6 SOILS, AND GEOLOGY AND HYDROGEOLOGY

6.1 INTRODUCTION

The existing facility is located in a large Bord na Móna landbank in north County Kildare. The entire Bord na Móna landbank, comprising 2,544 ha, is divided into a northern portion of 799 ha and a southern portion of 1,745 ha. The northern portion and southern portions of the Bord na Móna property are divided by the L5025 County Road, which crosses the narrowest Section of the peat deposit.

The existing facility occupies approximately 179 ha and is located in the southern portion of the landbank. The site investigation baseline assessment concentrated on the characterisation of the soil and geology environment within the southern portion of the Bord na Móna property, although the literature review focused on a wider area.

The entire Bord na Móna landbank in this area has been utilised for approximately 50 years for the industrial harvesting of peat and, therefore, the soil environment is characterised at its current state, which is significantly altered from its original setting.

The baseline assessment of the soils and geology is concerned with an appraisal and description of the deposits within the site. The information contained in this Section has been divided into sub-sections, so as to describe the various aspects pertaining to soil and geology. The sub-terrain environment is described from the surface down, as this is considered the easiest method to describe and conceptualise the different layers occurring under the site. The groundwater movement through the various sub-terrain media is also described.

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The existing geological environment at the site and surrounding areas is characterised as follows:

- Description of the geological environment from literature review;
- Description of the geological environment from site investigation data;
- Hydraulic testing and determination of the composition of various geological strata;
- Assessment of the aquifer potential of the geological material;
- Determination of groundwater vulnerability;
- Details of groundwater abstraction points from the regional geological environment;
- Determination of the groundwater piezometry of the shallow subsoil groundwater and the deeper bedrock groundwater; and
- Characterisation of groundwater transmitted and stored in the geological environment.

The extent of investigation is considered to be adequate to allow the characterisation of the geological and hydrogeological setting of the site and to determine the use of natural resources as a result of the existing facility. Historical and recent information was available from a number of sources, with the majority of the published information available from the Geological Survey of Ireland (GSI).

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Site specific data, regarding the geological setting of the site, was available from earlier investigations (2002-2008) undertaken by TOBIN Consulting Engineers, APEX Geoservices Ltd, Glovers Site Investigations, and from other previous investigations undertaken by Fehily Timoney and Company Ltd. on behalf of Kildare County Council (KCC). Additional site investigation works were undertaken in 2016 by TOBIN Consulting Engineers, Apex Geophysics, Causeway Geotech and IGSL.

The information included in this Chapter of the EIAR is set out to meet the data requirements specified in the Institute of Geologists of Ireland publication *A Guide to Geology in Environmental Impact Statements*, (2013) and to meet the data requirements suggested in the EPA's *Guidelines on the Information to be contained in Environmental Impact Statements* (March 2002).

This Chapter has been prepared in the main by Mr. John Dillon, who is employed as a Senior Scientist with TOBIN Consulting Engineers. Mr. Dillon holds an Honours Degree (BScEnv) in Environmental Science from National University of Ireland, Galway (2001) as well as a Master's and Diploma in Environmental Engineering (2003), from Imperial College London and is also a Professional Geologist (P.Geo.). Mr. Dillon was supported in the compilation of this chapter by the wider team of geologists and hydrogeologists employed by TOBIN Consulting Engineers.

6.2 METHODOLOGY

This Chapter has been prepared using the recommendations set out in the EPA *Guidelines on the Information to be contained in Environmental Impact Statements* (March 2002).

The Draft EPA *Guidelines On The Information To Be Contained In Environmental Impact Assessment Reports* (August 2017) have also been used, in addition to the guidelines and recommendations of the Institute of Geologists of Ireland (IGI) publication *Geology in Environmental Impact Statements – A Guide* (IGI 2002) and *Guidelines for the Preparation of Soils, Geology and Hydrogeology Chapters of Environmental Impact Statements* (IGI 2013).

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In the preparation of this Chapter, relevant information was collated and evaluated, and the sources of this information are detailed further in this chapter.

The principal objectives of this chapter are to identify:

- Geological and groundwater factors which might affect the technical viability of the existing facility;
- Impacts that the existing facility may have on natural resources (soils, geology and groundwater), on geological heritage, including worst case scenario;
- Mitigation measures which may be required to minimise any adverse impacts related to the existing facility; and
- Evaluation of significance of any residual impacts.

Criteria for evaluating impact levels are shown in Table 6.1. The magnitude of any effects considers the likely scale of the predicted change to the baseline conditions resulting from the predicted effect and

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takes into account the duration of the effect, i.e. temporary or permanent. Definitions of the magnitude of any effects are also provided below, in Table 6.1.

Table 6.1: Impact Magnitude Definitions

Magnitude	Criteria
Very High	An impact, which obliterates sensitive characteristics of the soil or geology environment
High	Fundamental change to ground conditions, groundwater quality or flow regime
Moderate	Measurable change to ground conditions, groundwater quality or flow regime
Low	Minor change to ground conditions, groundwater quality or flow regime
Negligible	No measurable impacts on ground conditions, groundwater quality or flow

Source: EPA's *Guidelines on the Information to be contained in Environmental Impact Statements* (March 2002)

Effects may have negative, neutral or positive application where:

- Positive effect – A change which improves the quality of the environment;
- Neutral effect – A change which does not affect the quality of the environment; and
- Negative effect – A change which reduces the quality of the environment.

Terms relating to the duration of effects are as mainly described as:

- Temporary effect - lasting one year or less;
- Short term effect - lasting one to seven years;
- Medium term effect - lasting seven to fifteen years;
- Long term effect - lasting fifteen to sixty years; and
- Permanent effect - lasting over sixty years.

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A qualitative approach was used in this evaluation, generally following the significance classification in Table 6.2, and through professional judgment. The significance of a predicted impact is based on a combination of the sensitivity or importance of the attribute and the predicted magnitude of any effect. Effects are identified as beneficial, adverse or negligible, temporary or permanent and their significance as major, moderate, minor or not significant (negligible).

Table 6.2: Assessment Criteria

Sensitivity	Magnitude				
	Very High	High	Medium	Low	Negligible
High	Major	Major	Moderate	Moderate	Minor
Medium	Major	Moderate	Moderate	Minor	Negligible
Low	Moderate	Moderate	Minor	Negligible	Negligible

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Negligible	Minor	Minor	Negligible	Negligible	Negligible

In order for a potential effect to be realised, three factors must be present. There must be a source or a potential effect, a receptor which can be adversely affected, and a pathway or connection which allows the source to effect the receptor. Only when all three factors are present can an effect be realised.

The site investigation data and existing monitoring data enabled predictive modelling to be carried out. LandSim Version 2.5 (Golder Associates, 2007) and diffusion modelling (EA, 2004) was undertaken to supplement the impact assessment. LandSim is used to predict leachate concentrations and elevations during the lifetime of the landfill and to estimate advective fluxes from the landfill when leachate heads exceed groundwater levels in the surrounding clay subsoils and the potentiometric surface in the aquifer unit.

The Environment Agency's *Contaminant fluxes from hydraulic containment landfills spreadsheet v1.0* has been used to predict concentrations of the priority contaminants at their respective compliance points, through the process of diffusion when leachate heads are below groundwater levels in the surrounding subsoils.

6.3 RECEIVING ENVIRONMENT/BASELINE DESCRIPTION

6.3.1 Historical & Recent Geological Information from Literature Review

Soils

The distribution of soil types in the vicinity of the existing facility is shown on Figure 6.1, which is an extract from the Soils Map of Ireland, prepared by the National Soil Survey (1980). The soil map indicates that the principal dominant soil within the site comprises basin peat deposits. The entire site footprint is mapped as peat soils. However, based on site data, in some areas of the existing landfill, peat was completely removed.

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Quaternary Geology

The origin of the unconsolidated materials in this area is associated with the movement and deposition from the Irish Ice Sheet during the last Ice Age. The last Ice Age occurred during the Quaternary Period (1.6 million years to 10,000 years ago), which is the most recent period in the geological timeframe.

The Quaternary map (2004), produced by the GSI as part of the Groundwater Protection Scheme for County Kildare, indicates that the landfill activity boundary is covered with peat deposits (Figure 6.2). This is supported by the Teagasc Subsoil (Parent Material) dataset which is available on the GSI website. The free draining lands on the verge of the applicant's property and underlying agricultural lands bordering the site are underlain by '*Till chiefly derived from Limestone*' (GSI website). This till is known to underlie the peat material within the site.

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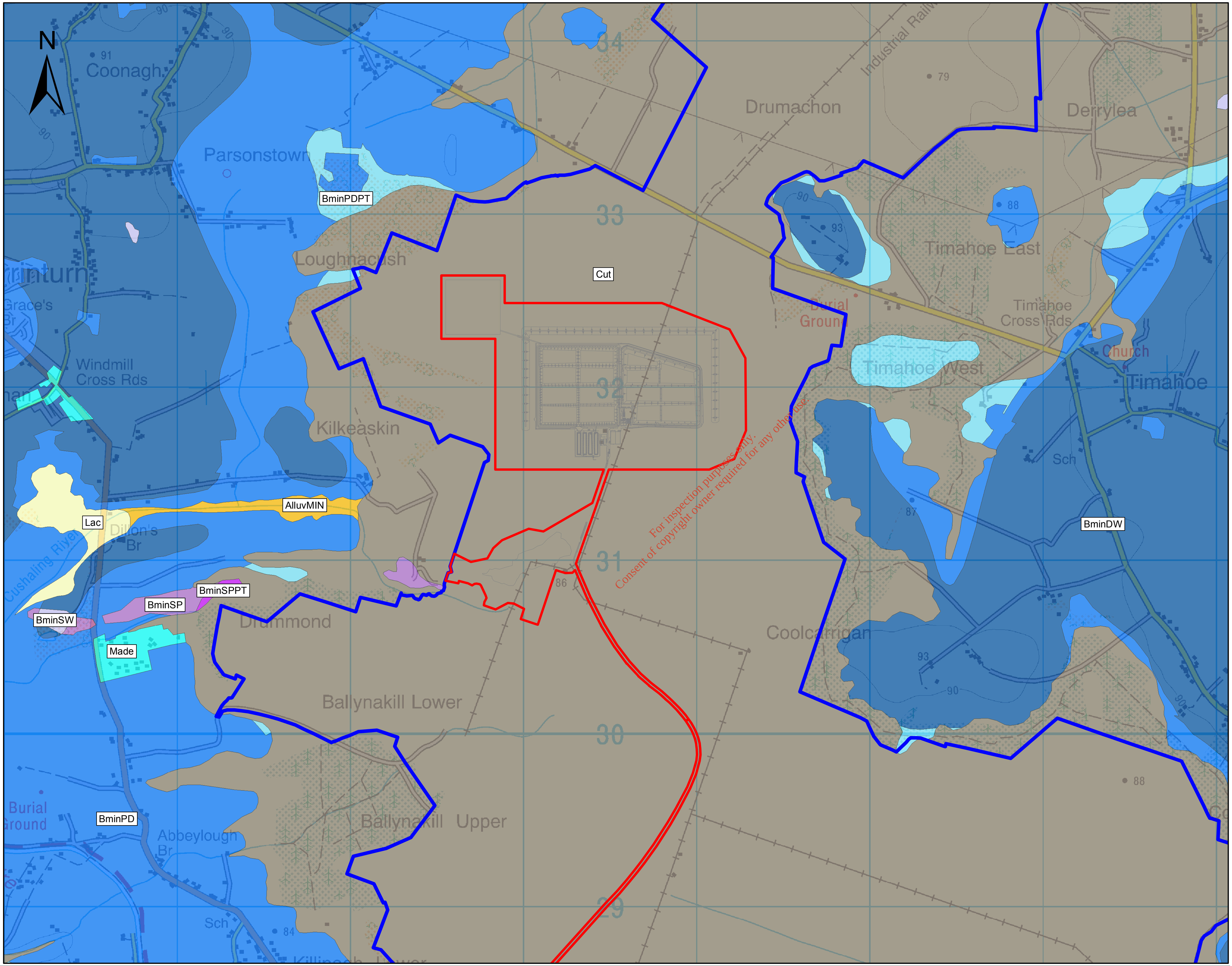

Legend

- Site Boundary
- Bord na Móna Ownership Boundary
- Existing MSW Landfill

Soils

BminDW	Deep well drained mineral
BminPD	Deep poorly drained mineral
BminPDPT	Poorly drained mineral soils with peaty topsoil
BminSW	Shallow well drained mineral
BminSP	Shallow poorly drained mineral
BminSPPT	Poorly drained mineral soils with peaty topsoil
Lac	Alluviums
Cut	Peats
AlluvMIN	Alluviums
Made	Made Ground

0 125 250 500 750 1,000
Metres

NOTES

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Issue	Date	Description	By	Chkd.
D01	AUG '18	EIAR Issue	F.H.	J.D.

