus of regional investigations is usually on overall water resources availability.

Local scale: sometimes referred to as the zone of influence of the abstraction, and much harder to define. It depends on many factors, such as the size of the abstraction, and the nature of the local hydrogeology. It will be seen later that defining the local zone of influence of the abstraction is an integral part of the HIA process. At the local scale, close to the abstraction, direct impacts of abstraction (on both flows and levels) are much more likely to be significant.

The focus of investigations when undertaking HIA is at the local scale, but the regional picture also has to be taken into account. Under certain hydrogeological conditions, for large abstractions or for confined aquifers, for example, the regional and local scales will sometimes merge. Suffice it to say at this point that the HIA methodology concentrates on the local scale, but moves out as far as is necessary to examine the most distant impacts.

3.2 Tiered approach

The HIA methodology is designed to operate within a tiered approach, which was introduced in Section 2.3, and will now be discussed further. The Environment Agency has chosen a tiered approach for the following reasons:

- It is in line with the Government's recommendations on environmental risk assessment (DETR 2000), which address the issue of having to make robust and defensible decisions on environmental matters in the face of significant uncertainty.
- It enables the level of effort to be matched to the risks associated with the decision being made. For example, when undertaking HIA, much greater effort is likely to be required for a public water supply abstraction in a major aquifer, close to some Ramsar sites, pumping large quantities of water, compared to a small abstraction for domestic supply, in an unproductive aquifer, with no sensitive conservation sites in the area.
- It minimises unnecessary expenditure on investigations to back up the HIA, because it allows regular assessments to be made of whether the uncertainty has been reduced to an acceptable level.

A rough guide to the level of effort associated with each of the three tiers is as follows:

Tier 1 (Basic): Conceptual model developed from information and data that are fairly easily available from published sources, bodies such as the Environment Agency, the British Geological Survey, and the Centre for Ecology and Hydrology, or the abstractor's own historical monitoring data. The conceptual model is typically tested using simple analytical equations, to arrive at a ‘best basic’ conceptual model. A Tier-1 assessment is likely to be required in virtually all cases.

Tier 2 (Intermediate): The sophistication of the conceptual model is increased by testing it using more detailed data, such as time-variant heads and flows. More detailed analytical solutions may be used (to investigate the impact of abstraction on river flows, for example), or two-dimensional steady-state groundwater models. Limited field investigations may be required to fill important gaps in the data. Tier-2 assessments are likely to focus on (and be limited to) specific areas of uncertainty that have been highlighted during Tier 1.

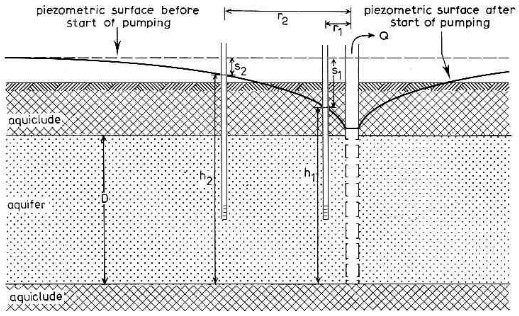
Tier 3 (Detailed): The conceptual model represents a high degree of understanding of the hydrogeological and hydrological system, and is likely to be tested using a spatially-distributed and time-variant numerical groundwater model, calibrated and validated against historical data. This is likely to require the collection of data from a wide range of sources, including more field investigations. It is likely that Tier-3 assessments will only be required in a relatively small number of cases.

It is not possible to be prescriptive when describing the tiers, and indeed it is preferable that as much flexibility as possible is retained throughout the process (the information and data requirements will become clearer when the HIA methodology itself is described in Section 4).

Box 3.1: Thiem and Thiem-Dupuit equations

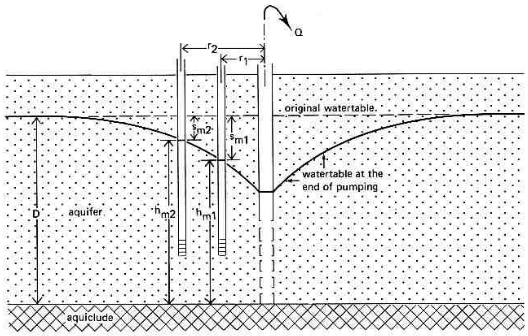
Thiem equation (steady-state confined flow)

$$Q = \frac{2\pi KD(h_2 - h_1)}{2.30\log(r_2/r_1)} = \frac{2\pi KD(s_1 - s_2)}{2.30\log(r_2/r_1)}$$



Thiem-Dupuit equation (steady-state unconfined flow)

$$Q = \frac{\pi K(h_2^2 - h_1^2)}{2.30\log(r_2/r_1)}$$



Both diagrams from Kruseman and de Ridder (1990).
Q = pumping rate [L^3/T]; K = hydraulic conductivity [L/T];
D = saturated aquifer thickness [L];
h_i = elevation of water table or piezometric surface [L];
s_i = drawdown [L]; r_i = radius [L];
where L = length and T = time.

These equations are given here in their most general form, but they can be used in other ways. For example, if only one piezometer is available (at distance r_2 in the diagrams above), the water level in, and radius of, the pumping well (h_w and r_w) can be used instead of the 'inner' piezometer. However, care must be taken to allow for the effects of well losses and the breakdown close to the well of some of the assumptions built into the equations. The radius of influence (R_o) of a groundwater abstraction, defined as the radius at which drawdown is zero, is sometimes estimated by setting h_2 to the original water table or piezometric surface, if all other parameters are known.

3.3 Tools and techniques

There are many tools and techniques available that can be of great help when undertaking HIA. Unfortunately, there is no single tool or technique that covers everything, so it is a question of using technical judgement on when to use which tool or technique. It is also a question of being realistic about the limitations and built-in assumptions of each tool or technique. Let us now look briefly at some possible tools and techniques.

3.3.1 Tier 1 tools

The main tools likely to be used at the level of Tier 1 are simple analytical equations and the analysis of test pumping results. Two good examples of useful analytical equations are the Thiem equation and Thiem-Dupuit equation for steady-state flow in confined and unconfined aquifers respectively (Kruseman and de Ridder 1990). The equations and parameters are shown in Box 3.1.

Such equations must always be used with care, bearing in mind all the assumptions on which the equations are based. As part of this project, over 20 analytical equations have been assembled from various sources (textbooks and other publications), and put into an MS Excel spreadsheet for convenience, for use when assessing the impacts of groundwater abstractions. Many

4 The HIA methodology

4.1 Overall HIA structure

The HIA methodology is presented as a sequence of steps (Box 4.1), which should be followed for all groundwater licence applications. This may at first seem onerous, but the process has a logical progression, and the steps impose some discipline on each appraisal. At the same time, the steps in the process are not prescriptive, and the level of effort expended on each step can be matched to the situation. In other words, some steps will be a formality for many applications, but it is very important that the same thought-process occurs every time, to ensure consistency.

In many cases, the process will be able to be streamlined. For example, it is recognised that the impacts of some groundwater abstractions are mitigated, by a proportion of the abstracted water being discharged back into the environment, for example. The HIA methodology assesses the impacts as if there were no mitigation, then adds back in the beneficial effects of mitigation. This is done because the locations and timing of the abstraction impacts may be different from the beneficial effects of the mitigation, and the mitigation measures may need to be optimised. Obviously, if all the abstracted water is consumed, and there are no mitigation measures, then Steps 5, 10 and 13 (see Box 4.1) can be omitted.

The steps will now be considered in more detail. When following the procedure, the tiered approach described earlier should always be kept in mind, and the procedure repeated as many times as necessary (iterations within the tiers and moving through the tiers) until the required level of confidence has been achieved. Also, the basic principles established earlier (recharge makes no difference to impacts; impacts are the same upstream and downstream; and the abstraction spreads until it has stopped an equal amount of water leaving the aquifer) should be kept very much to the fore.

Box 4.1: The HIA methodology

Step 1: Establish the regional water resource status.

Step 2: Develop a conceptual model for the abstraction and the surrounding area.

Step 3: Based on the conceptual model, identify all potential water features which are susceptible to flow impacts.

Step 4: Apportion the likely flow impacts to the water features, again based on the conceptual model.

Step 5: For the relevant water features, allow for the mitigating effects of any discharges associated with the abstraction, to arrive at net flow impacts.

Step 6: Assess the significance of the net flow impacts.

Step 7: Define the search area for drawdown impacts.

Step 8: Identify all the features within the search area which could potentially be impacted by drawdown.

Step 9: For all these features, predict the likely drawdown impacts.

Step 10: For the relevant water features, allow for the effects of any measures being taken to mitigate the drawdown impacts.

Step 11: Assess the significance of the net drawdown impacts.

Step 12: Assess the water quality impacts.

Step 13: If necessary, redesign the mitigation measures to minimise the flow and drawdown impacts.

Step 14: Develop a monitoring strategy, focussing on the features likely to experience flow or drawdown impacts.

C Environment Agency, Groundwater Risk Assessment for your Environmental Permit

Guidance

Groundwater risk assessment for your environmental permit

How to carry out a groundwater risk assessment as part of an application for an environmental permit.

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England (see guidance for Northern Ireland (https://www.doeni.gov.uk/articles/regulating-water-discharges), Scotland (https://www.sepa.org.uk/regulations/water/), and Wales (http://naturalresources.wales/apply-for-a-permit/water-discharges/?lang=en))

Contents

You may need to carry out a groundwater risk assessment to carry out activities that could directly or indirectly pollute groundwater. This is all water underground in the saturation zone (below the water table) and in direct contact with the ground or subsoil.

> Read the risk assessment overview (https://www.gov.uk/guidance/risk-assessments-for-your-environmental-permit) to find out if you need to carry out a groundwater risk assessment as part of your permit application.

If you're carrying out groundwater risk assessments, you should be an industry professional with an appropriate accreditation, or working under the supervision of one, towards an accreditation such as a:

- chartered geologist
- Chartered Institution of Water and Environmental Management (CIWEM)
- chartered engineer

You should read this guide along with:

- Protect groundwater and prevent groundwater pollution (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution)
- Groundwater protection technical guidance (https://www.gov.uk/government/publications/groundwater-protection-technical-guidance)
- Groundwater activity exclusions from environmental permits (https://www.gov.uk/government/publications/groundwater-activity-exclusions-from-environmental-permits)

When the Environment Agency will do your risk assessment for you

The Environment Agency will usually carry out a risk assessment for you if you're applying for a permit to discharge to ground:

- waste sheep dip, pesticide, or pesticide washings (liquid waste left over from washing or cleaning equipment used to apply pesticides)
- less than 15 cubic metres of treated domestic sewage, for example from a septic tank or small sewage treatment plant in non-sensitive areas – discharges within sensitive areas, such as a groundwater Source Protection Zone 1 (SPZ1) require you to undertake the risk assessment and submit to the Environment Agency for approval

Contact the Environment Agency before you apply for a permit.

Develop your conceptual model

You need to develop a conceptual model. This will form the basis for your risk assessments and will help you successfully evaluate environmental risks.

You'll need to develop and refine your model iteratively within each level of risk assessment you carry out.

Conceptual models for groundwater protection describe important hydraulic, hydro-chemical and biological processes that are at work in the soil, the unsaturated zone and the groundwater itself.

Your model should describe potential environmental impacts associated with the site, and any uncertainties in how the activity will interact with the hydrogeological setting. The nature and scale of these uncertainties will determine the need for any subsequent site investigations and guide the development of any monitoring programmes.

What your model should show

Your model should aim to demonstrate the:

- physical and chemical nature of the discharge or source of contamination (installation or contaminated part of the subsurface)
- physical and chemical characteristics of the aquifer
- subsurface processes (for example dilution and degradation) that act on the pollutant as it moves down towards the water table or moves within the groundwater flow
- location of all the receptors and their relationships to groundwater flow
- environmental standards (for water quality) that apply to the receptors and by which harm can be measured, as well as criteria to protect groundwater ecosystems

As pollutants often travel through the unsaturated zone to reach groundwater, you should include the processes acting on pollutants in the unsaturated zone where appropriate.

The conceptual model must explicitly identify whether there is potential for a direct or indirect input (https://www.gov.uk/government/publications/groundwater-protection-technical-guidance/groundwater-protection-technical-guidance#inputs) of any hazardous substances or non-hazardous pollutants to groundwater. All hazardous substances and non-hazardous pollutants (with the exception of ammoniacal nitrogen, ammonium and suspended solids) are known as specific substances. If your discharge includes specific substances, a specific substances assessment will be needed as part of your risk assessment.

If you identify the potential for a direct discharge in the conceptual model and risk screening stage, then you must carry out a risk assessment that is correspondingly more detailed.

The main stages to developing an effective conceptual model include:

- a desk study and site reconnaissance – this should provide enough information to develop an initial iteration of the conceptual model
- site investigations to test and refine the model if necessary
- environmental monitoring to validate the model if necessary
- identification of any important source-pathway relationships on site, including relevant compliance points, and any environmental standards associated with them

How to carry out a desk study

The desk study examines the environmental setting and any potential contamination from past activities on or next to the site where the activity is proposed.

> You can find more guidance on the development of desk studies and ground investigations in the British Standards Institution’s code of practice for ground investigations (BS 5930:2015) (http://shop.bsigroup.com/ProductDetail/?pid=000000000030268443).

Collect together all available and relevant information to characterise the site and its surroundings from literature, public registers and site reconnaissance.

Sources of information include:

- historical maps and plans
- geological maps, cross-sections and schematic diagrams
- any available ground condition reports, or pre-existing soil and groundwater testing

- MAGIC map (http://magic.defra.gov.uk/MagicMap.aspx) for the location of any Source Protection Zones (SPZ), surface water features on or close to site, groundwater vulnerability, aquifer type or any Safeguard Zones (SgZs) – find under designations, land based non statutory designations
- British Geological Survey (http://www.bgs.ac.uk/research/groundwater/quality/home.html) for hydrological or hydrogeological (https://www.bgs.ac.uk/products/hydrogeology/home.html?src=topNav) information for that location, such as groundwater levels, groundwater chemistry
- Ordnance Survey (https://www.ordnancesurvey.co.uk/) for surface water features on or close to site, direction and rate of flow of surface water
- local authorities (https://www.gov.uk/find-your-local-council) and the Environment Agency's water resource licensing for hydraulic gradients, known abstraction points or wells, and depth to groundwater table with any known seasonal variations
- site walk-over reports, for example for direction and rate of flow of surface water

See the guidance for an understanding of the hierarchy of groundwater protection (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#sensitive-groundwater-locations).

Water features survey

You should undertake a water features survey to include the details of any private and licensed groundwater abstractions in the vicinity of the proposed activity including their:

- location on a map
- use (for example potable water supply or water for food manufacturing)
- rate at which they are licensed to abstract

The search radius for these will depend on the activity, but typically should be about 1 km radius from your discharge area.

Where the geology and hydrogeology of the area is layered, you need to ascertain the construction details of wells and springs to check whether the abstraction is from a shallow vulnerable layer or deeper, confined and protected layer.

Your water features survey should also include information on surface water receptors.

The desk study will identify any uncertainties related to both the activity and the site's hydrogeological setting, and how these might interact. The nature and scale of these uncertainties will determine your need for site investigations and guide the development of any site investigation programme.

Use this information to form an initial site conceptual model. This is an iterative process and as you get further site-specific information, you'll need to review and refine your model.

You should get preliminary views from the Environment Agency and other interested parties (such as local authorities) through a pre-application meeting using the initial site conceptual model as a basis for discussion. You may need to update your conceptual understanding of the activity and its potential impact on the environment accordingly.

You can then use this information to produce a more detailed conceptual model.

Sources, pathways and receptors

As part of your desk study, you need to research how your activity may be a 'source' of pollution (https://www.gov.uk/guidance/control-and-monitor-emissions-for-your-environmental-permit#pollution) to groundwater, the 'pathways' that the pollution could take to reach groundwater from your site, and the potential groundwater ‘receptors’ that could be affected by that pollution.

For example:

- sources – such as discharging treated sewage effluent to ground, landfill or other permanent deposits of waste on land (for example, for recovery)
- pathways – such as through engineered measures (a landfill lining system or infiltration system), or via contaminants passing through the unsaturated zone and saturated zone
- receptors – such as abstraction boreholes used for drinking water, the ecosystem dependent on the groundwater, the groundwater itself, or any other conservation site, like a Site of Special Scientific Interest (SSSI)

Research the source

You need to research and model both hazardous substances and non-hazardous pollutants that are likely to be present depending on the type of activity being proposed. For example, a landfill source will need to include a range of hazardous substances and non-hazardous pollutants. The risk assessment for land spreading of domestic treated sewage effluent may only need to include a limited range of non-hazardous pollutants.

You can read guidance on:

- which discharges are excluded from environmental permitting (https://www.gov.uk/government/publications/groundwater-activity-exclusions-from-environmental-permits)
- what hazardous substances (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#hazardous-substances) and non-hazardous pollutants (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#non-hazardous-pollutants) are

For some activities there may only be a single substance on which any subsequent risk assessment should focus, for example land spreading waste sheep dip.

Activities involving discharges (such as landfill) with many potentially polluting substances need a more complex risk assessment which usually needs site-specific data.

You’ll need to include a section in your risk assessment stating why you decided which substances to model.

Understand the pathways

You’ll need a basic understanding of the possible pathways the pollutant may take (and the factors that affect flow along these pathways) before you can identify likely receptors.

Effective rainfall and recharge

Effective rainfall is the proportion of rainfall that does not run-off directly to surface waters, evaporate or get taken up by vegetation, but which percolates into the ground and ‘recharges’ underlying aquifers. A change in the amount of effective rainfall will alter the rate of recharge and the flow of any contaminants. Different types of aquifer also have different recharge characteristics.

You need to investigate whether effective rainfall is an important consideration for your activity and its proposed location.

If it is, you need to estimate how much becomes recharge (expressed as mm of rain per year) as part of your risk assessment.

Drainage, flood risk and surface water features

You need to research surface water features (wetlands, ditches, streams, rivers, estuaries or coastal waters) that may:

- influence or interact with groundwater flowing from beneath the site
- receive drainage (or are a receptor) from your discharge area

Geology and hydrogeology

The unsaturated zone is where (ideally) the concentration of all hazardous substances in any discharge is attenuated to below detectable levels before it enters groundwater (the saturated zone). In addition, the concentration of all non-hazardous pollutants should have been sufficiently reduced through attenuation, degradation and dilution to prevent pollution after mixing with groundwater.

You can find more guidance on the hierarchy of groundwater protection (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#sensitive-groundwater-locations).

Your conceptual model will normally include a description (geological nature and thickness) of the soils (including fill material), strata and rocks separating the activity from the groundwater. You can get this information from regional maps (normally 1:50 000 scale from the British Geological Survey) and using logs from any boreholes or excavations in the vicinity of the activity. It's important that you describe the spatial variability in the location, nature or thickness of such strata. You should do this by including a geological map and cross section(s) in your groundwater risk assessment.

You must provide as part of your conceptual model:

- a description of any engineered barriers in terms of their nature (including clay, sealed concrete surface) and thickness separating the discharge from underlying natural ground or historically placed fill (such as landfill liners and sand filters beneath infiltration systems)
- a description of the groundwater vulnerability (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#groundwater-vulnerability)
- logs of boreholes (or wells) or excavations (such as trial pits) that have been constructed in the vicinity of your discharge, and that provide details on what lies beneath (include the logs and a plan of the site showing the locations of these boreholes)
- a description of any man-made (for example unsealed boreholes and wells, foundations and piles from buildings and structures, and mine shafts) and karst or karstic features (for example sinkholes, pipes, large fissures and cave systems) that could provide rapid pathways between the activity and groundwater
- information on the thickness of the unsaturated zone and, for some activities, measurements of water levels in wet and dry periods from boreholes or wells – seasonal variations are often important for specific types of aquifer, such as chalk

You may need to monitor the site to find out the typical maximum upper level of the saturated layer of the unconfined aquifer, if the records show uncertainty about what the maximum groundwater levels is likely to be.

You may also need to examine the effect of non-typical maximum groundwater levels in areas sensitive to groundwater flooding, or those with a high water table, to see if the likely effect on groundwater levels during periods of prolonged rainfall affects the overall risk that the activity presents to water quality.

If you need to carry out a quantitative assessment, you'll also need to provide information on the moisture content of the unsaturated zone and saturated effective porosity of the different soils and rocks.

Character and importance of the aquifer

You need to investigate the character and importance of the aquifer at your site as part of your conceptual model. Aquifers differ in the way they transmit water to springs, wells, boreholes and rivers. Locally their importance in providing water to receptors also varies as does their vulnerability to pollution.

You can read guidance on aquifers (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#geological-characteristics).