Client:
BORD NA MÓNA
Naturally Driven

Project:
EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:
REGIONAL SOIL TYPES

Scale @ A3: 1:20,000

Prepared by: F.Healy
Checked: J. Dillon
Date: August 2018

Project Director: D.Grehan

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Figure 6.1

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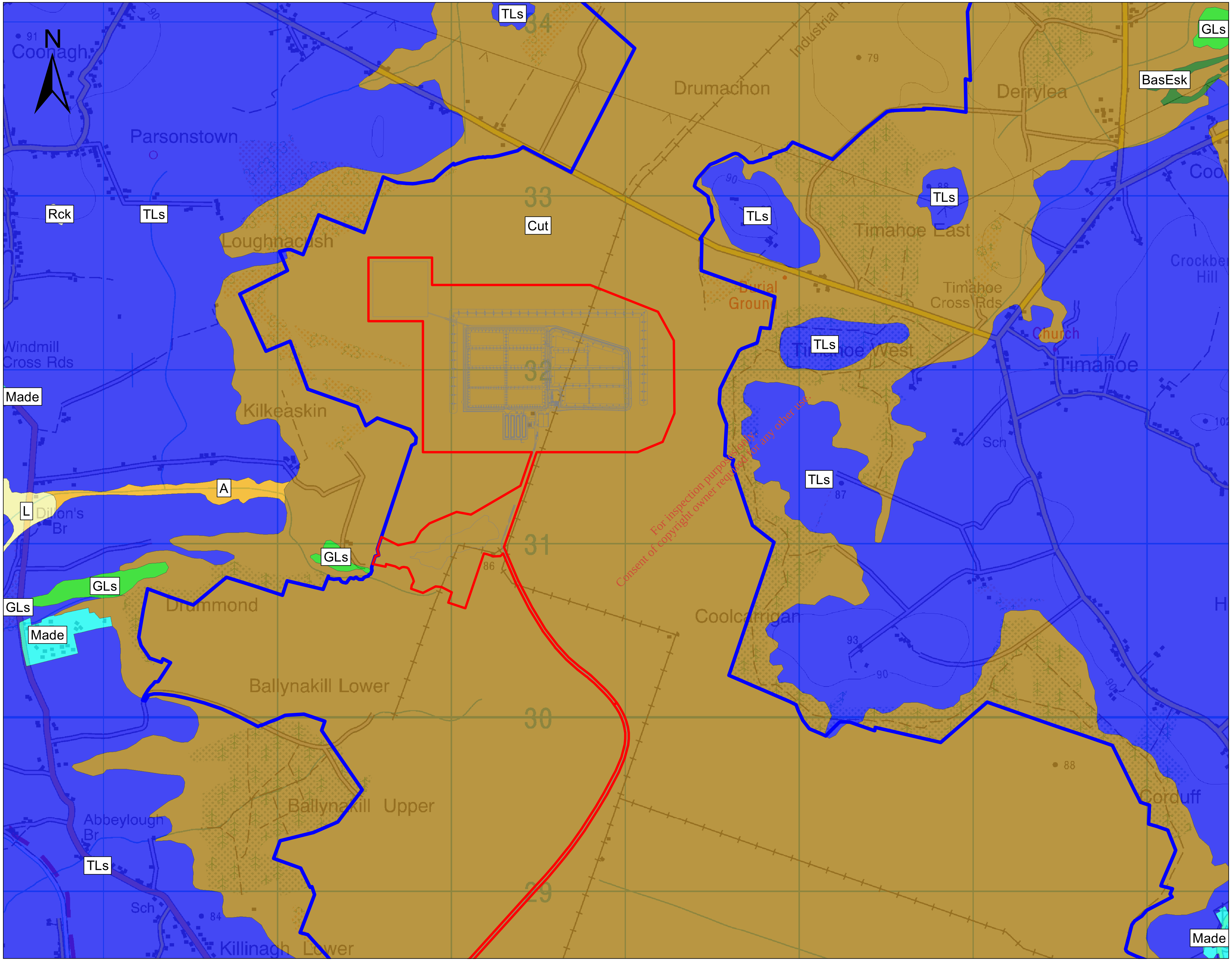

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Legend

- Site Boundary
- Bord na Móna Ownership Boundary
- Existing MSW Landfill

Subsoils

- A Alluvium
- Cut Cutover Peat
- GLs Limestone sands and gravels (Carboniferous)
- L Lake sediments undifferentiated
- Made Made ground
- Rck Bedrock at surface
- TLs Limestone till (Carboniferous)

0 125 250 500 750 1,000
Metres

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Issue	Date	Description	By	Chkd.

Client:

BORD NA MÓNA
Naturally Driven

Project:

EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:

REGIONAL SUBSOIL TYPES

Scale @ A3: 1:20,000

Prepared by: F. Healy
Checked: J. Dillon
Date: August 2018

Project Director: D.Grehan

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Figure 6.2

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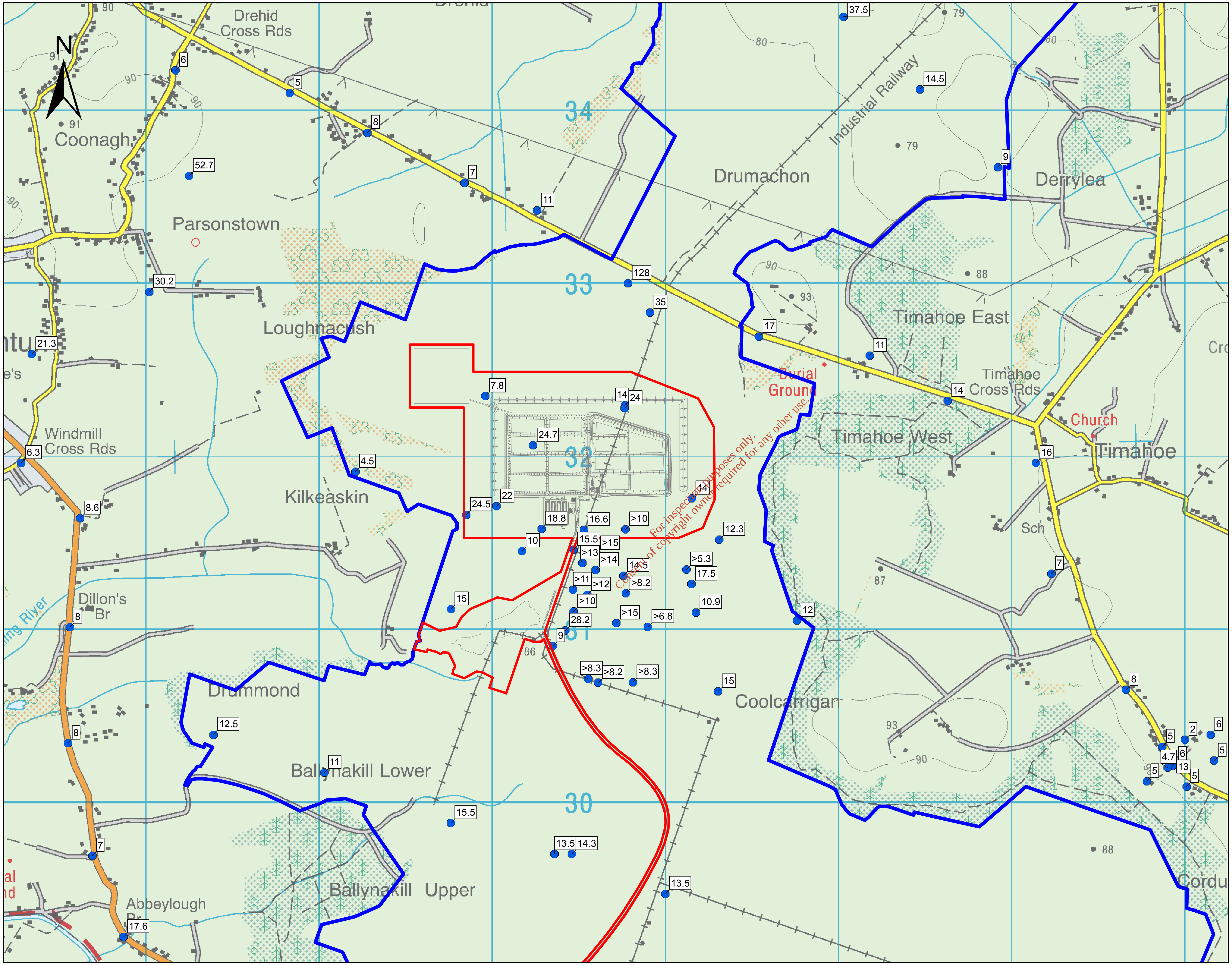

Legend

- Site Boundary
- Bord na Móna Ownership Boundary
- Existing MSW Landfill
- Depth to Bedrock (metres)

0 125 250 500 750 1,000
Metres

NOTES

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D01	AUG '18	EIAR Issue	F.H.	J.D.