You need to define the character and importance of the aquifer by:

- using a hydrogeological assessment to investigate the aquifer's general capacity to transmit water
- carrying out a water features survey
- describing whether the aquifer transmits water by intergranular flow, fracture flow or by dual porosity flow
- describing the background quality of the water – you'll need to provide monitoring data from boreholes around the proposed activity for some assessments
- including the presence of any geological layering or preferential pathways (for example, faults) within the strata that could affect flow and mixing

Direction and rate of groundwater flow

The direction and rate of groundwater flow are important for indicating:

- in which direction receptors may be at risk
- the ability of the underlying groundwater to dilute the concentrations of any non-hazardous pollutants
- the rate at which any residual pollutants could move towards the receptors

You need to provide the direction of groundwater flow in your conceptual model. This should be based where possible on gradients derived from water level measurements in boreholes, but in the absence of these you can use published maps. As a last resort, you can infer the direction if you cannot find either of these – groundwater usually flows naturally from hills to rivers.

You need to consider whether your activity will affect the natural flow gradient and whether the direction of groundwater flow may change seasonally.

Other potential future influences on the direction of groundwater flow could be from:

- mine water rebound (the flooding back of deep mines)
- stopping quarry dewatering
- changes in borehole abstraction regimes

Identify the receptors

You must identify all relevant receptors.

The receptors are the actual, or potential (plausible) future, uses of groundwater that receive their flow, at least in part, from the vicinity of the discharge.

Main receptors include:

- groundwater as a resource in aquifers, including all current abstractions from groundwater and all feasible future uses
- discharges from groundwater, such as springs and base flow to rivers
- surface watercourses, lakes and ponds

- wetlands and groundwater dependent ecosystems
- estuaries and foreshore environments

If you cannot identify a specific groundwater receptor in the vicinity of the groundwater resource, then you should aim to protect the resource itself. In these cases, you should create a surrogate receptor (such as a hypothetical abstraction borehole) and assign it the relevant environmental standard which must be met.

You need to take into account the sensitivity of the receptor, the timescale necessary for the assessment and the consequences of any impact within the risk assessment.

If surface water is a possible receptor you need to research:

- the probability that there is hydraulic continuity between groundwater and surface water
- stream and river water quality information (for example chemical and biological status)
- flood risk and presence of indicative flood plains (flooding could lead to contamination of surface waters or more rapid movement of pollutants to groundwater)

If there is a potential risk to groundwater and specific receptors, you need to assess how to protect receptors through the use of compliance points.

The risk assessment also needs to consider the potential future use of groundwater. This should include a discussion with the Environment Agency about:

- resource potential (yield and quality)
- planned exploitation
- likelihood and feasibility of water resource development

Carry out a site investigation

You'll need to carry out a site investigation for some activities.

You should always carry one out for:

- landfill activities and other permanent deposits of waste on land
- higher risk activities such as a complex sewage effluent discharge

This will be confirmed in a pre-application discussion with the Environment Agency.

Site investigation can include soil and water sampling and the excavation of trial pits including drilling, construction, testing and sampling of boreholes. You can find more guidance in the British Standards Institution's code of practice for ground investigations (BS 5930:2015) (http://shop.bsigroup.com/ProductDetail/?pid=000000000030268443).

How to present your conceptual model

Use your knowledge from carrying out your desk study and establishing the source-pathway-receptor relationship to produce your conceptual hydrogeological model.

You can present your model in a number of different ways. The aim is to:

- present the characteristics of the site
- provide a systematic indication of the risks that your activity presents
- identify any uncertainties, further assessment needs or other actions

The main approaches – which you can combine – are:

- a written description of the site
- tabular or matrix description
- a drawing or other diagrammatic illustration

One of the clearest ways of representing a conceptual model is on an annotated hydrogeological conceptual model plan (a map and cross section). The cross section should be oriented in the direction of groundwater flow – see an example of a hydrogeological conceptual model plan (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/466621/hydrogeological_conceptual_model_plan.pdf) (PDF, 68.9KB, 1 page) .

Refine your model

You need to update and refine your model throughout the assessment as you get more data or your parameters change. You should aim to include as much data and remove as much uncertainty from the processes of the model as you can.

Use a tiered approach to your risk assessment

You should carry out your risk assessment after you've developed your conceptual hydrogeological model.

You should follow a 'tiered approach' to your risk assessment. This means that the greater your risk of groundwater pollution is, the more detailed assessment you undertake. You can stop your risk assessment at any stage if you obtain enough information to demonstrate that your activity does not pose a pollution risk to groundwater.

By adopting this method, it should ensure that the cost, time and effort you put into your risk assessment are proportional to the effort or measures needed to make the risks from an activity acceptable.

The 3 tiers are:

- Tier 1 – qualitative risk screening – investigate what the risks are, whether more detailed assessment is needed and what that would need to focus on (risk prioritisation)
- Tier 2 – generic quantitative risk assessment – to collect more information so you can make an informed decision on the risk posed by the site – you'll also need to identify your compliance points
- Tier 3 – detailed quantitative risk assessment – to collect more information and formulate a plan if there are clear source-pathway-receptor relationships

For each tier of assessment, you should assess and report the following considerations:

- identify the consequences
- estimate the magnitude of the consequences ('impacts')
- estimate the probability of the consequences ('impacts')
- evaluate the significance of the risk

Identify compliance points

As part of the overall risk assessment process you'll need to identify compliance points.

The compliance point is the point along the groundwater flow pathway where the defined target concentration (compliance limit or value) must not be exceeded, as this would represent an unacceptable risk of harm to the receptor. The compliance point may be the receptor itself or a specified point along the source–pathway–

receptor linkage (for example, within an aquifer nearer to the contamination source). Alternatively, it may represent pore water in the soil zone.

The location of the compliance point will depend on the circumstances, the level of assessment and the sensitivity of the receptor. The compliance point may be a virtual point for the purpose of predictive assessments (modelling) or it may be a physical monitoring point (such as a borehole or spring).

A compliance point lets you:

- calculate an acceptable concentration of pollutant and volume of discharge that complies with environmental standards at a receptor
- decide where to put a monitoring point (for example at an observation borehole or natural spring) to check that you're complying with your permitted discharge (under the Environmental Permitting Regulations 2016 this is known as requisite surveillance)

You can set a limit on your compliance points which can be used as a value to trigger action (at a physical monitoring point). If the limit is exceeded you must take action because there is evidence of a polluting discharge that could result in a breach of a compliance limit.

Where to put your compliance points

You can set a compliance point at the receptor itself but this may not be possible or desirable. You may want to set the compliance point between the point of discharge and the receptor. If so, you should assess it using criteria that predict the effects of dilution, attenuation and degradation, to protect the downstream receptors.

If your compliance point is also your physical monitoring point, you may need to site it closer to the discharge than the receptor to:

- be sure the monitoring takes place near enough to the discharge's zone of influence (the area of aquifer that has the potential to be impacted by the discharge)
- get advance warning of the development of any contaminant plume – data can then be gathered on the contaminant flux to protect the receptor before any environmental threshold is breached
- overcome constraints you have on accessing any sampling points

If the receptor is not an abstraction point, but could be one in future, you should set a compliance point that protects the nearest point where you reasonably expect abstraction could take place. This may be subject to practical constraints.

Where there is no plausible use of groundwater closer to the point of discharge use the following to form your pollution assessment:

- existing abstractions
- natural discharges
- other passive uses of groundwater

Setting the compliance limit

The target concentration (also known as a compliance limit) is a concentration at the compliance point that must not be exceeded. Provided the target concentration is met, the relevant environmental standard for the receptors should also be met or complied with.

Where the compliance point is the receptor, the target concentration will be set as the relevant environmental standard or natural background groundwater quality.

A compliance value can be:

- theoretical if used during predictive modelling
- a limit set in a permit for physical monitoring

Decide which environmental standards to use

Tailor the environmental standard to protect the use of the identified aquifer at risk. The Water Framework Directive (standards and classification) Directions (England and Wales) 2015 sets out values for assessing the status of groundwater bodies. These standards should not be used as part of site specific (local) investigation. They may, however, prove useful as overall indicators of groundwater quality when protecting groundwater dependent wetlands.

The following standards are often used as surrogates to represent a protection of groundwater relevant to the current or intended use of the aquifer (for example for strategic potable water resources, or base flow support to river flows):

- Drinking Water Standards (DWS) which are maximum acceptable concentrations in consumer supplies after treatment
- Surface Water Environmental Quality standards (EQS) which are set to protect the ecology in rivers, lakes, estuaries and coastal waters

However, the inappropriate use of standards intended for other purposes can lead to over or under-protection of the resource. You should only use values from other regimes (such as DWS or EQS) after you've carefully considered whether or not their inclusion is relevant to the local circumstances

Include other factors such as the natural background quality, or flow regimes. You may need to use a safety factor at the compliance point, suitable to the level of risk and accuracy in the assessment, to ensure that the receptor is protected.

Environmental standards for some contaminants (such as pesticides) can be very low, and their use ensures that there is unlikely to be any deterioration in background quality. For other contaminants, the standard may be significantly above background quality.

For example, the standard for chloride would be the drinking water maximum acceptable concentration of 250mg per litre which is much higher than the background concentration which is often less than 50mg per litre. In these circumstances it's possible that some local deterioration in groundwater quality may occur but not to the extent of allowing deterioration up to the DWS.

The acceptability of this should be assessed in relation to the:

- sensitivity of the receptor at risk
- current or potential use of the water resource
- degree to which the down gradient quality will deteriorate as a result

You may need to set the target concentrations at a level between an appropriate environmental standard and natural background level dependent on sensitivity of the site to sufficiently protect water quality for good quality aquifers which are either:

- extensively developed for potable supplies
- providing a significant flow component to surface water

You should take into account the compliance regime that the site will be operating under when setting a compliance limit.

Compliance regimes

A compliance regime is what you must do to meet compliance in your particular circumstance. The complexity of your compliance regime should depend on the overall risk, regulatory effort and necessary sampling frequency.

As a minimum, the compliance regime should set out the:

- compliance limit
- compliance location
- sampling frequency
- compliance statistic associated with the value (for example, a mean, percentile or absolute limit)
- time period for monitoring
- area the criteria apply to (for example at a point or as a spatial average over a groundwater body)

The regime should also include information on:

- detection limits
- precision of measurement

When identifying parameters to use in a compliance regime, you need to consider what pollutants are in your discharge. It’s often impractical to derive standards for all the discharge constituents, so select representative parameters, including some of the mobile constituents and likely key indicators of pollution for the type of discharge. You should take into account the likely fate and transport characteristics of the key components in your discharge.

Qualitative risk screening

Your qualitative risk screening should assess whether the potential discharge from your activity is acceptable and so will not require further assessment.

This could be because:

- the discharge has acceptably low concentrations of hazardous substances, or in concentrations that are the same as the natural background levels in the groundwater (whichever is the higher concentration)
- the discharge has concentrations of non-hazardous pollutants that are within the relevant environmental standards, or in concentrations that are the same as the natural background levels in the groundwater
- there’s a very low risk to groundwater-fed receptors due to the presence of unproductive drift or unproductive bedrock strata (and there are no aquifers present or near your activity) and remoteness from surface waters
- the volume or hydraulic loading rate of the discharge is so small such that only minimal dilution in underlying groundwater will be needed to avoid pollution by non-hazardous pollutants

Read the groundwater guidance for the definition of hazardous substances (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#hazardous-substances) and non-hazardous pollutants (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#non-hazardous-pollutants).