Client:
BORD NA MÓNA
Naturally Driven

Project:
EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:
DEPTH TO BEDROCK

Scale @ A3: 1:20,000

Prepared by:	Checked:	Date:
F. Healy	J. Dillon	August 2018

Project Director: D.Grehan

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Figure 6.3

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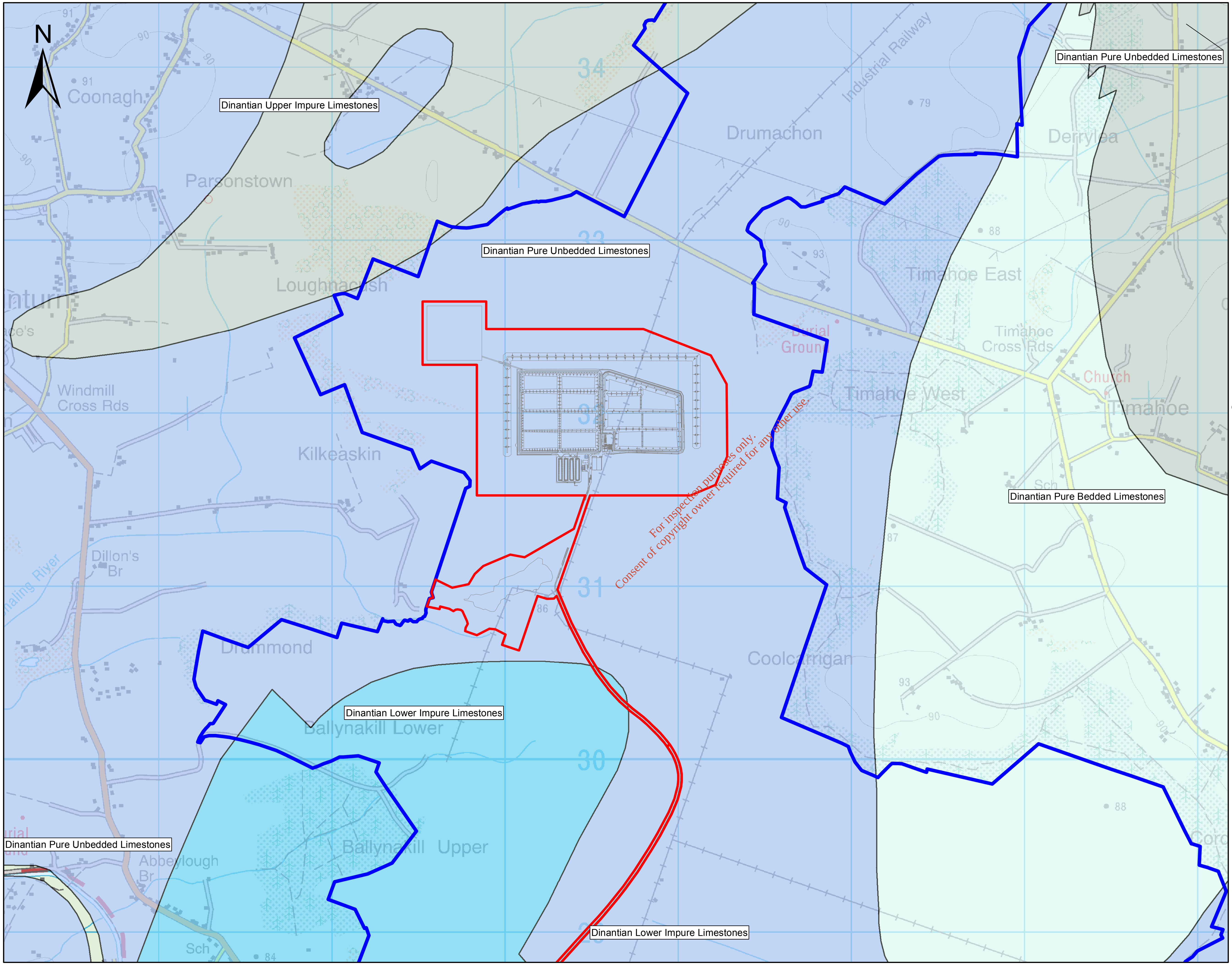

Legend

- Site Boundary
- Bord na Móna Ownership Boundary
- Existing MSW Landfill

Bedrock

- Dinantian Lower Impure Limestones
- Dinantian Pure Bedded Limestones
- Dinantian Pure Unbedded Limestones
- Dinantian Upper Impure Limestones
- Depth to Bedrock (metres)

0 125 250 500 750 1,000
Metres

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D01	AUG '18	EIAR Issue	F.H.	J.D.

Client:
BORD NA MÓNA
Naturally Driven

Project:
EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:
REGIONAL BEDROCK GEOLOGY

Scale @ A3: 1:20,000

Prepared by: F. Healy
Checked: J. Dillon
Date: August 2018

Project Director: D.Grehan

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Figure 6.4
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Reference to the 19th century, 6-inch to 1-mile scale, field sheets indicates that the till comprises Clay and Gravel, with sporadic isolated lenses of Sand and Gravel interbedded with the till. The field sheets do not record any rock outcrops in the vicinity of the applicant's property.

Information available from the GSI open file records indicates that a number of mineral exploration boreholes were drilled in this area and data on the depth to bedrock are available from these records. Depth to bedrock information in the environs of the existing facility boundary from these GSI mineral exploration borehole records, are shown on Figure 6.3. These GSI records indicate that the Quaternary deposits are quite thick in this area with the depth to bedrock varying between 17 m and 35 m in the vicinity of the site.

Bedrock Geology

Reference to the published geological map for this area, the 1:100,000 scale Sheet 16 – Geology of Kildare-Wicklow (GSI 1995), indicates that this area of County Kildare is underlain by Carboniferous aged (355 million years to 290 million years ago) limestone deposits.

The Carboniferous bedrock forms low elevation ground and is covered by overburden deposits. Outcrops of Carboniferous bedrock are scarce in the vicinity of the site. The current understanding of the bedrock geology in this area is based on the extensive mineral exploration boreholes that have been drilled in this locality.

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Figure 6.4 is an extract from the GSI Sheet 16 publication and shows the lithological distribution in the vicinity of the existing facility and the broader succession groups, which are described below.

The Carboniferous limestone succession underlying the site was deposited in a shallow water shelf environment, which is referred to as the 'Kildare Shelf' succession. The 'Kildare Shelf' succession is bound to the west by the 'Portarlington Trough' succession and to the north by the 'Dublin Basin' succession. The Portarlington Trough and the Dublin Basin successions are described as basin successions that were deposited in a deeper marine environment following erosion of the Kildare Shelf succession. The Kildare Shelf succession in the vicinity of the site, based on the geological map, comprises the Boston Hill Formation, the Waulsortian Limestone and the Allenwood Formation.

- The Boston Hill Formation comprises rather uniform, thick successions of nodular and diffusely bedded, argillaceous limestones (fine grained limestone, comprising predominantly clay minerals) and subordinate thin shales. The contact with the Waulsortian Limestone is gradational.
- The Waulsortian Limestone consists mainly of pale grey biomicrite (a limestone consisting of skeletal debris and carbonate mud). The sediments commonly form individual and coalesced mounds with depositional dips of 30-40 degrees. Argillaceous bioclastic limestones are interbedded with the Waulsortian Limestones in the study area.
- The Allenwood Formation comprises peloidal and crinoidal limestone and minor oolite at the base

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with micrites and minor shales overlying and mainly pelsparite (limestone consisting of peloids and spary-calcite) at the top of the succession. The Edenderry Oolite Member, which is part of the Allenwood Formation, is not distinguished on all locations of the map due to its irregular distribution.

- The Dublin Basin depositional succession and the Portarlington Trough depositional succession are dominated by the Calp Limestones. The term 'Calp' is used to refer to the various basinal limestone and shales occurring in these successions. The Calp units generally consist of dark grey, fine grained, graded limestone with interbedded black shales. The variation in bed thickness, grain size, colour and proportion of shale is a feature of the depositional environment in which these sediments were deposited in the basin.
- The structural geology of the Carboniferous Limestones is poorly understood, and any faults shown on the geological map are considered to be very tentative, as indicated by the GSI. The poorly understood tectonics is due to the poor control of the bedrock geology as a result of the lack of outcrop exposure.

6.3.2 Geological Heritage

The GSI provides scientific appraisal and interpretative advice on geological and geomorphological sites and is responsible for the identification of important sites that are capable of being conserved as Natural Heritage Areas (NHAs). The National Parks and Wildlife Service (NPWS) of the Department of Culture, Heritage and the Gaeltacht (DCHG) have the responsibility of designation and management of sites, with appropriate advice from GSI.

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The GSI has also determined a secondary list of County Heritage Areas, which may be considered for protection at local authority functional control level (i.e. may be included in County Development Plans). There are no Geological heritage sites within 2 km of the existing facility.

6.3.3 Groundwater Status

Hydro-ecology conditions in the vicinity of the existing facility are considered to be of low sensitivity, with no Groundwater Dependent Terrestrial Ecosystems (GWDTEs) in close proximity to the site; nor are there any GWDTEs located downgradient of the existing facility.

The nearest GWDTE to the existing facility is Ballynafagh Lake, located 5.8 km to the east. Ballynafagh Lake is not located in the same groundwater/surface water catchment as the Drehid WMF. Ballynafagh Lake is an artificial waterbody created as a reservoir to feed the Grand Canal. A review of surface water drainage patterns, topography, soils and bedrock indicates that Ballynafagh Lake is fed by surface water runoff and a number of small springs which rise to the north-east of the lake. This was confirmed during a walkover of lands at Ballynafagh Lake in June 2007, November 2011 and July 2016 where groundwater was seen to discharge to deep drainage ditches to the north-east of the lake.

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The study area is located within the 'Kildare Groundwater Body', of the South Eastern River Basin District. The Kildare Groundwater Body is currently achieving Good status (www.epa.ie accessed on 27/07/2018).

6.3.4 Geological Information Gathered from Site-Specific Investigations

Nature and Extent of Peat Material

Visual assessment of the existing facility indicates that peat deposits occur across the majority of the site. Peat is a soil that is made up of the partially decomposed remains of dead plants that have accumulated on top of each other in waterlogged conditions over thousands of years. Peat is brownish-black in colour and in its natural state is composed of 90-95 % volume/volume water and 5-10% solid organic material. The entire site footprint is underlain by peat soils. Based on the Von Post scale, the peat varies from H2-H7 and is predominantly dry (B1 to B3). Laboratory moisture content of the peat typically varies from 100 to 500%[27].

Industrial harvesting of the peat deposits at the site has occurred in the past. In order to allow for such harvesting of the peat, a network of large drains was opened up across the bog to reduce the moisture content of the material, thus allowing the land to be traversed by specialist plant and machinery. The appearance of the bog is heavily influenced by the drainage network, which divides the bog into a number of sections. The topography of the site is heavily influenced by the previous industrial activity, where the harvesting has resulted in a relatively flat relief across the site.

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The remaining peat deposits within the site have been investigated on a number of occasions using different intrusive and non-intrusive methods.

- Bord na Móna undertook a survey of the site in mid-1980s, using a ground penetrating radar technique, to determine the thickness of peat overlying glacial overburden;
- A peat probe investigation was undertaken in January 2002, based on a 100 m x 100 m grid at a total of 205 No. locations. The probing exercise indicated that peat thickness varies from 0.4 m to 2.3 m across the area of land surveyed on Timahoe Bog;
- Additional information regarding the peat thickness was available from the 32 No. trial pits excavated by Fehily Timoney & Company (FTC) in 2002;
- As part of the site investigation programme undertaken by TOBIN, the peat thickness was further investigated during the excavation of 37 No. trial pits;
- Further pre-construction site investigations of the borrow pits and administrative area (associated with the existing waste management facility) was undertaken by TOBIN and comprised 42 No. trial pits;
- Peat Probing Survey was carried out on behalf of TOBIN by BRG Ltd to test the depth of the peat and soft clay along route of the access road. The depths of the peat along the route of the access

[27] Oven drying method of peat soil return results >100% in accordance with British Standard BS1377-2

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road varied from 0.1 m – 7.7 m with an average of 1.5 m;

- Trial pitting by Causeway Geotech in 2016 to test peat and subsoil depths. Testing of soil samples was undertaken to characterise the subsoil;
- Trial pitting by TOBIN Consulting Engineers in 2016 to determine peat and subsoil characteristics of the ground in the vicinity of the existing facility; and
- Peat probing by Apex in 2016 to determine peat depths in the vicinity of the existing facility.