You should aim to get from your risk screening assessment:

- justification for the level (tier) of risk assessment you’re going to use next
- prioritisation of the most important source-pathway-receptor relationships for further evaluation

You must carry out a generic quantitative risk assessment if your risk screening suggests there’s an unacceptable risk.

How to carry out a qualitative risk screening

You can support your qualitative risk screening by carrying out some basic calculations in the following order.

1. Calculate the dilution factor for the discharge diluted by groundwater flowing in the mixing zone beneath the site.
2. Calculate the attenuation factor for each of your selected substances for downwards movement from your discharge to the point of arrival in groundwater beneath the site. You should calculate separate attenuation factors for movement through different layers (for example, soil, drift, unsaturated bedrock) where these have different properties and where confidence in their properties varies due to data availability.

If these calculations suggest the pollution risk to groundwater is low you should submit them as evidence as part of the risk assessment document in your permit application.

The Environment Agency will use this evidence together with consideration of other issues such as the risk your discharge represents to nature conservation and Habitat Directive sites, to decide if your permit application is successful.

You must use conservative or well-supported data.

Generic quantitative risk assessment

A generic quantitative risk assessment involves a relatively simple assessment of the impact your activity may have on water quality, including groundwater.

You may need to carry out a generic quantitative risk assessment if any of the following apply:

- your qualitative risk screening was not detailed enough to allow you to make an informed decision on the risk posed by the site
- you've identified a link from source to path to receptor that you think is feasible
- you're preparing to carry out a more complex assessment
- hazards are relatively low and the location is insensitive enough to mean your activity will have no significant impact
- you can define source, pathway and receptor with enough certainty that you believe using worst case scenario figures represents them well enough

How to carry out a generic quantitative risk assessment

Generic quantitative risk assessments use hydrogeological calculations which are typically analytical solutions solved in a deterministic fashion.

You must use conservative (worst case) assumptions in your generic assessment.

There must be sufficient attenuation between the source of contamination and any potential groundwater receptor to demonstrate that the environmental protection afforded by any attenuating layer is sufficient, or if it will need to be artificially enhanced, for example by engineered solutions.

The assessment will need to demonstrate that the proposal poses little likelihood of unacceptable inputs to groundwater.

A detailed quantitative risk assessment should be carried out where a well-informed decision cannot be made using conservative inputs, methods and assumptions.

For example:

- there's uncertainty regarding any of the source, pathway and receptor terms
- there are undefined groundwater patterns including the potential for fissure or conduit flow
- where long-term liner integrity in a landfill or other permanent waste deposits needs further consideration or other engineering concerns

Detailed quantitative risk assessment

You should carry out a detailed quantitative assessment when:

- the site setting is sensitive – for example on permeable strata such as Principal or Secondary A Aquifers (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution/protect-groundwater-and-prevent-groundwater-pollution#geological-characteristics), within an SPZ (http://magic.defra.gov.uk/MagicMap.aspx) or close to sensitive surface water bodies
- the uncertainty in aspects of the source, pathway and receptor terms cannot be overcome using conservative assumptions, because those assumptions lead to an unsatisfactory outcome in terms of risks to groundwater

Where cause for concern is clearly demonstrated at an early stage it may be necessary to introduce risk management action directly rather than spend more time on higher tiers of risk assessment.

A detailed quantitative risk assessment will normally use a 'stochastic' risk assessment technique, such as a 'probabilistic approach', to assess the impact of uncertainties in input data.

Assess groundwater properties

For a detailed quantitative risk assessment you'll need to provide the:

- hydraulic gradient in the direction of groundwater flow and whether this changes seasonally or is affected by your discharge
- cross flow width of your discharge - the width of the area over which your discharge occurs measured perpendicular to the direction of groundwater flow
- saturated thickness over which groundwater flows laterally
- mixing zone depth over which any pollutants from your discharge are diluted
- hydraulic conductivity (permeability) and effective porosity of the aquifer
- groundwater flow rate in the mixing zone, calculated as the product of the hydraulic gradient, cross flow width, mixing zone depth and hydraulic conductivity
- groundwater flow velocity for water moving from beneath your site, calculated as the product of the hydraulic gradient and hydraulic conductivity divided by the effective porosity

Examine attenuation processes and dilution

You need to examine the natural processes that could reduce the concentration of hazardous substances and non-hazardous pollutants as the discharge migrates down and laterally beneath the discharge area.

Many of these processes affect different substances to different extents and also vary between different soils and substrata and different settings, for example in the hyporheic zone around streams and rivers.

You need to consider:

- physical processes, such as volatilisation, filtration, dispersion, dilution
- chemical processes, such as precipitation, sorption, retardation, oxidation, reduction, hydrolysis

- biological processes, such as nitrification, biodegradation

Although physical and chemical processes may occur throughout the movement of the discharged water, biological activity and processes become much less significant below the soil zone and away from the hyporheic zone.

Probabilistic calculations

The simplest form of probabilistic calculation of risks is to use a range of pessimistic, likely and optimistic input values in scoping calculations to illustrate what the outcome might be under the combination of these.

If you get:

- an acceptable result with all pessimistic values combined – it suggests there's a low risk
- an unacceptable result with all optimistic values – it suggests a very high risk that will not be reduced without risk management
- a mixture of answers – suggests you need to do probabilistic calculations

Probabilistic calculations use ranges of realistic input values, with an informed assumption of the distribution (for example normal, log normal) of values within the range, to produce a distribution of output values.

You can carry out probabilistic calculations using:

- the Crystal Ball add-in to Microsoft Excel
- probabilistic tools developed by the Environment Agency (ConSim (http://www.consim.co.uk/) and LandSim (http://www.landsim.co.uk/))
- risk assessment models from commercial organisations

The Environment Agency usually expects the 95th percentile concentration to meet acceptable concentrations when judging the acceptability of the range of output values produced by this approach. This means that the concentration predicted in 95% of all calculations or model runs, which use sensible and justified ranges of input data and have a sound underpinning hydrogeological conceptual model, should be lower than an agreed target concentration. In other words, there's a 1 in 20 chance of this concentration being exceeded. In sensitive settings, the Environment Agency may be more precautionary and require a higher percentile value (for example, the 99th percentile) to be acceptable.

Lifecycle phases and scenarios to assess

Your risk assessment needs to consider the potential effects on groundwater throughout the 'life' of the activity.

For many activities, the discharge will only occur during operation, and this usually means that a single risk assessment scenario is appropriate. There may, however, be occasions when the activity's setting changes, such as groundwater levels rise because dewatering activities stop in a nearby mine or excavation. If such a change is predictable, then the second scenario should be assessed to check if the discharge will also be safe under these changed circumstances.

For other activities (particularly landfill, where the discharge occurs as a result of leaching of solid wastes), the discharge will continue long after the operational period. After this period the discharge rate may change because of deterioration of barrier and collection systems. However, the quality of the discharge may improve with time.

You need to model scenarios reflecting different lifecycle phases where either of the following apply:

- activities have planned or anticipated phases of operation and aftercare

- the discharge may change as a result of deterioration in an irreplaceable barrier or control system

The risk assessment needs to include a section on how you have decided on the scenarios to assess if they are applicable.

Other things you need to consider

You need to provide as part of your risk assessment:

- an appraisal of the main uncertainties that may affect your predicted outcome
- a sensitivity analysis demonstrating how the predicted effect on groundwater and associated receptors may change if you use more conservative data
- any validation of the model used from field results or monitoring
- an assessment of the risk of accidents, their consequences and what you will do to reduce their likelihood

Uncertainties

Uncertainty is a measure of how far the result of an assessment is likely to be from the actual situation.

You need to consider, document and report uncertainties such as:

- whether the activity can be controlled as well as predicted
- the quality of the data that has been generated
- whether conservative assumptions for data are valid
- uncertainties in the hydrogeological conceptual model
- uncertainties in the ability of science to simulate natural processes through the use of mathematical expressions

The approach used to take account of uncertainty should be clearly documented in any modelling report.

Analysing uncertainties: Best Estimate (BE) Prediction

The calculation (or model) is performed using the most likely value for each parameter. This should always be carried out to get an understanding of what the model is doing. The value arising from this calculation gives a starting point for uncertainty analysis. This version of the calculation is the one that should be checked thoroughly because this model is the foundation of the prediction – if it's flawed then anything that follows from it has no value. However, on its own, this version of the model gives no understanding of the magnitude of uncertainty.

Analysing uncertainties: Worst Case (WC) Prediction

This is the same model as used for Best Estimate but with the parameters set at their most conservative possible values. This is a very useful calculation and will usually be overly conservative.

The difference between the Best Estimate prediction and the Worst Case prediction may indicate the magnitude of the uncertainty involved.

Sensitivity analysis

Sensitivity analysis is an important part of your risk assessment.

You can identify the most important factors affecting the outcome using sensitivity analysis. This will allow any variability in these factors to be better controlled through permit conditions.

A sensitivity analysis should be undertaken as part of the quantitative model to determine which parameters have the greatest influence on the model results. Some parameters and their input values have a much bigger influence on the predicted effect of the discharge than others.

A sensitivity analysis is usually undertaken by:

- varying each parameter in turn by a given percentage, for example by +20%
- calculating how this changes the model result

This analysis lets the most sensitive parameters be identified so a reasoned judgement can be made on whether further data is needed to better constrain the parameter that is being tested. This will provide greater confidence in the model results.

You need to consider:

- the sensitivity analysis provides information on the sensitivity of the model (the equations used to represent the site) and does not necessarily reflect the sensitivity of the real environment
- the range in the parameter values should reflect the range as determined from the field and laboratory testing – there's no benefit in demonstrating the model using parameter values which exceed the known range of feasible values

Validation

If the model correctly predicts observed contamination at the receptor or at any intervening point, this:

- significantly improves the confidence that can be attached to the model
- provides assurance that the model provides a credible and acceptable representation of system behaviour

In reviewing the results of a model validation exercise you should consider:

- whether sufficient field data are available to validate the model
- if the model fits the observed both spatially and with time – a model may be able to match field data at one particular time, but may fail to represent changes in contaminant concentrations with time
- the acceptability of the model fit to the observed data and whether any inconsistencies have been adequately explained – in some cases differences between the model and observed data can point to a flaw in the modelling approach
- to provide assurance that the model provides a credible and acceptable representation of system behaviour

Consider the risk of accidents

You must provide a section in the risk assessment for your activity which describes any possible accidents that could affect risks to groundwater and their consequences in terms of groundwater pollution.