Based on the above sources of information, the bottom contours of peat deposits remaining across the site are shown in the geophysical survey reports in Appendix 6.1 (note the 2016 report (Ref. AGL16157_01) was prepared as part of the Proposed Development EIAR and includes references to proposed future development lands). The permitted landfill footprint was positioned to, inter alia, minimise the volume of peat that was required to be moved.

Pre-development, peat depths ranged from approximately 0.5 m to 2.3 m at the landfill footprint with the shallowest peat depths located towards the central area of the existing landfill. Peat depths deepen to the south (2.5 m) at the infrastructural buildings. To the east and south of the landfill footprint, peat depths are typically 1 m to 1.5 m above the mineral subsoil.

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Subsoil Geology

The quaternary information detailed in this section is based on site investigations undertaken by FTC and TOBIN on the following dates:

- December 2002;
- March 2003;
- April to June 2006; and
- January to August 2016.

Site investigation information was also sourced from the site selection study (2002) undertaken by Fehily Timoney & Company (FTC) on behalf of KCC. This information is interpreted to determine the lateral and vertical variations across the site. The sources of site investigation data available from within the site comprise:

- 79 trial pit logs undertaken by TOBIN (2002);
- 12 boreholes drilled on behalf of TOBIN (2002);
- Geophysical surveys of the site, undertaken in January 2002 and November 2002 by APEX Geoservices Ltd;
- 32 trial pit logs undertaken by FTC (2003);
- 9 borehole logs drilled on behalf of FTC (2003);
- Peat Probe Survey (BRG Ltd) April 2006;
- Trial Pits and Boreholes (IGSL) 2006;

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- 7 Boreholes and 9 Trial Pits by Causeway Geotech January 2016;
- 30 Trial Pits and Soil exposure mapping by TOBIN– June 2016;
- Geophysics survey of the site, undertaken by Apex Geophysics in July 2016; and
- 4 Boreholes by IGSL in July 2016.

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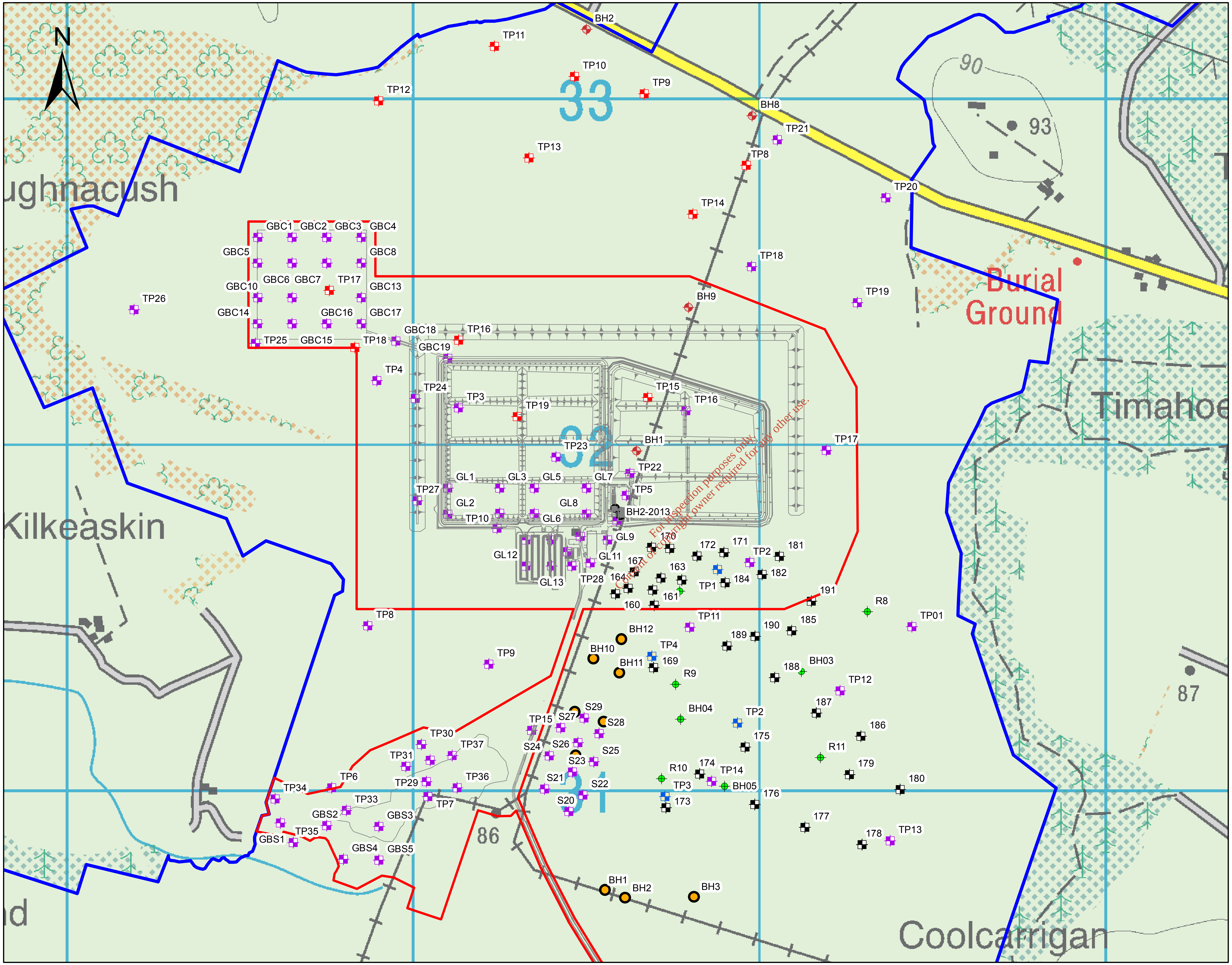

Legend

- Site Boundary
- Bord na Móna Ownership Boundary
- Existing MSW Landfill
- 2001 FTC BH
- 2001 FTC TRIAL PITS
- 20003-2008 TOBIN Trial Pits
- 2013 BHs
- 2016 Cause Way Trial Pits
- 2008 IGSL Trial Pits
- 2016 Trial Pit TOBIN
- 2003-2014 IED Licence Monitoring Wells
- 2016 CG and IGSL Boreholes

0 200 400
Metres

NOTES

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Issue	Date	Description	By	Chkd.

Client:
BORD NA MÓNA
Naturally Driven

Project:
EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:
SITE INVESTIGATION AND ENVIRONMENTAL MONITORING LOCATIONS

Scale @ A3: 1:10,000

Prepared by: F. Healy | Checked: J. Dillon | Date: August 2018

Project Director: D.Grehan

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Draft:
Figure 6.5
D01

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The locations of trial pits and boreholes are shown on Figure 6.5 and the descriptive logs from these boreholes are presented in Appendix 6.2. The trial pit depths varied within the range of 2.1 m to 5.5 m below ground level (bgl). Most trial pits were terminated due to collapsing side walls, unstable ground conditions or the compactness of the subsoil material at depth. Bedrock was not encountered in any trial pits excavated within the vicinity of the existing facility. The average depth of peat above the mineral subsoil in the vicinity of the landfill is 1.0 m.

No significant marl layer was encountered in the boreholes or trail pits located in the vicinity of the existing facility. Minor horizons (0.2 m) of soft organic clays/silts are present underlying the peat with occasional to rare rootlets/rhizomes 0.3 m into the underlying till material in the land to the south-east of the existing facility.

The subsoils which underlie the site are predominantly fine grained. The composition of the subsoil, recorded from each trial pit, was relatively consistent across the site, with some notable exceptions. The subsoils encountered in the trial pits underlying the peat comprise soft to very stiff, grey to blue-grey, SILTs, CLAYs and SILT/CLAYs with occasional to frequent sub-angular to sub-rounded gravels and cobbles. Cobbles are predominantly argillaceous limestones (>75%) with occasional siltstone, sandstones and pale limestones.

A sharp increase in stiffness occurs at >3 m bgl with estimated acceptable ground bearing pressure of >500 kPa[28]. The average percentage fines were 48% and varied from 34% to 76% in the lands adjacent to the existing landfill footprint. Shell and Auger Boreholes confirmed the presence of very stiff, grey gravelly SILT/Clay throughout the area.

A lens of cross bedded, slightly to very silty, sand and gravel is present underlying the peat deposits, east of the Compost Facility (TP167). The gravel clasts vary from angular to sub-rounded, with clasts generally ranging from pebble to cobble size.

The extent of the sand and gravel was defined through the excavation of a number of trial pits in this north western area of the existing facility in 2016. The interface between the sand and gravel deposit and the silt/clay appears to be sharp, with a distinctive change over a short lateral distance (<5 m). The sand and gravel deposit at this location is both horizontally and vertically limited.

In tandem with the trial pitting and borehole programme, Apex Geoservices Ltd. was contracted to carry out a geophysical survey of the site in 2002 and to update the survey in 2016 (Appendix 6.1). The objective of the non-intrusive geophysical survey, in terms of Quaternary characterisation, was to indicate the type and thickness of overburden and determine any lateral variation of overburden type.

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[28] Causeway Geotech (2016)-Drehid Waste Management Facility– Site Investigation

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Site investigation data from previous reports were consistent with the geophysics data. The results of the geophysical survey were good in extrapolating the coverage within the areas where intrusive investigations were not undertaken.

A good correlation was observed between the 2D Resistivity survey and the intrusive site investigation data, with respect to overburden thickness. The resistivity values and seismic refraction values (velocities) recorded during the survey were typical for the peat upper layer and the underlying, stiff, gravelly SILT/CLAY layer.

The depth to bedrock under the existing facility is > 10 m below ground level (m bgl), based on borehole data. Geophysical surveys have confirmed the borehole data and identified deeper bedrock (>120 m) to the centre of the existing landfill. The minimum depth to bedrock identified in the Apex geophysical survey is 9 m. As part of the site investigations undertaken on behalf of Bord na Móna in 2003, a deep borehole was drilled, GW7, which continued to a depth of 128.3 m bgl before bedrock was encountered.

In order to define the depth to bedrock partially underlying the existing MSW Landfill and determine the nature of the bedrock, Briody Aquadrill Ltd., under the joint supervision of TOBIN and the Geology Department of Trinity College Dublin, were contracted to drill a borehole (borehole GW7) towards the centre of the deep channel, to the north of the site. This borehole was completed in June 2003. The borehole continued through 128.3 m of unconsolidated material before encountering bedrock. The unconsolidated material recorded during drilling was recovered and logged. The borehole log is included in Appendix 6.2 and shows that Grey, Sandy Clay and Gravelly Clay were recorded to a depth of 8.25 m bgl.

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A lens of granular material, which was interbedded with the gravelly Clay, was recorded from 8.25 m bgl to 21 m bgl. From 21 m bgl to 63.7 m bgl, grey Clay and gravelly Clay was noted. A distinctive interface between the Quaternary unconsolidated material and older unconsolidated material was noted at 63.7 m bgl. The older deposits comprised orange, yellow and brown Clays from 63.7 m bgl to 100.3 m bgl and thereafter white Silcrete, with white, pale grey, orange and pinks clays were noted to a depth of 115.8 m bgl. A very compact, grey/purple/yellow Clay was recorded from 115.8 m bgl to 128.3 m bgl, at which depth bedrock was encountered. The Edenderry Member of the Allenwood Formation was recorded at the base of the borehole, based on description of the rock chippings recovered.

Based on the findings of the deep borehole drilling and other pertinent information collected during the site investigation programme, the valley feature is not considered to result from dissolution of the bedrock, i.e. it is not karstic in nature. The borehole drilling on the edge of the valley feature (Ref. BH1 & BH9 – FTC logs and GW6PW, GW1D, GW3D – TES logs) recorded competent rock, with low to moderate permeability characteristics. The unconsolidated material recorded within the valley feature would also disagree with the hypothesis that the valley is a dissolution/karst feature.

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The occurrence of the deep overburden channel within the Drehid landholding is not unique. Aeromagnetic data for Central Ireland identifies a remarkable pattern of northeast to southwest trending linear magnetic and negative gravity anomalies, some of which are considered to be related to tectonic and volcanic activity during the Tertiary period (65 million years to 1.6 million years ago) (Williams and Brown, 1986). Many of the gravity anomalies correlate with zones of anomalously high depth to bedrock, some of which are considered to be fault related. The main features identified on the aeromagnetic data are up to 3 km wide and 165 m deep. The faulting along these linear features would have created catchment boundary conditions and controlled the palaeo-drainage from the Tertiary landscape.

The Tertiary Period (65 to 16 million years ago) in the British Isles was marked by a distinct pattern of erosion and deposition. Due to tectonic activity, east Scotland and northeast Ireland were uplifted, with this area commonly termed the Thulean High. As outlined above, this uplifted area was transected by high energy river channels and underwent very rapid river erosion, with large rivers then crossing the midlands of Ireland before depositing their load in the faulted basins off the west coast of Ireland such as the Erris Trough and Porcupine Basin.

The steeply incised valley does not appear to be of sufficient width to concur with the major faults identified on the aeromagnetic data. Such a feature is considered to have resulted from powerful fluvial erosion (i.e. river erosion) forces resulting in progressive deepening of the valley floor. These deep river channels flowed across arid plains similar in appearance to modern arid environments. In later times, perhaps when subsidence of a fault block resulted in a lowering of the level of the terrain, the fluvial system stagnated and lakes resulted. These lakes would have resulted in the deposition of great thickness of clays.

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During this period there was large scale volcanic activity in the north of Ireland and Scotland associated with the Antrim Plateau Basalts. This released large quantities of volcanic ash, which were deposited as far down as the midlands of Ireland. When this alkaline volcanic ash fell on water bodies such as lakes, it not only resulted in the deposition of Jasper (mineral), but also resulted in an increase in the pH of the water, on which the ash was deposited as fall-out. This increase in pH to levels above pH 8.6 resulted in a very unusual occurrence - conditions suitable for silica to come out of solution and be deposited as Silcrete. These Silicretes often formed in stagnant lakes and so are often interbedded with tertiary clays which have distinct colours such as orange and very light browns. As the Tertiary period advanced, this entire landscape may again have been buried in further sediment deposited over the whole area.

Later in the quaternary period, global temperatures fell and the landscape would have been covered in glaciers which would have advanced and retreated several times eroding all soil and stripping the terrain surface down to bare rock, which it then eroded. All evidence of the Tertiary arid landscape was obliterated from the entire island of Ireland except for a few isolated protected pockets. Deep buried river gorges would have been too deep for the glacial action to reach and so isolated pockets of the Tertiary

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deposits survived. The retreating glaciers deposited a layer of clay dominated till over the whole area, with bog later forming on top of this as the glaciers retreated and the climate warmed.

During the early Tertiary period Ireland was an arid area, with very low rainfall, but the area was transected by a number of deep river gorges, which were very prone to flash flooding, resulting in the very rapid incision of the gorge into the landscape, which was probably undergoing tectonic uplift at the time. The waters flowing through the gorge flowed from the uplands of west Scotland and north-eastern Ireland, carrying large amounts of sediment to the ocean basins to the west. Due to the flashy nature of the river, which scoured out the bed, there was very little deposition of rivers sediments. On the contrary, the area was one of rapid erosion and hence there are no sediments to record this period in the channel's history. However, the shape of the channel very clearly indicates the very rapid erosion which cut down into the arid plane, but at some point, the drainage in the area changed dramatically. Perhaps the entire plain on which the river flowed subsided due to faulting, or sea levels rose, resulting in a decrease in the elevation head of the river. The entire river flow slowed, very dramatically, with the area rapidly becoming a low energy environment and deposition site, with deposition of fine coloured clay sediments, often with a volcanic influence. The clays deposited are distinctive bright oranges and light browns, typical of the Tertiary clays. Jasper and Silcrete bands in the clay near the base of GW7, as well as reworked clasts of Silcrete in the deposits further up the succession also indicate that there was a volcanic content and influence on the clays which were deposited.

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As with any fluvial system, especially in a rapidly eroding area, the presence of minor channels and tributary canyons, as well as hanging river valleys, is to be expected. It is therefore not surprising that mineral exploration drilling has located several deep anomalies in depth to bedrock in the surrounding area, as detailed on the GSI depth to bedrock map suite for the Kildare Groundwater Protection Scheme, which records some dramatic changes in depth to bedrock in places.

The depth, width and very sharp edges of the feature, into which borehole GW7 was drilled in 2003, as well as the thickness of the clay deposits, are of a scale that is unusual in Ireland and would be considered very unusual for a karst feature. The level at which rock was encountered either side of the feature, and the rock quality shown by the 2-D Resistivity sections, show no evidence of karstification in the bedrock. It is highly improbable that the feature could be due to karstification on such a scale and that the adjacent bedrock would not show any indication of karstification.

The GSI, which has compiled the depth to bedrock maps and Groundwater Protection Scheme for the area, has no record of any karst feature in the Waulsortian Limestone in Kildare, with only 3 features (all in the Calp Limestone) being recorded for the county.

From the evidence of the 2002-2003 site investigations, including the geophysical survey and the drilling of the site, the clay filled, weathered-out valley feature identified at that time, is not believed to be karstic in nature. The feature is thought to be a Tertiary fluvial feature, which is filled with clay, with possible

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tributaries to this channel present in the area. The presence of deeper subsoil to the centre and south of the existing facility has no negative impact on the suitability of the site.

Bedrock Geology

The bedrock encountered within the site was generally in accordance with the GSI geologic map. Waulsortian limestone, which comprises pale grey, fine grained limestone, was encountered throughout most of the site (boreholes GW1D, GW4D and GW6). To the west and south of the site, where boreholes GW2D and GW3D were installed, dark argillaceous limestone was encountered. Boreholes R9 to R11 encountered mid to dark grey argillaceous limestones underlying the site. This rock is considered to be consistent with the description of the Boston Hill Formation.

The bedrock material encountered at the base of the deep borehole (GW7) was classified as the Edenderry Oolite Member of the Allenwood Formation based on material recovered during drilling. Bedrock was not encountered to a depth of 27.5 m bgl in borehole GW5, which is located close to the centre of the deep unconsolidated feature.

The site-specific borehole information suggests that the contact between the Boston Hill Formation and the Waulsortian Limestone extends further to the east than shown on the GSI geology map and may underlie the site. As the bedrock at the base of the deep borehole is the Edenderry member, the lithological divide between the Waulsortian and the Allenwood Formation extends further west than shown on the GSI geology map. Notwithstanding the difference in the lithological divides between the Waulsortian Limestone and the Boston Hill Formation/Allenwood Formation, the borehole drilling is generally consistent with the GSI geology map.

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The geophysical reports (2002 and 2016) recommended that the significance of dolomitisation, in terms of increased permeability, should be investigated. As part of the 2002 drilling and hydraulic testing programme, undertaken as part of the environmental baseline assessment, the significance of dolomitisation was assessed.

Dolomitisation of limestone bedrock can commonly lead to enhanced porosity of the rock, through chemical reaction. Hence, the presence of dolomitisation is an indicator that permeability may potentially be higher than an undolomitised rock. Though flow in the bedrock aquifer is limited due to the low gradient and small upgradient groundwater catchment.

The results of the 2002 geophysical survey were used in order to target borehole drill locations, so that control points could be used by APEX Geoservices Ltd. to refine their report. Minor dolomitisation was encountered during drilling of GW6. A Pumping test of GW6 showed the bedrock to have a low Transmissivity (permeability). The drilling records do not indicate any large groundwater strikes and the drill returns did not indicate any zones of notable weathering or solution, with the exception of borehole GW6 and GW7.

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The bedrock encountered in GW6 was weathered and partially dolomitised, however the borehole is located on the side wall of the incised unconsolidated valley feature. It could reasonably be expected that the erosion of the bedrock would have resulted in a degree of weathering on the side walls. The extent of the weathering does not continue laterally in the bedrock, as no weathering or solution of the bedrock was noted in borehole GW1, located close to GW6.

6.3.5 Geotechnical Analysis of Subsoil Material

Samples of the Quaternary material encountered within the site were obtained during site investigations. A total of 27 No. disturbed samples were obtained to determine the PSD of the unconsolidated material (10 in the 2002-2003 programme; 17 in the 2006 programme) from trial pits TP2, TP5, TP8, TP11, TP16, TP18, TP32, TP33, TP35 and TP36, GBS2, GBS3, GBS4, GBC3, GBC10 (2 Samples), GBC13, GBC16, GBC20, GL1, GL2, GL4, GL9, GL11, GL14, GL15 and GL16. They are considered to be representative of the fine-grained subsoil (SILT, SILT/CLAY, CLAY) that dominates within this site. Disturbed bulk samples were obtained from trial pits TP32, TP33, TP35, TP36 and GBS2, GBS3, GBS4 excavated within the Sand and Gravel deposit delineated to the south of the site

The grading of the disturbed bulk samples was determined by wet sieving, in accordance with Test 9.2 and 9.3 of BS1377: Part 2, 1990. All peat material was excluded from the sample. The results of the PSD laboratory tests are included in Appendix 6.3.

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The PSD laboratory results from trial pits TP2, TP5, TP8, TP11, TP16 , TP18, GBC3, GBC10 (2 Samples), GBC13, GBC16, GBC20, GL1, GL2, GL4, GL9, GL11, GL14, GL15 and GL16 confirm the field descriptions of Gravelly SILT/CLAY, gravelly SILT, and gravelly CLAY, as described in the trial pit logs based on on-site visual assessment. Gravelly SILT/CLAY is the dominant subsoil type. A summary of the laboratory testing is detailed below.