You must say how you will reduce the likelihood of these accidents happening.

Where the consequences of plausible accidents are serious, you should say how you'll reduce the likelihood of accidents happening and their consequences should they happen.

How to submit your risk assessment

You can submit your risk assessment as a:

- chapter in a groundwater risk assessment report
- separate report that is to be used in combination with an underpinning activity and site setting report (such as a Hydrogeological Risk Assessment report template (https://www.gov.uk/government/publications/hydrogeological-risk-assessment-report-template) designed for use in permit applications for landfill)

Model output should be clearly and succinctly presented and in graphical format where this is appropriate. Validation data (such as comparison of modelled and observed contaminant concentrations) should be given for key model runs or checked where models are supplied on disk. Decisions made on the basis of model results should be justified with the appropriate model output.

For spreadsheet models and those using common codes such as LandSim or ConSim, the input files or spreadsheets should be provided in digital format. This lets the simulations be re-run and checked (for example to check consistency between the model and the reported results).

Review your risk management options

After you've completed your risk assessment, you'll need to identify and evaluate your options for risk management. For example:

- pre-treating the source material
- enhancing the engineering measures, such as a different landfill liner or upgrading effluent treatment schemes prior to discharge
- tightening the operational and aftercare controls

Groundwater monitoring

If your activities could affect groundwater it's very likely that you'll need to carry out groundwater monitoring. When assessing your permit application, the Environment Agency will decide whether monitoring is needed.

Your permit will tell you whether you need to carry out groundwater monitoring and if so:

- how often you need to monitor
- what type of data to collect
- how to store it

You must carry out your monitoring in accordance with the design and frequency stipulated in your specific risk assessment and as reflected in your permit.

Regular monitoring allows you to check that you're successfully preventing hazardous substances or non-hazardous pollutants from entering groundwater.

If your risk assessment shows that the risk to groundwater from your operation is non-existent, or very low, the Environment Agency may decide that groundwater monitoring is not necessary. Depending on the size and type of discharge from your activity you may still have to monitor any potential impact on groundwater by checking your discharge against limit values. These requirements will be specified in your permit.

The Environment Agency will ask to see your monitoring data either as part of an inspection or they may ask you to send them your data on a regular basis so they can review it. In some cases they may also carry out monitoring of effluent and groundwater (where boreholes are available) to check you're complying with your permit.

How to monitor

The level of monitoring you need to do will depend on the size and type of the discharge and the sensitivity of the environmental setting.

Your risk assessment supporting your application should set out proposals for:

- which compliance points you will monitor
- which substances you're measuring
- how often you will monitor
- how you will record and report monitoring information

Examples of types of monitoring you may need to carry out include measuring the quality of water in:

- a borehole or spring after the attenuated discharge has mixed with the underlying groundwater beneath your site
- a stream or other water course that is groundwater baseflow fed (following mixing with your discharge) – if that stream or water course is the main receptor, or supplies water to the main receptor, for example wetlands

It may not always be feasible to install boreholes for monitoring, due to cost or practicality, so compliance point monitoring may need to be done in other ways. For example, by testing soils to check that waste sheep dip chemicals have not travelled beyond the base of the soil layer.

For infiltration systems, monitoring could include the measurement of:

- the discharge rate and effluent quality
- groundwater levels and groundwater quality in boreholes located around the infiltration system
- water quality in related receptors, for example a down gradient spring source

Where groundwater levels affect the outcome of your risk assessment, you should include proposals of how you will monitor these levels. Groundwater levels change seasonally affecting the thickness of the unsaturated zone, and the slope and direction of the hydraulic gradient.

A minimum of 3 monitoring points in triangulation formation is needed to define a gradient. Routine monitoring of each of these points will allow you to check on whether the gradient is different from the assumptions in your risk assessment.

Where the geology and hydrogeology is complex, with groundwater present in 2 or more separated layers, then use this system of monitoring for each layer. Additional monitoring points are likely to be needed if the site is complex.

Designing groundwater monitoring

Groundwater monitoring needs to be designed on a case-by-case basis in order to work out the right:

- parameters to measure, sample or analyse
- frequency for sampling
- location of monitoring points

Refer to British Standard BS ISO 5667-11:2009 (Guidance on sampling of groundwater) (http://shop.bsigroup.com/ProductDetail/?pid=000000000030152313) for more detail on groundwater monitoring.

You should design your groundwater monitoring programme in line with CIS17 (European Commission, 2007).

Up-gradient or background monitoring

You may need to report on the unaffected or background quality of the groundwater either before a new activity is set up or up-gradient of an existing source of contamination.

Your report lets the Environment Agency know the baseline quality of the groundwater before you discharge waste so they can:

- monitor any deterioration in the groundwater quality down-gradient of your discharge
- compare and contrast to what the quality was before you started your activity

If the groundwater is contaminated from a historic source of pollution the Environment Agency will know:

- how the baseline has changed before your works starts
- what additional impacts they may have down gradient when you start work

Monitoring intervals

Your monitoring frequency should take into account:

- the behaviour (such as travel time) of known pollutants and their degradation products
- the hydrogeological conditions underlying your site (this links to your conceptual model)

Construction

The technical characteristics of the monitoring wells and the depth of monitoring in each observation well should be designed according to the type of pollutant present and seasonal water level fluctuations.

Sampling methods

Sample preservation and analysis methods will be dependent on the nature of the input and its expected pollutant concentration. Commercial analytical laboratories can advise on sample preservation and analysis.

Parameters to monitor

The parameters monitored at each well should be indicative of the type of pollutant(s) and their expected impact. Possible indicator parameters (redox, pH, electrical conductivity, temperature, salts) could be used to reduce the monitoring effort.

Cost and benefits

You should look at the cost benefit ratio between the number of wells and the levels of information they will provide.

If you have more wells, you'll have more data for collection and analysis. This will give a better understanding of your site's hydrogeology and its impact.

Contact

Contact the Environment Agency if you need help with your risk assessment.

General enquiries

National Customer Contact Centre
PO Box 544
Rotherham
S60 1BY

Email enquiries@environment-agency.gov.uk

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Monday to Friday, 8am to 6pm

Published 1 February 2016
Last updated 3 April 2018 + show all updates

1. 3 April 2018 All hazardous substances and non-hazardous pollutants (except ammoniacal nitrogen, ammonium and suspended solids) are known as specific substances. If your discharge includes specific substances your risk assessment will need to include a specific substances assessment.
2. 14 March 2017 Definitions and guidance on hazardous substances and non-hazardous pollutants have been moved to the groundwater content. Added links to the groundwater content.
3. 13 January 2017 New link for the updated list of hazardous substances on JAGDAG's website.
4. 1 February 2016 First published.

Related content

- Protect groundwater and prevent groundwater pollution (https://www.gov.uk/government/publications/protect-groundwater-and-prevent-groundwater-pollution)
- Landfill developments: groundwater risk assessment for leachate (https://www.gov.uk/guidance/landfill-developments-groundwater-risk-assessment-for-leachate)
- Groundwater protection technical guidance (https://www.gov.uk/government/publications/groundwater-protection-technical-guidance)
- Values for groundwater risk assessments (https://www.gov.uk/government/publications/values-for-groundwater-risk-assessments)
- H1 annex J5: infiltration worksheet (https://www.gov.uk/government/publications/h1-annex-j5-infiltration-worksheet)

Collection

- Risk assessments for specific activities: environmental permits (https://www.gov.uk/government/collections/risk-assessments-for-specific-activities-environmental-permits)
- Water discharge and groundwater activity environmental permits (https://www.gov.uk/government/collections/water-discharge-and-groundwater-activity-environmental-permits)
- Groundwater protection (https://www.gov.uk/government/collections/groundwater-protection)

Explore the topic

- Environmental permits (https://www.gov.uk/topic/environmental-management/environmental-permits)

D Natural England SSSI notified under Section 28 of the Wildlife and Countryside Act, 1981

County: North Yorkshire **Site Name: Askham Bog**

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act, 1981.

Local Planning Authority: Selby District Council

National Grid Reference: SE 570480

Ordnance Survey Sheet 1:50,000: 105 **1:10,000:** SE 54 NE

Area: 44.7 (ha) 110.7 (ac)

First Notified: 1961* **Date of Revision:** 1984

Description:
Askham Bog is the remnant of a valley-mire which formed between two ridges of glacial moraine in the Vale of York just southwest of the City. Base-rich ground-water draining the moraines has led to the development of a rich-fen community which demonstrates stages in seral succession to fen woodland. In the central areas there is a poor-fen community, thought to represent incipient raised-bog, where vegetation has grown above the influence of the ground-water and conditions have become acidic through the leaching action of rain-water and the growth of bog mosses *Sphagnum* spp.

The present habitats are considered to be secondary, raised-bog having largely replaced the original fen before peat-cutting in the Middle Ages brought the vegetation back within the influence of base-rich ground-water with the consequent reversion to fen conditions.

The majority of the site consists of birch *Betula pubescens* and oak *Quercus robur* woodland with alder *Alnus glutinosa* at the dyke margins. There is extensive willow carr *Salix cinerea*, and the shrub layer also includes alder buckthorn *Frangula alnus* and bog myrtle *Myrica gale*. The open fen communities are very rich in flowering plants such as meadowsweet *Filipendula ulmaria*, common meadow rue *Thalictrum flavum*, yellow loosestrife *Lysimachia vulgaris*, common marsh bedstraw *Galium palustre* and woody nightshade *Solanum dulcamara*. Sedges are particularly well represented and include fibrous tussock-sedge *Carex appropinquata*, elongated sedge *C. elongata* and great fen-sedge *Cladium mariscus*. The site is also noted for the occurrence of royal fern *Osmunda regalis* and marsh fern *Thelypteris thelypteroides*. More acidic elements of the ground flora include broad buckler-fern *Dryopteris dilatata*, narrow buckler-fern *D. carthusiana*, purple moor-grass *Molinia caerulea* and bog mosses *Sphagnum fimbriatum*, *S. squarrosus* and *S. palustre*. In addition to the peatland habitats there is grassland along the northern and southern margins which has several species of interest such as adder's-tongue fern *Ophioglossum vulgatum* and early marsh-orchid *Dactylorhiza incarnata*, and the dykes are rich in aquatic plants, in particular the water violet *Hottonia palustris*.

The site is renowned for its insect fauna which includes the scarce beetles *Dromius sigma* and *Agabus undulatus* and the fen square-spot moth *Diarsia florida*.

Reference:
Fitter, A. and Smith C., editors, (1979). A Wood in Ascam. Ebor Press, York.