Table 6.3: Particle Size Distribution of Fine Grained Samples

Sample ID	% Clay	% Silt	% Sand	% Gravel
TP2	16	50	16	18
TP5	14	45	28	13
TP8	13	37	26	24
TP11	11	29	29	31
TP16	9	24	24	43
TP18	16	32	23	29
GBC3	6	36	24	34
GBC10	8	56	25	14
GBC10	10	41	22	28
GBC13	6	33	25	36
GBC16	7	56	21	16

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GBC20	8	37	24	31
GL1	9	42	19	30
GL2	8	42	26	24
GL4	12	38	21	29
GL9	8	17	55	18
GL11	5	15	35	35
GL14	5	11	20	59
GL15	14	14	22	41
GL16	8	37	33	21
BH02	**6**	**36**	**24**	**34**
BH03	**2**	**63**	**35**	**1**
BH04	3	71	21	5
TP 160	6.7	40.0	27	27
TP 162	5.0	44.0	50	1
TP 163	21.9	54.2	14	10
TP 164	9.8	34.1	27	29
TP 166	7.7	36.9	29	26
TP 167	6.1	49.0	33	12
TP 176	13.6	37.0	25	25
TP 180	10.7	36.9	26	26
TP 181	8.1	43.0	35	14
TP 183	12.5	47.9	23	17
TP 185	11.0	23.2	40	26
TP 187	7.1	36.9	27	29
TP 188	12.0	52.2	21	15
Average	9.3	38.9	26.9	24.3

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The PSD laboratory results from trial pits TP32 *(Sample Ref. THGV1*[*]*)*, TP33 *(Sample Ref.: THGV2)*, TP35 *(Sample Ref.: THGV4)* and TP36 *(Sample Ref.: THGV3)* confirm the field description of Sand and Gravel, as described in the trial pit logs. A summary of the laboratory testing is detailed below:

Table 6.4: Particle Size Distribution of Sand and Gravel Samples

Sample ID	% Silt/Clay	% Sand	% Gravel
TP32	2	38	60
TP33	2	51	47

[*] Sample Refs given in this instance for cross reference with copy of PSD results from laboratory included in Appendix C-VI

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TP35	1	39	60
TP36	1	45	54
GBS2	5	29	66
GBS3	2	19	52
GBS4	6	50	42
Average	3	39	58

Subsoil Permeability

To determine the vertical permeability of the glacial deposits, 10 No. undisturbed soil samples were obtained for tri-axial constant head permeability analysis. The samples were obtained from the glacial subsoil material in the vicinity of the landfill footprint and the clay borrow area, however the permeability values are considered representative of the grey gravelly SILT/CLAY which dominates within the entire site.

The laboratory test sheets of the most recent (2016) tri-axial constant head permeability analysis are included in Appendix 6.4, with the results summarised below.

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Table 6.5: Results of Triaxial Constant Head Permeability Analysis

Sample Ref.	Trial Pit Ref.	Vertical Permeability (m/sec)	Mean Effective Stress (kPA)
TH1	TP22	6.3×10^{-10}	24
TH2	TP23	5.4×10^{-10}	25
TH3	TP24	6.0×10^{-10}	25
TH4	TP25	6.3×10^{-10}	24
TH5	TP26	7.1×10^{-10}	26
TH6	TP27	1.1×10^{-9}	25
TH7	TP28	1.5×10^{-9}	25
3-1	GBC3	4.5×10^{-10}	80
10-1	GBC10	2.2×10^{-10}	80
16-1	GBC16	4.0×10^{-10}	80
	$K_{(V)}$ Average	**6.78×10^{-10}**	**41.4**

The visual description of the material by Glovers Site Investigation Ltd. generally concurs with the description noted by TES. The test results indicate that the in-situ natural vertical permeability of the quaternary overburden varies between 2.2×10^{-10} m/s (lower limit) to 1.5×10^{-9} m/s (upper limit), with an average vertical permeability of 6.78×10^{-10} m/s. Permeability values in this range are considered to be low permeability and in the lower range of permeability values for Irish Tills.

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6.3.6 Groundwater Vulnerability

Groundwater protection is based on the concept of groundwater contamination risk and risk management. The conventional hazard-pathway-target model for environmental management can be applied to groundwater risk management. The risk of contamination of groundwater depends on three elements.

Firstly, the hazard in this case is represented primarily by the existing landfill and, to a lesser extent, by the composting facility, the designs of which are detailed in Chapter 3 (Description of the Existing Environment, Current and Ongoing Activities). The high specification design criteria are not accounted for in the groundwater protection scheme; however, it is an implicit requirement that the risk of potential contamination is minimised. Secondly, the target is represented in this case as the top of the bedrock aquifer. The GSI have classified the bedrock aquifers underlying the site as Locally Important. No beneficial users of groundwater (groundwater abstractions) have been identified within 1 km (closest domestic dwelling is in excess 1 km of the landfill footprint).

The final part of the model is the potential pathway linking the hazard to the target, in this case the low permeability Silt/Clay overburden (average vertical permeability is 6.78 x 10^{-10} m/s). PSD data indicates the subsoil material is comprised of a SILT/CLAY with a high % fines.

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Groundwater vulnerability is a term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities. The vulnerability category is based on the relative ease with which infiltrating water and potential contaminants may reach groundwater in a vertical or sub-vertical direction. The permeability and thickness of the subsoil, which influences the attenuation capacity, are important elements in determining the vulnerability of groundwater.

A groundwater vulnerability map for County Kildare has been prepared by the GSI as part of the Groundwater Protection Scheme. According to the information available at present from the GSI, the vulnerability rating for the site is classified as Low over the majority of the site, which is the rating that affords greatest natural protection against contamination.

The borehole records for the site indicate that rockhead varies from 9 m at the composting facility to 128 m to the centre of the site (GW7 – adjacent to the L5025 road). Rockhead was encountered at a depth of >10 m based on borehole and geophysics data.

Testing conducted on the gravelly silt/clay indicated the subsoil material has a low vertical permeability, between 1x10^{-9} m/s to 7x10^{-10} m/s respectively. Significant sand and gravel deposits do not underlie the existing landfill footprint.

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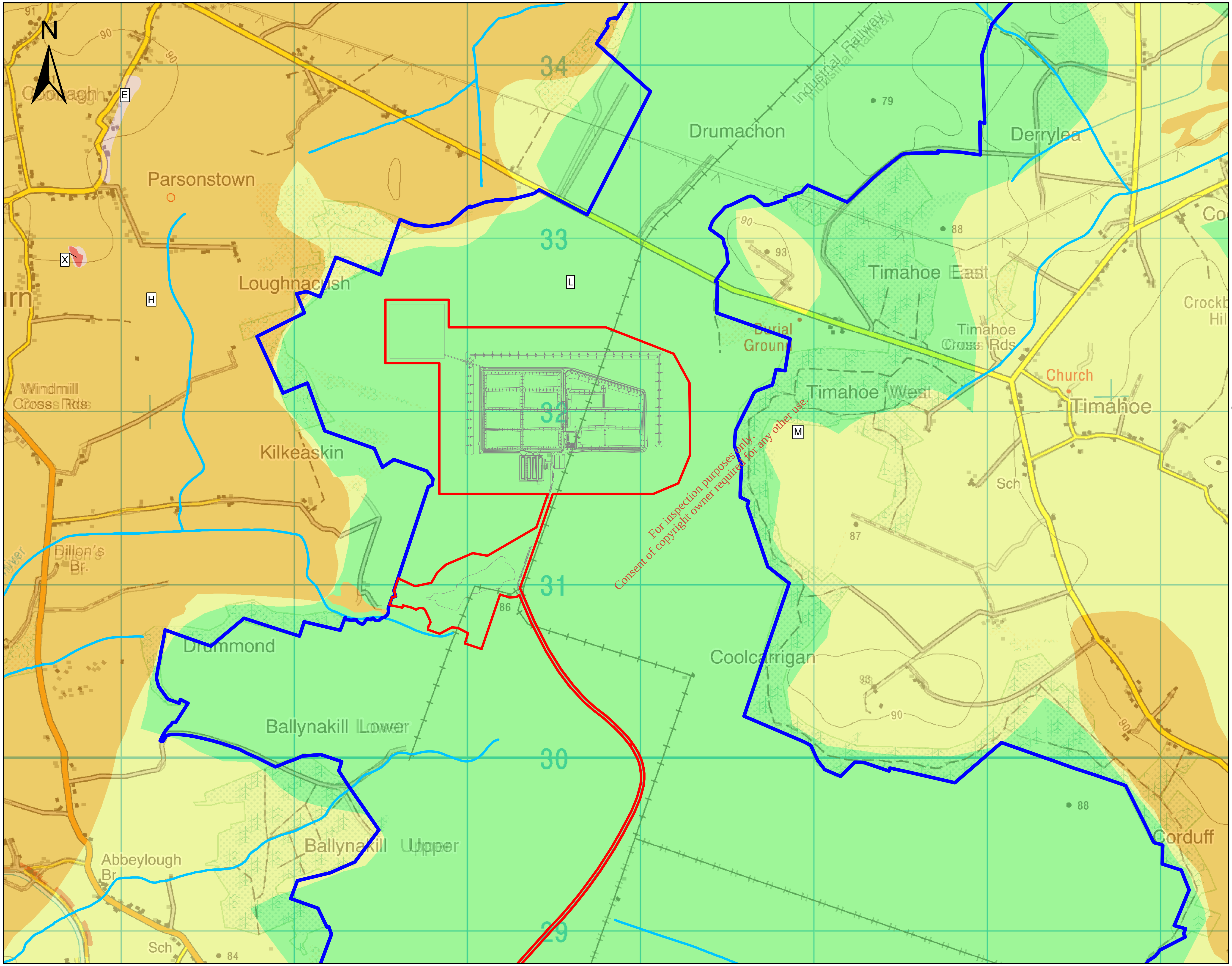

Legend

- Site Boundary
- Bord na Móna Ownership Boundary
- Existing MSW Landfill

GSI Vulnerability

- X (Rock near surface or Karst)
- E (Extreme)
- H (High)
- M (Moderate)
- L (Low)
- Rivers
- Lakes

0 125 250 500 750 1,000
Metres

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL DRAWINGS TO BE CHECKED BY THE CONTRACTOR ON SITE
3. ENGINEER TO BE INFORMED OF ANY DISCREPANCIES BEFORE ANY WORK COMMENCES
4. ALL LEVELS RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.
D01	AUG '18	EIAR Issue	F.H.	J.D.

Client:
BORD NA MÓNA
Naturally Driven

Project:
EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:
REGIONAL GROUNDWATER VULNERABILITY

Scale @ A3: 1:20,000

Prepared by: F. Healy | Checked: J. Dillon | Date: August 2018

Project Director: D.Grehan

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Figure 6.6
D01

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6.3.7 Groundwater Protection Response Matrix

The Groundwater Protection Response Matrix for Landfills (GSI, 1999), included in Appendix 6.5, has defined hydrogeological situations, which are considered suitable or unsuitable for landfill facilities. The groundwater protection responses outline the likely acceptability of landfills in each groundwater protection zone and the recommended level of response/restriction, which depends on the groundwater vulnerability, the value of the groundwater environment and the contaminant loading.

Using the aquifer classification, in association with the vulnerability rating, a groundwater resource for the particular site is determined. With regard to the landfill facility, the existing groundwater resource at the landfill sites is determined as Ll/Low (locally important aquifer with a vulnerability rating of Low), which is assigned a R1 rating – Acceptable subject to guidance in the EPA Landfill Design Manual or conditions of an IED Licence.

Based on the site investigation data, the aquifer underlying the existing facility has been classified as an Ll aquifer, i.e. (locally important aquifer) with the groundwater vulnerability having been classified from site investigation as Low to Moderate groundwater vulnerability. Therefore, using the GSI Response Matrix for the siting of Landfills, the groundwater protection responses are R1 and R2, based on Low to Moderate groundwater vulnerability. The response matrix deems that the siting of a landfill is acceptable, subject to guidance outlined in the EPA design manual or conditions of an IED Licence. Special attention was given to checking for the presence of high permeability zones but no significant zones were identified within the footprint of the landfill.

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As discussed previously, the geophysical survey was undertaken by APEX Geoservices Ltd. across the site area to check for depth to bedrock to supplement the existing borehole data. The geophysical report is included in Appendix 6.1. Interpretation of the geophysical survey data did not detect any significant anomalies, other than the deeper subsoil depth, which affords the aquifer greater protection. From the site investigations and surveys carried out, there is no evidence of high permeability zones across the site.