Other Information:

1. The importance of this site is such that although not included in ‘A Nature Conservation Review’ at the time of its publication, it has nevertheless since been recognised as an integral part of the national peatland series listed in that volume.
2. During the 1983 revision the boundary has been extended.
3. Part of the site is managed as a nature reserve by the Yorkshire Naturalists’ Trust.

*Under Section 23 of the National Parks and Access to the Countryside Act, 1949.

E Natural England (2011), A review of techniques for monitoring the success of peatland restoration NECR086

Natural England Commissioned Report NECR086

A review of techniques for monitoring the success of peatland restoration

First published 02 September 2011

www.naturalengland.org.uk

NATURAL ENGLAND

Foreword

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

Background

An important element of all peatland restoration projects is a programme of monitoring to check results and progress. Several peat project workshops identified a demand for technical guidance on monitoring techniques. So Natural England commissioned this study to:

- Review the range of peatland restoration monitoring techniques available.
- Identify those that were consistent, informative and easily applicable for peatland restoration projects at a range of scales and budgets.

Tables to identify appropriate monitoring techniques for specific projects are published in the Technical Information Note TIN097 - *Guidelines for monitoring peatland restoration.* Further information on these techniques is provided in this report.

The findings of this study have been used to:

- Inform the JNCC project to design a research programme on UK Peatland Green House Gas and Carbon Flux.
- Develop thinking on monitoring peatlands in the IUCN UK Peatland Programme.
- Inform hydrological monitoring programmes for the Dartmoor and Exmoor Mires Project.

These findings are being disseminated to:

- Encourage the use of balanced and consistent approaches to peatland restoration monitoring.
- Develop consistency in monitoring approaches so as to enable possible future collation of peatland monitoring data as a single database resource.

A single database resource of peatland restoration would enable more robust analyses of monitoring data to support the development and implementation of future support and management techniques for peatland restoration.

This report should be cited as:

BONNETT, S.A.F., ROSS, S., LINSTEAD, C. & MALTBY, E. 2009. *A review of techniques for monitoring the success of peatland restoration*. University of Liverpool. Natural England Commissioned Reports, Number 086.

Natural England Project Manager - Matthew Shepherd, Renslade House, Bonhay Road, Exeter, EX4 3AW **matthew.j.shepherd@naturalengland.org.uk**

Contractor - Institute for Sustainable Water, Integrated Management and Ecosystem Research, University of Liverpool, Nicholson Building, Brownlow Street, Liverpool, L69 3GP

Keywords - peat, peatlands, bog, blanket bog, fen, mire, raised bog, monitoring, surveillance, carbon budget, greenhouse gases, carbon dioxide, hydrology; restoration, rewetting, bird survey, microorganisms, invertebrates survey, grip blocking, water quality, carbon, erosion, habitat monitoring

Further information
This report can be downloaded from the Natural England website: **www.naturalengland.org.uk**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

ISSN 2040-5545

3.1. Defining objectives of restoration and monitoring

3.1.1. Identify restoration objectives

Hobbs & Norton (1996) identified a number of key processes in restoration ecology that they considered essential for the successful integration of restoration into land management:

1) Identify processes leading to degradation or decline.
2) Develop methods to reverse or ameliorate the degradation or decline.
3) Determine realistic goals for re-establishing species and functional ecosystems, recognizing both the ecological limitations on restoration and the socioeconomic and cultural barriers to its implementation.
4) Develop easily observable measures of success.
5) Develop practical techniques for implementing these restoration goals at a scale commensurate with the problem.
6) Document and communicate these techniques for broader inclusion in land-use planning and management strategies.
7) Monitor key system variables, assess progress of restoration relative to the agreed goals, and adjust procedures if necessary.

Restoration measures that do not ameliorate or reverse the processes causing degradation may not work as hoped because the degrading influences will continue to operate and work against restoration efforts (Hobbs & Norton, 1996). However, it was suggested at a meeting of experts at the Natural England peat restoration workshop that most peatland restoration projects are at the stage of peat stabilization and have not yet begun true restoration (Appendix 2). Many restoration projects have proceeded with only the broadest of objectives, often with little consideration of whether these objectives are attainable, and with no means of assessing the degree to which the objectives have been met. Monitoring methodologies developed for restoration projects also have been largely ad hoc and site-specific, and there has been little attempt to generalise from one site to another (Berger, 1990). The drivers for restoration in recent years have been the government's public service agreement (PSA) to have 95 % of the SSSI area in favourable or recovering condition by 2010, SAC and SPA management driven by the Habitat Regulations, Biodiversity Action Plans (BAP) and Higher Level Stewardship (HLS) targets. It has been mentioned that one objective of restoration should be to aim to restore the functions attributed to biogeochemical processes in wetlands rather than short-term gains in biodiversity since functions support the goals of restoration such as *Sphagnum* growth and development and carbon sequestration (Appendix 2). The results of a survey on restoration monitoring (Appendix 1) showed that of the 29 projects biodiversity, conservation status (e.g. BAP), and vegetation cover/composition were deemed the most important for instigating the project followed by hydrological parameters and carbon storage/sequestration. The importance of restoration purpose was obvious from results presented for Wicken Fen at the Natural England conference (Appendix 2) that showed that standing water above the soil surface was required to increase the soil carbon (C) store, but that this environmental condition was adverse to the situation required by the BAP for the habitat. Also, the question was raised whether restoration should aim for the most sustainable habitat rather than the most bio-diverse. As an example, it was suggested that bunded grazing marsh would be better at Wicken Fen than fen or bog as that type of wetland would be more sustainable in the long-term (Appendix 2). Agreement was reached that no loss of peat or chemical change in the peat was a common restoration objective which may not be achievable in practice and that the objective of restoration needs clear definition prior to even pre-restoration monitoring.

A properly planned restoration project attempts to fulfil clearly stated goals that reflect important attributes of the reference ecosystem (SER, 2004). Goals are attained by pursuing specific objectives. The goals are ideals and the objectives are the desired results of actions taken to attain those goals. In the case of peatlands, Quinty & Rochefort (2003) state that the goal of current restoration is often to re-establish self-regulatory mechanisms that will lead back to functional peat accumulating ecosystems. Peat will not accumulate during the short-term period of restoration. However, the objective in the short-term is to establish plant communities which will eventually in the long-term (10-100 years) produce debris that will accumulate and become peat. Dead plant parts will accumulate only if the water table is high enough throughout the year to impede decomposition, and a restoration target identified some years ago for important peatland sites was to retain rainwater within 10 cm of the peat surface for ombrotrophic peatlands, and reduce seasonal fluctuations (Johnson, 1997).

Objectives are linked to activities that produce measureable results that determine or indicate if a site develops toward successful restoration (Quinty & Rochefort, 2003). For example, the approach to peatland restoration developed in Canada, has two specific objectives:

1. Re-establishing a plant cover dominated by peatland species including *Sphagnum* mosses, and

2. Re-wetting harvested sites by raising and stabilizing the water table near the surface.

These two specific objectives focus on peatland vegetation and the hydrological regime because they are the key factors responsible for most functions of peatlands as well as being the principal elements affected by degradation such as peat extraction (Quinty & Rochefort, 2003). However, this example relates to restoration of raised and blanket bogs in Canada and objectives can differ between habitats and countries. The principle restoration methods in lowland peat are blocking drains, felling trees, raising ground water levels, landscape change and reducing cover of purple moor-grass (Appendix 2). In some cases objectives might be synergistic or contradictory, such as management for biodiversity, carbon storage and greenhouse gas emissions. For example, re-wetting through ditch blocking in upland peat bogs, for instance, may enhance biodiversity but may also lead to increased methane emissions. At Wicken fen, restoration is occurring but there is no remaining mire vegetation present, leading to discussion as to whether restoration or re-creation was the objective. It is therefore important to implement an ecosystem approach by considering all objectives carefully and assessing also their effects on other ecosystem services. More details on setting restoration goals and objectives can be found in Quinty & Rochefort (2003), and Schumann & Joosten (2008) as well as from the survey results presented in Appendix 1; Q5 for each restoration project surveyed.

3.1.2. Identify monitoring objectives

In this section, we consider the monitoring objective to be a target level of a particular monitoring parameter that indicates that the objective of restoration has been met. Goldsmith et al. (1991) suggest that monitoring can be considered at a number of levels, for example:

F **Lindsay R., Birnie R., and Clough J. (2014), Programme Briefing Note No3, Impacts of Artificial Drainage on Peatlands, IUCN UK Committee Peatland**

IUCN UK Committee Peatland Programme
Briefing Note N^{o} ***3***

Impacts of Artificial Drainage on Peatlands

Problem
Wider impacts of drains are poorly recognised

Two **common misconceptions are associated with artificial drainage of peat bogs**. The first is that drainage impacts are largely confined to drain margins. In fact they can impact across a much wider area – in some cases, across the whole bog. The second **misconception is that the bog water table should be the main focus of attention** when studying the effect of drainage. Although it is important to measure the water table, the **value of such data is much reduced if surface subsidence is not also measured**. In the long term, surface subsidence rather than the water table is likely to show the greater drainage effect.

Impacts of Drainage

A peat bog is a wetland in which the peat soil is likely to have a **moisture content of greater than 95%** in the undisturbed state – "there are more solids in milk than in peat". Bog surfaces also often have areas of standing surface water. This water-logging is what creates a peatland and allows it to function. Consequently drainage is generally regarded as the first essential activity when attempting to develop the peatland in some way and is thus one of the most widespread forms of human impact on peat bog ecosystems. The effect of such drainage is often disappointing because the anticipated drying effects often appear extremely limited in their extent. Peat just a metre or so from a drain will often still contain more than 80% moisture content by weight. The main effect of peatland drainage is thus frequently described as merely "*more rapid removal of surface water*" rather than deep water-table draw-down.

Main impact of drainage is the re-shaping of the bog system

In fact the main long-term effect of drainage is to re-shape the bog itself, with major implications for water, carbon and biodiversity, yet this re-shaping is rarely recorded or monitored.

Understandably, **much research into peat bog drainage has focused on the behaviour of the water table**. This is because drainage is largely undertaken to lower the water table and thereby provide a deeper zone of aerated soil for exploitation. However, achieving this in a bog is much more difficult than is the case for most mineral soils because a bog has two layers – the **acrotelm** and the **catotelm** (see ***Biodiversity Briefing Note 2***) - and it is only the thin surface acrotelm which can readily be drained.