Groundwater water abstractions are discussed further in Section 6.3.9 below. Special attention was given to existing wells. There are no potable groundwater abstraction wells located down-gradient within 1 km of the landfill footprint. There are no source protection zones within 4 km of the existing facility. In addition, the potential to develop groundwater sources on the site is negligible due to the significant treatment requirement to treat groundwater from the area to a potable water quality. Groundwater at the site is not and will not be used as a drinking water supply.

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6.3.8 Hydrogeology Data

Aquifer Classification

The GSI has prepared a Groundwater Protection Scheme for County Kildare (2004). The GSI aquifer classification (2007) for the bedrock units underlying the existing facility are obtained from the GSI website and an extract from the groundwater web mapping is provided in Figure 6.7 and in Appendix 6.6.

The Boston Hill Formation and the Waulsortian Limestone are classified as Locally Important Aquifers, which are moderately productive only in localised zones (Ll) (Figure 6.7). As is stated above, the boundary of the Boston Hill formation may extend into the footprint of the landfill. The Calp limestone located 1.5 km to the north of the site is classified as a Locally Important Aquifer, generally moderately productive (Lm).

The Allenwood Formation and the Ballyadams Formation are located to the east and west of the site. The Allenwood Formation and the Ballyadams Formation located >4 km to west of the site are classified as a Regionally Important Karst Aquifer (Rkd), while the Allenwood Formation located 1 km to the east of the site is classified as a Locally Important Karst aquifer (Lk). Based on extensive site investigation works conducted on the site it has been shown that these bedrock units, i.e. the Ballyadams and Allenwood formations do not underlie the site application boundary.

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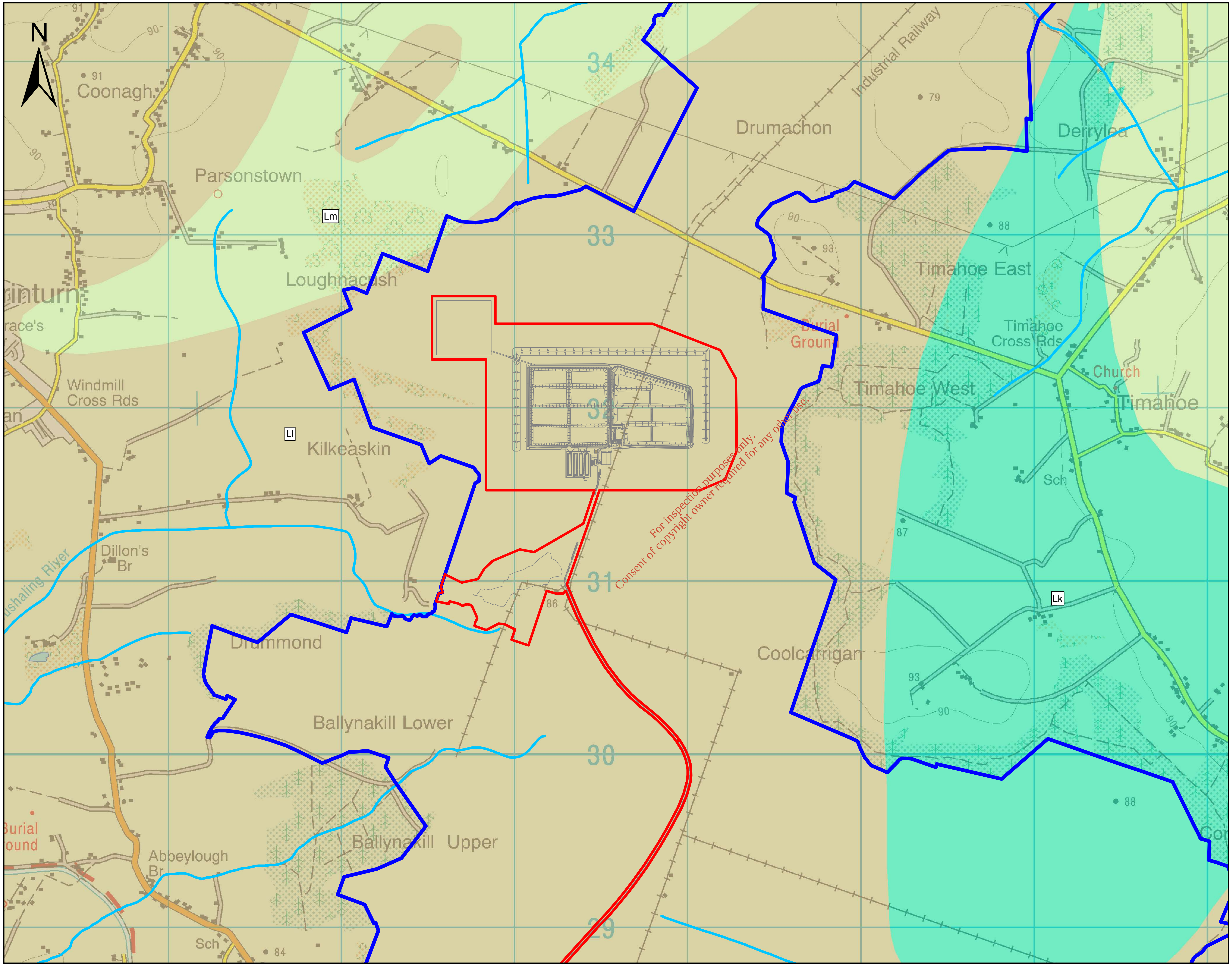

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Legend

- Site Boundary
- Bord na Móna Ownership Boundary

Aquifer Category

- Lk
- Ll
- Lm
- Rivers

0 125 250 500 750 1,000
Metres

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL DRAWINGS TO BE CHECKED BY THE CONTRACTOR ON SITE
3. ENGINEER TO BE INFORMED OF ANY DISCREPANCIES BEFORE ANY WORK COMMENCES
4. ALL LEVELS RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.
D01	AUG '18	EIAR Issue	F.H.	J.D.

Client:
BORD NA MÓNA
Naturally Driven

Project:
EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:
AQUIFER CLASSIFICATION

Scale @ A3: 1:20,000

Prepared by: F. Healy
Checked: J. Dillon
Date: August 2018

Project Director: D.Grehan

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Draft:

Figure 6.7

D01

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Aquifer Potential

The groundwater flow characteristics within the limestones underlying the site are dominated by secondary permeability, i.e. fissure flow. There is effectively no primarily permeability (inter-granular permeability) in these rocks.

As part of the hydrogeological investigations of the aquifer potential, a 72 hour pump test was carried out in 2003 to determine the characteristics of the aquifer close to the landfill footprint. The pump test was undertaken on the most permeable borehole drilled within the Bord na Móna landholding, GW6, which is approximately 450 m north of the existing landfill footprint. Before the pump test began, the static water level (SWL) in all monitoring boreholes was recorded to act as a datum for measurement during the test. The water levels in all boreholes were measured periodically to determine if the pumping was resulting in a radial cone of depression as a result of drawdown from the pumped borehole.

The pump test was undertaken by pumping from GW6, which was drilled to a finished 150 mm diameter borehole. The other boreholes installed at the site were monitored during the course of the pump test to observe any water level fluctuations. The discharge drawdown data from the pump test are included in Appendix 6.7.

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The only water level fluctuation in the observation wells was recorded in monitoring wells BH1D and BH1S, which are approximately 35 m from the pumping well. A drawdown of 1.53 m was achieved in BH1D with a drawdown of 0.6 m being achieved in borehole BH1S indicating the pumping and drawdown only had a localized effect.

The peak pump rate measured during the test was 56 m^3/day. The pump rate of 43 m^3/day was used for calculations as an average pump rate maintained during the log cycle in which the data was interpreted (i.e. 10 to 100 minutes), due to slight fluctuation in discharge during the test. These fluctuations in pumping rate are discussed below. The yield of the boreholes is "moderate" according to GSI classification and the productivity is Class IV or V.

Due to slight variation in the pumping rates observed during the test, the pumping rate used in the Jacob Calculation was correlated with the pumping rate observed during a full log cycle. A value of 43 m^3/day was used for the calculation of the aquifer Transmissivity in the 10 to 100 minutes log. The drawdown per log cycle during the 10 to 100 minutes log cycle was 37.2 m (with actual observed drawdown between 25 and 27 m; however as per the Jacob Method the drawdown per log cycle is used). Therefore, the figures used for calculating the Transmissivity are a drawdown per log cycle of 37.2 m and the pumping rate of 43 m^3/day, giving a calculated Transmissivity of 0.215 m^2/day (See calculation Appendix 6.7).

Following 100 minutes of pumping, the drawdown in the well began to vary, making the determination of a straight line slope for calculation difficult. A similar slope (and hence Transmissivity value) is noted from 1709 minutes to 2909 minutes. Notwithstanding the slight variation, the drawdown in the pumped well

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was at a relatively steady-state (though oscillating) at a level between 23 m and 27 m (with an approximate average value of 25 m).

A Logan approximation calculation which relates Transmissivity to the pumping rate and steady-state drawdown in a well was applied to this data for pumping after 100 minutes. The Logan approximation was deemed an appropriate method to approximate the aquifer Transmissivity due to the slight variation in drawdown in the pumped well. The values used were a pumping rate 48.5 m^3/day (an average pumping rate over the 100 to 4,349 minute period) and a drawdown of 25 m. This Logan calculation gave a Transmissivity result of 2.37 m^2/day, which is presented as a rounded value of 2 m^2/day (see calculation in Appendix 6.7). The calculated specific capacity of the pumping well is 1.94 m^3/day/m, using the above values of the average mid to late test pumping rate of 48.5 m^3/day and an average drawdown of 25 m. This means the well would be classified as Well Productivity Class V (the lowest classification), as per the GSI well classification system.

An additional analysis of the pump test data was undertaken using a simplified Thiem equation formula. This simplified Thiem equation was derived by Aslibekian (1998) and is normally applied to steady radial flow in a confined aquifer in typical Irish Aquifers. The simplified Thiem equation gave a Transmissivity result of 2.31 m^2/day, confirming the values obtained through other methods of data interpretation (see calculation in Appendix 6.7).

The values for Transmissivity calculated from drawdown data from GW6 are given in Table 6.6.

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Table 6.6: Transmissivity Values from Drawdown Data at Pumping Well GW6

Analytical Method used	Jacob Straight Line (10 to 100 minutes)	Logan Approximation (100-4349 minutes)	Aslibekian (simplified Thiem equation)	Arithmetic Mean
T (m^2/day)	0.215	2.37	2.31	1.7

The recovery period of the aquifer pump test was monitored, and the data interpreted using the Jacob Straight Line Method using a semi-log plot of residual drawdown (s') vs. t'/t (time since cessation of pumping divided by time since commencement of pumping). The recovery period was 210 minutes long with water levels recovering from a drawdown of 25.93 m to within 1.37 m of zero drawdown (the SWL prior to the test).

Monitoring of the data ceased after continuous monitoring of the data curve showed there was sufficient data to allow an analysis to be carried out and also due to the incrementally slower recovery which always occurs in the final metre of any recovery test, but which is more due to well effects than aquifer response.