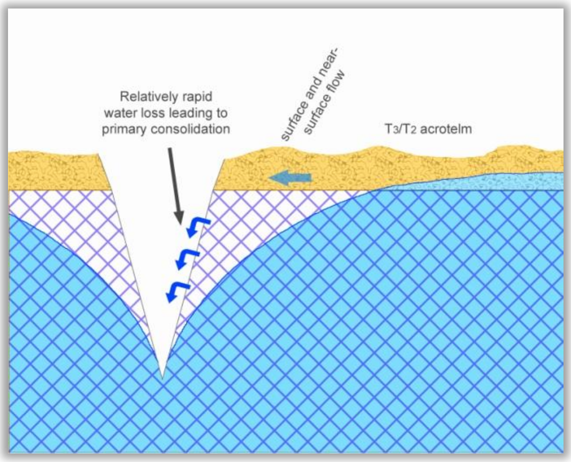
Two-layered system, only one layer freely-draining

The acrotelm layer of a bog offers relatively low resistance to vertical and, more importantly, lateral water movement. Consequently **drainage tends to empty the acrotelm of water fairly readily, sometimes over considerable distances (potentially**

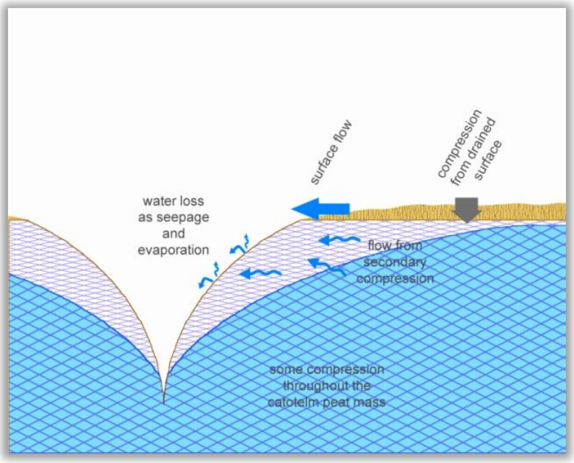
Drainage can affect the acrotelm over hundreds of metres

over several hundred metres). With an acrotelm thickness of only 10-20 cm, it is easy to understand, however, why such drainage effects are regarded as 'insignificant' and little more than removal of surface and near-surface water. From the perspective of the bog ecosystem, however, such effects represent a **very significant impact**. Peat-forming conditions exist because the high and relatively stable water table in the acrotelm maintains waterlogged conditions and enables bog species to resist competition from other plant species which are not normally peat forming.

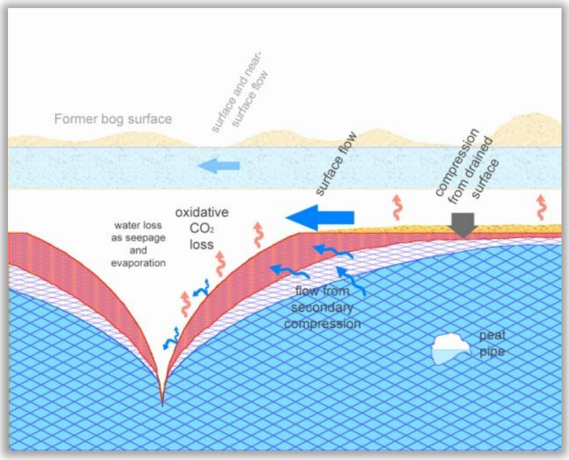
Loss of peat-forming species means loss of peat forming function in the acrotelm



Catotelm resists drying, but responds instead to water loss by collapse and shrinkage



Primary con-solidation is relatively rapid but short-lived



Drying of the acrotelm results in progressive loss of peat-forming conditions and peat-forming species, which means that the acrotelm is no longer capable of providing fresh peat material to the catotelm. Indeed many plant species which typically colonise a dry acrotelm surface **have root systems which further dry out both the acrotelm and the upper layers of the catotelm**, thus enhancing the impact of the drains.

The lower catotelm layer responds to drainage in a completely different way - apparently resisting all attempts to achieve significant water-table draw-down. **Water movement in the catotelm is extremely slow**, up to 1 million times slower than the speed of a snail. It has been estimated that it would probably take **around 90 years for a single raindrop to filter downwards through the 10 m thickness of a raised bog system**. A drain therefore has relatively little *immediate* effect on the water held in the main body of catotelm peat, but *in the immediate vicinity of the drain*, water held in the larger spaces between peat fragments seeps fairly readily into the drain through gravity drainage (visible on the drain walls of the photograph at the start of this Briefing). This water loss results in a draw-down of the water table adjacent to the drain. **This draw-down is often the only *measured* effect of drainage.**

Prior to drainage, water typically occupied as much as 50% of the catotelm peat volume and loss of this water therefore **results in collapse and shrinkage of the peat adjacent to the drain. This process is called *primary consolidation***. Its effects are felt immediately but may continue for some years. The key impact of this primary consolidation is that the drain, in effect, becomes wider because the ground immediately adjacent to the drain subsides.

This subsided, drained acrotelm and catotelm peat still has significant mass because somewhat more than 40% of its volume consists of water held in large storage spaces within the preserved plant fragments, most notably within leaves of *Sphagnum* bog moss. Consequently once the 'free' (or interstitial) water has been lost from the peat, the somewhat drier catotelm peat adjacent to the drain itself becomes a heavy load on the peat beneath because the drained layer no longer floats buoyantly within the bog water table. This load **compresses the peat beneath it and squeezes more water from the peat into the drain, causing the bog surface to subside still further.** Perhaps surprisingly, this downward pressure even forces water upwards into the drain from peat below – with the result that the *entire* depth of catotelm peat experiences some degree of subsidence. The effect is most marked in surface layers but can still be detected even at the base of the catotelm. This type of subsidence is called ***secondary compression***. Secondary compression acts across a steadily widening area beyond the drain, demonstrably over several hundred metres in some cases, and continues as long as drainage is present.

Secondary compression

Oxidative wastage

The third catotelm process associated with drainage occurs because drainage allows oxygen to penetrate the catotelm. Under natural conditions the catotelm peat remains permanently waterlogged preventing oxygen-fuelled decomposition – and thus peat material is preserved for millennia. Once oxygen penetrates the catotelm peat store, relatively rapid decomposition can take place. Preserved plant material is thus lost in the form of carbon dioxide gas (CO_2), leading to further subsidence as the peat material itself vanishes into the atmosphere. This process is called **oxidative wastage**.

Secondary com-pression and oxidative wastage are long-term impacts

Unlike primary consolidation, the effects of secondary compression and oxidative wastage continue as long as there is a load caused by drainage and catotelm peat is exposed to the air. For certain locations such as the Holme Fen Post in Cambridgeshire (also Clara Bog's 'famine road' in Ireland and the Donaumoospegel in Bavaria) the effect has been well documented over periods of more than 150 years. Nor is the effect restricted to deep lowland raised bogs; significant subsidence has also been recorded in drained blanket bog. The **three drainage processes – primary consolidation, secondary compression and oxidative wastage** – cause the peat to subside progressively and continuously across an ever-expanding area. Drainage in effect continually widens the dimensions and impact of the drain *even though measurements only a few metres from the drain may still indicate that the water table is close to the bog surface*. Apart from the 2-5 metres immediately adjacent to the drain, the water table *cannot normally be drawn down more than a few centimetres into the catotelm by drainage*.

Limited water-table draw-down does not mean limited drainage effects

The few centimetres of drained catotelm peat will, however, in due course be lost through oxidative wastage in a constant process of drying, subsidence and loss, and so the *entire* peat mass of an area subject to a regular pattern of drains will experience subsidence. In the case of a lowland raised bog (see ***Definitions Briefing Note 1***) large-scale changes to the shape of the bog (the *mesotope* – see ***Definitions Briefing Note 1***) can often be attributed to individual drains which have been continually maintained, while drainage of the lagg fen surrounding the bog - often resulting in a truncated margin to the dome - will bring about long-term subsidence across the entire raised bog dome.

The wetter the peatland the greater the initial response through primary consolidation, but all peatlands exhibit similar long-term effects. Drained areas which appear to support vegetation unaffected by the drainage should be checked for evidence of past vegetation in the recent peat archive. **Areas of deep peat with dense heather and areas rich in lichens or non-*Sphagnum* mosses are often indicators of vegetation change due to drainage**.

Shrinkage causes sub-surface pipe formation

Shrinkage of the peat mass also causes it to deform in other ways. Like mud or clay when they dry, cracks may develop in the peat, particularly along the base of drains or parallel to the drains, and there is evidence to suggest that formation of sub-surface 'peat pipes' is more frequent in drained or drying peat.

If trees then colonise the drained peat, their roots will suck water from the peat and the canopy will prevent rainfall reaching the bog surface, while the weight of the trees further compresses the peat. This combination of effects results in even more dramatic rates of subsidence, even though adjacent areas of open bog may still appear to have high water tables (because these adjacent areas will also be sinking).

Impacts on carbon balance

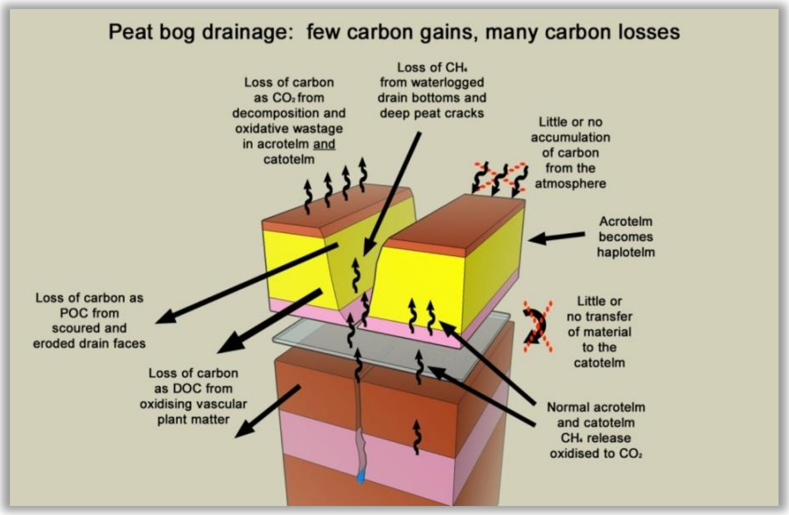
Quantifying the effect of drainage on the carbon balance of a bog is a challenging task because there are several potential pathways of loss. There is also the need to balance methane emissions against carbon dioxide emissions, the extent of drainage impacts may not be evident, and the changes brought about by drainage are expressed over a long period of time.

Oxidative loss

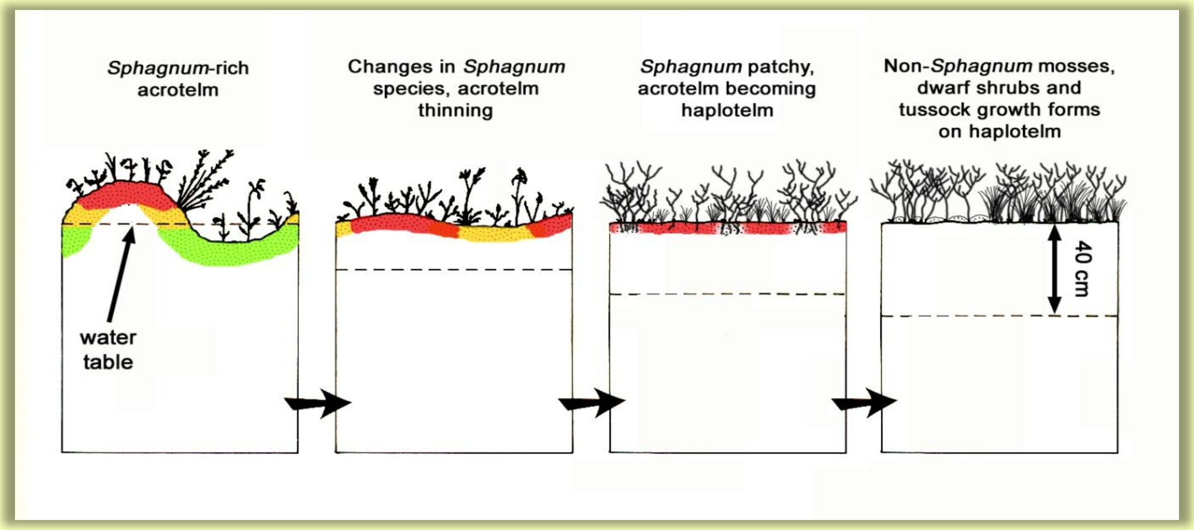
POC
DOC

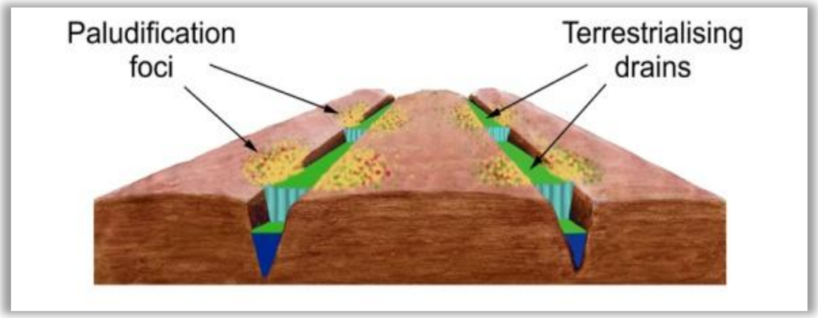
Methane

In terms of carbon loss, carbon dioxide (CO_2) is released as the dried peat oxidises. This is likely to be most intense close to the drains but the effect may be more widespread during extended periods without rain because the acrotelm may already be largely empty, thus permitting the water table to fall into uppermost layers of the catotelm. Particulate organic carbon (POC) is also washed from the face of the drain, while dissolved organic carbon (DOC) is released directly from the drain sides as well as in water squeezed from the peat by secondary compression. Meanwhile, the drier nature of the peat may reduce methane (CH_4) emissions from the bog surface, particularly if bog hollows or pools are lost, but methane may then be emitted from the drain bottoms, particularly if there are cracks in which water becomes ponded. If shrinkage pipes are also formed, this provides another route by which POC and DOC can be lost. In addition, loss of a functioning acrotelm means loss of carbon-sequestering capacity, diminishing or halting the process of peat accumulation.



There are relatively few reliable figures for oxidative losses from peat bog systems, and even fewer for the balance between methane release in natural bogs compared with its release from drained bogs. Losses of POC and DOC which are directly attributable to drainage have also not been well documented, but if high levels of organic matter enters the water treatment process, chlorination can produce the carcinogen trichloromethane (chloroform). Water utility companies therefore invest heavily to reduce the level of organic matter entering the treatment process.

Subsidence of 1-2 cm/yr, with perhaps 0.5 cm being carbon loss	Long-term figures for overall subsidence indicate that, after the initial rapid effects of primary consolidation, long-term subsidence of bog peat is typically around 1-2 cm per year, and measurements of CO_2 emissions suggest that up to 0.5 cm per year of this may be due to oxidative loss. POC losses tend to be greatest when the drains are first dug, but also during periods of heavy rain. Meanwhile DOC release appears to be most intense during heavy rain following a dry period.
Impacts on micro-topography and bog vegetation	Returning to the question of the acrotelm and the apparent high water tables close to drainage, the bog vegetation may *appear* to be largely unaffected by these major changes to the catotelm and gross morphology of the peat, but careful inspection will often reveal that this is not the case. The vegetation patterns found within the microtopography of a bog (see ***Biodiversity Briefing Note 2***) are adapted to the very stable water table typical of an undamaged bog. Each small-scale vegetation assemblage typically occupies a particular zone above or below the water table. **Such zones are often no more than 10-20 cm in vertical range.** **If the average water table falls by 15 cm, this may represent the entire zonal range for certain vegetation assemblages.** Consequently these assemblages may take up new positions within the microtopography, or they may disappear entirely.  A bog surface which before drainage had a **characteristic surface pattern of low ridges and hollows would thus, after drainage, tend to show a shift towards a surface pattern largely dominated by high ridge**. The vegetation may still be rich in peat-forming species, but the *ecosystem diversity* of the bog has changed and diminished. Evidence for such change can often be found by digging into an area which no longer supports peat-forming species. The underlying peat will often have abundant *Sphagnum* remains even though the present surface vegetation contains no *Sphagnum*. Ultimately, if there is continued maintenance of the drainage system, the peat-forming species are likely to be overwhelmed and completely displaced by species of drier habitats such as heather and non-*Sphagnum* mosses.
Reversing Drainage Effects	If drains are **not maintained**, they usually begin to choke up with slumped peat and pockets of vegetation, but can be actively blocked through **conservation management to speed up this process**. This ultimately allows **the bog vegetation to re-establish**. Aquatic species infilling the drains (through ***terrestrialisation*** of the open ponded water)

Drain blocking helps re-establish bog vegetation ***Terrestrialis-ation*** ***Palu-dification***	will contribute relatively little in terms of long-term peat formation because aquatic *Sphagnum* species are poor peat formers. Their **key role is to help stabilise and establish a high water table again across the adjacent bog surface. This wetter bog surface will then be capable of supporting more vigorous peat-forming species through *paludification*.** In the long term, although little can be done about the subsidence which has already occurred, such re-invigorated bog vegetation is capable of laying down fresh peat and ultimately restoring the original shape of the bog, albeit over a long timescale. 
Other benefits of re-wetting	The re-establishment of a high, stable water table leads to active bog vegetation and a functioning ecosystem complete with all the associated ecosystem services, including, generally, attenuation of flood peaks, a reduction in POC and DOC release into catchment waters, reduced water-treatment costs and lowered threat of trihalomethane production.
Areas impacted by drainage at risk of being missed	Areas potentially subject to drainage impacts but often not realised to be as such: • entire lowland raised bog mesotopes where the surrounding lagg fen has been drained; • areas close to, or distant from, areas of drainage but which still support an 'active' bog vegetation; • eroded bog where the erosion drainage pattern leads to the head of a drain.
Gaps in Knowledge	Identified gaps are: • Subsidence is rarely measured when peat bogs are drained. Consequently there are relatively few records, given the extent of drainage, for the scale of subsidence and scale of carbon loss through oxidative wastage. • The extent of the hydrological footprint of a drain is poorly documented in terms of its impact on both the acrotelm vegetation and the morphological, hydrological and chemical impacts on the catotelm peat. • Given that the majority of GHG studies undertaken on UK bogs have used degraded sites, there is still a need for data describing the short-term and long-term relationships between drainage and GHG exchange in natural and drained sites and sites undergoing restoration management in differing parts of the UK. • Given that the majority of hydrological studies undertaken on UK bogs have used degraded sites, the relationship between natural peatland water storage, drainage

	and flood-water discharge is not yet well understood. Of particular interest are questions of 'surface roughness' and peat-forming vegetation compared with drainage-induced vegetation which is not peat-forming, and also in terms of the active storage capacity of the natural acrotelm and catotelm. • In blanket mires, loss of particulate matter and dissolved organic carbon from drained areas also remains relatively poorly documented. Consequently the relationship between drainage in the catchment and levels of trihalomethane production within peat-dominated catchments used for public water supplies merits appropriate examination and monitoring.
Practical Actions	Practical actions: • Careful long-term measurement of peat subsidence across relevant microtope and mesotope areas, linked to measurements of water-table behaviour, wherever there is peatland drainage. • Encourage the recovery of peat-forming vegetation, particularly of terrestrial *Sphagnum* species through paludification, by the blocking of drainage ditches, and, where appropriate, erosion gullies. Such actions can potentially be assisted and encouraged by the reintroduction of *Sphagnum*. • Establish national catalogue of near-natural peatbog sites which can be used as reference sites in GHG and hydrological studies.
More Information	Underpinning scientific report: http://www.rspb.org.uk/Images/Peatbogs_and_carbon_tcm9-255200.pdf (low resolution) http://www.uel.ac.uk/erg/PeatandCarbonReport.htm (high resolution : downloadable in sections) IUCN UK Peatland Programme: http://www.iucn-uk-peatlandprogramme.org/ Natural England Uplands Evidence Review: http://www.naturalengland.org.uk/ourwork/uplands/uplandsevidencereviewfeature.aspx Scottish Natural Heritage Report on peat definitions: http://www.snh.org.uk/pdfs/publications/commissioned_reports/701.pdf Peatland Action: http://www.snh.gov.uk/climate-change/what-snh-is-doing/peatland-action/ *This briefing note is part of a series aimed at policy makers, practitioners and academics to help explain the ecological processes that underpin peatland function. Understanding the ecology of peatlands is essential when investigating the impacts of human activity on peatlands, interpreting research findings and planning the recovery of damaged peatlands.* *These briefs have been produced following a major process of review and comment building on an original document: Lindsay, R. 2010 'Peatbogs and Carbon: a Critical Synthesis' University of East London. published by RSPB, Sandy. http://www.rspb.org.uk/Images/Peatbogs_and_carbon_tcm9-255200.pdf, this report also being available at high resolution and in sections from: http://www.uel.ac.uk/erg/PeatandCarbonReport.htm* *The full set of briefs can be downloaded from:www.iucn-uk-peatlandprogramme.org.uk* *The International Union for the Conservation of Nature (IUCN) is a global organisation, providing an influential and authoritative voice for nature conservation. The IUCN UK Peatland Programme promotes peatland restoration in the UK and advocates the multiple benefits of peatlands through partnerships, strong science, sound policy and effective practice.*

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