Analysis of the graphs showed three subtly different slopes for late, mid and early points in the recovery (highest values of t'/t are early time, lowest values are late time). Values of Transmissivity were calculated

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using the highest pumping rate observed of 56 m^3/day and also the average pumping rate over the 72 hours of 49 m^3/day. The calculated values of Transmissivity for the recovery data are presented below in Table 6.7. The Transmissivity data calculated from the recovery data is in agreement with the values determined from the pump test drawdown data, with Transmissivity values of approximately 2 m^2/day (see graph and calculations in Appendix 6.7).

Table 6.7: Transmissivity Values from Recovery Data recorded at Pumping Well GW6

Pumping Rate	Late	Mid	Early	Average
m^3/day	T (m^2/day)	T (m^2/day)	T (m^2/day)	T (m^2/day)
56.68	3.84	1.7	0.72	2.09
49.14	3.3	1.47	0.62	1.81

Analysis of drawdown data from observation well GW1D gave calculated Transmissivity of 16 m^2/day. Analysis of recovery data using the two pumping rates resulted in Transmissivity values in general agreement with the values calculated using drawdown data, with values of 16.06 and 18.5 m^2/day being calculated, as presented in Table 6.8.

Table 6.8: Transmissivity Values from Recovery Data recorded at Observation Well GW1D

Pumping Rate	Average Transmissivity
m^3/day	T (m^2/day)
56.68	**18.5**
49.14	**16.06**

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A distance drawdown analysis was carried out by plotting the two data points on a semi-log plot (using 25 m as the steady drawdown for the pumping well and 1.53 m as the maximum drawdown for GW1D) the straight line intercepts the zero drawdown line at 19.6 m from the pumping well. This indicates that the zone of depression induced by pumping extends approximately 20 m. While this is a correctly calculated value, it is most likely not a valid number given the very low drawdown achieved. It does however demonstrate that the cone of depression is quite restricted in area due to the low Transmissivity of the bedrock aquifer.

When a Jacob straight line analysis is applied, using the distance drawdown method based on the maximum and averaged pumping rates over the test, the calculated Transmissivity values of 0.76 and 0.88 m^2/day (as presented in Table 6.9) are in general agreement with values calculated with the Jacob drawdown and recovery and Aslibekian calculations above.

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Table 6.9: Transmissivity Values from Distance Drawdown Analysis

Pumping Rate	Average
m^3/day	T (m^2/day)
56.68	**0.88**
49.14	**0.76**

No appreciable drawdown was detected in the other monitoring boreholes. While minor water level fluctuations occurred these cannot logically be related to the pumping well, with SWLs actually increasing (GW5D) and one well (GW4S) showing a decrease in water levels of 0.19 m and then an increase in water levels after 2000 minutes, halfway through the pumping period (see graphs in Appendix 6.7).

Discussion of Results

Although there is an order of magnitude difference between the calculated Transmissivity values for mid and late pumping time values, the numbers are only important in that they express that the Transmissivity is low. The calculated Transmissivity values for the pumping well of 0.2 m^2/day (for drawdown) to 2 m^2/day (for recovery) at GW6 and 18.5 m^2/day (for drawdown) and 18.5 m^2/day (for recovery) at observation well GW1D are typical of the Waulsortian Limestone in the northern half of Ireland.

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These values concur with Transmissivity values ranging from 0.3 to 115 m^2/day with a 50th Percentile value of 10 m^2/day (Aslibekian 1998) for the Waulsortian elsewhere in the Midlands. The consistency of the results allows for a high degree of confidence in the Transmissivity value as being in the region of 2 to 18.5 m^2/day, with the Transmissivity value of 16 m^2/day to 18.5 m^2/day used as a conservative value for the underlying aquifer. The higher values of 115 m^2/day are included within the hydrogeological risk assessment (HRA) calculations to account for variability within the limestone aquifer and the potential for enhanced permeability at depth highlighted within the APEX report (See Appendix 6.1).

Permeability Calculation

The estimation of Permeability (K) from Transmissivity values in fractured or fissured aquifers is very difficult, as interpretive hydraulic methods are based on the assumption that the aquifer is a homogenous porous medium. Permeability is normally determined by dividing the Transmissivity by the aquifer thickness. In unconfined aquifers, where drawdown results in a decrease in the saturated thickness of the aquifer, the estimation is further complicated.

The values of Transmissivity have been demonstrated to be in the range of 2 to 18.5 m^2/day. Caution needs to be applied to these values; as shown by the pump test, the interconnectivity of pores, fissures or any conduits are very limited - demonstrated by the very narrow cone of depression generated by the c. 25 m drawdown in the pumping well. The in-situ hydraulic testing of the aquifer is consistent with the GSI classification of the aquifer. The localised nature of the cone of depression demonstrates the poor and localized nature of the permeability in the bedrock underlying the site, which is consistent with the

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GSI aquifer classification. The higher Transmissivity (115 m^2/day) value in the Waulsortian Limestone is used as a conservative value to account for variability in the aquifer.

These Permeability values range from:

- K= 4.6 x 10^{-7} using a T value of 2 m^2/day;
- K= 4.3 x 10^{-6} m/s using a T value of 18.5 m^2/day; and
- K= 2.7 x 10^{-5} m/s using a T value of 115 m^2/day.

An assessment of the potential groundwater through flow (groundwater flux) was undertaken at the landfill. The groundwater recharge rate is generally estimated on an annual basis and assumed to consist of input (i.e. annual rainfall) less water loss prior to entry into the groundwater system (i.e. annual evapotranspiration and runoff). The recharge is estimated using Guidance Document GW5 (Groundwater Working Group 2005) and based on the aquifer category (Locally Important Aquifer which is moderately productive only in local zones (Ll)), and moderate to low vulnerability in the upgradient groundwater catchment. Potential recharge upgradient of the landfill is estimated at 102.5 mm/year, based on a potential recharge of 430 mm/year and 25% recharge to groundwater. Based on the upgradient groundwater catchment (2.3 km^2) and a potential recharge of 110 mm per year, the through flow is calculated as 690 m^3/day. A through flow of 690 m^3/day would indicate a permeability value of 1.13 x 10^{-6} based on the Darcy's Law equation Q = KiA.

Where: Q = Aquifer through flow m^3/s;

K = permeability (m^2/s);

i = hydraulic gradient; and

A = Cross Section area in m^2 (1700 m x 50 m).

A figure of 1.13 x 10^{-6} m/s is consistent with the pump tests carried out on the site. The pumping test values are therefore considered a reasonable value for permeability.

6.3.9 Water Abstractions

During the course of the environmental baseline assessment, information was collated regarding the provision of services to the community surrounding the facility.

KCC operates two large water distribution networks in County Kildare. The water provision centres are located at the Hill of Allen and the Hill of Carbury, two topographically elevated sites, whereby water flows by gravity to the distribution network.

The Hill of Allen reservoir is fed from the Ballymore Eustace Treatment Works, whose source of supply is the River Liffey. This reservoir supplies Newbridge, Naas and the surrounding environs in County Kildare.

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The Hill of Carbury network supplies much of north Kildare. The reservoir supplies water to distribution networks in the vicinity of the site, including Drehid Association Group Water Scheme (GWS), Johnstown Bridge GWS, and Timahoe GWS. The Hodgestown GWS is in operation to the east of the development, approximately 5 km east of the existing landfill footprint.

KCC had adopted a water strategy to meet the water requirements for the county up to the year 2020. The Council intend to develop groundwater sources in the Carboniferous Limestones to augment the current supply network. The two groundwater well fields that were proposed to be developed which are closest to the facility are located near Johnstown Bridge (approximately 8 km to the northeast of the landfill) and near Robertstown (approximately 6.5 km southeast of the landfill) respectively.

A detailed Environmental Report (K.T. Cullen, 2001) was compiled for each well field and related infrastructure. A brief summary of each well field is detailed below.

It was previously envisaged that the Johnstown Bridge well field would abstract 3,750 m^3/day from 7 production wells drilled into the Calp Limestone aquifer. This project has not progressed since drilling of the original wells in 1990s and is not in the Irish Water's current plans.

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The production wells are located in Dunfierth Wood (WW2), Coolree (WW23), Dysart (WW17), Clonagh (WW20), Clonagh (WW21) and Hortland (WW24) and Hortland (WW25). The location of the well field is shown on Figure 2.1 in Appendix 6.9, which is an extract from the Environmental Report. The source protection zones for the Johnstown Bridge scheme are also included in Appendix 6.9.

The Johnstown Bridge well field is located in the River Boyne catchment area. The water abstracted from the Johnstown Bridge well field is proposed to be treated and pumped to a new reservoir to be constructed on the Hill of Carbury. With reference to the Source Protection Scheme for the Johnstown Bridge well field, the landfill is approximately 5 km to the south of the outer protection zone for the scheme. Therefore, the existing facility will not impact upon the quantity or quality of water abstracted during the operation of the Johnstown Bridge scheme, if commissioned.

The Robertstown well field envisages abstracting 6,500 m^3/day from 9 No. production wells drilled into gravel deposits, which constitute an important potential groundwater resource in the Robertstown area. All production wells are located on Council property or adjacent agricultural land approximately 750 m east of Robertstown Village. The location of the well field is shown on Figure 2.1 (contained in Appendix 6.9). The source protection zones for the Robertstown scheme are also included in Appendix 6.9.

The Robertstown well field lies in the headwaters of the River Slate catchment, which is a sub-catchment of the River Barrow catchment. The well field is positioned close to the watershed with the River Boyne and the River Liffey. The groundwater flow direction in the environs of the Robertstown well field is from a southeast/east direction towards the northwest/west.

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Therefore, the existing facility will not impact upon the quantity or quality of water abstracted from the gravel aquifer during the operation of the scheme.

The landfill footprint is c. 1 km from the nearest domestic dwelling. Groundwater from the site discharges to the River Cushaling. There are no domestic water supplies between the landfill and the River Cushaling. The water distribution network from public supply and group water schemes is extensive in this area; however, some households may have retained private wells to meet their own water requirements.

No drinking water abstractions are located downgradient of the landfill i.e. between the landfill and the River Cushaling Tributary; therefore, no groundwater abstraction wells have been impacted by the existing landfill operations to date and will not be impacted by ongoing operations at the existing facility. The existing groundwater gradient from the landfill is towards the River Cushaling as shown on Figure 6.8.

Extensive groundwater monitoring is undertaken downgradient of the landfill including GW9, GW10, GW11s, GW11d, GW12s, GW12d, GW13s and GW13d. All parameters in the upgradient and downgradient monitoring wells are consistent with predevelopment concentrations.

6.3.10 Groundwater Piezometry

In order to determine the groundwater flow direction and the groundwater gradients within the existing facility, the topographic elevation of all monitoring points was established.

Based on the water level monitoring and the topographic elevation it was possible to establish the piezometric head at each monitoring point.

Paired monitoring boreholes / piezometers in the bedrock and overburden were drilled at five different locations within the Bord na Móna Landholding (Figure 6.5) which provided for monitoring of the shallow and deep groundwater levels. These boreholes are designated a number and the letter "D" if the borehole is screened only in the bedrock (e.g. GW1D); or the letter "S" if it is a shallow overburden borehole screened only in the Till (e.g. GW1S).

These boreholes are generally within 5 to 20 m of each other and so it is possible to monitor the water level in the overburden and bedrock at approximately the same point. The pumping borehole GW6 is within 16 m of GW1S and so this represents a 6th pairing.

All levels were measured relative to Ordnance Datum (Malin Head). The elevation and piezometric head of all measured points are tabulated on Table 6.10.

The piezometric data and inferred groundwater contours are shown on Figure 6.8.

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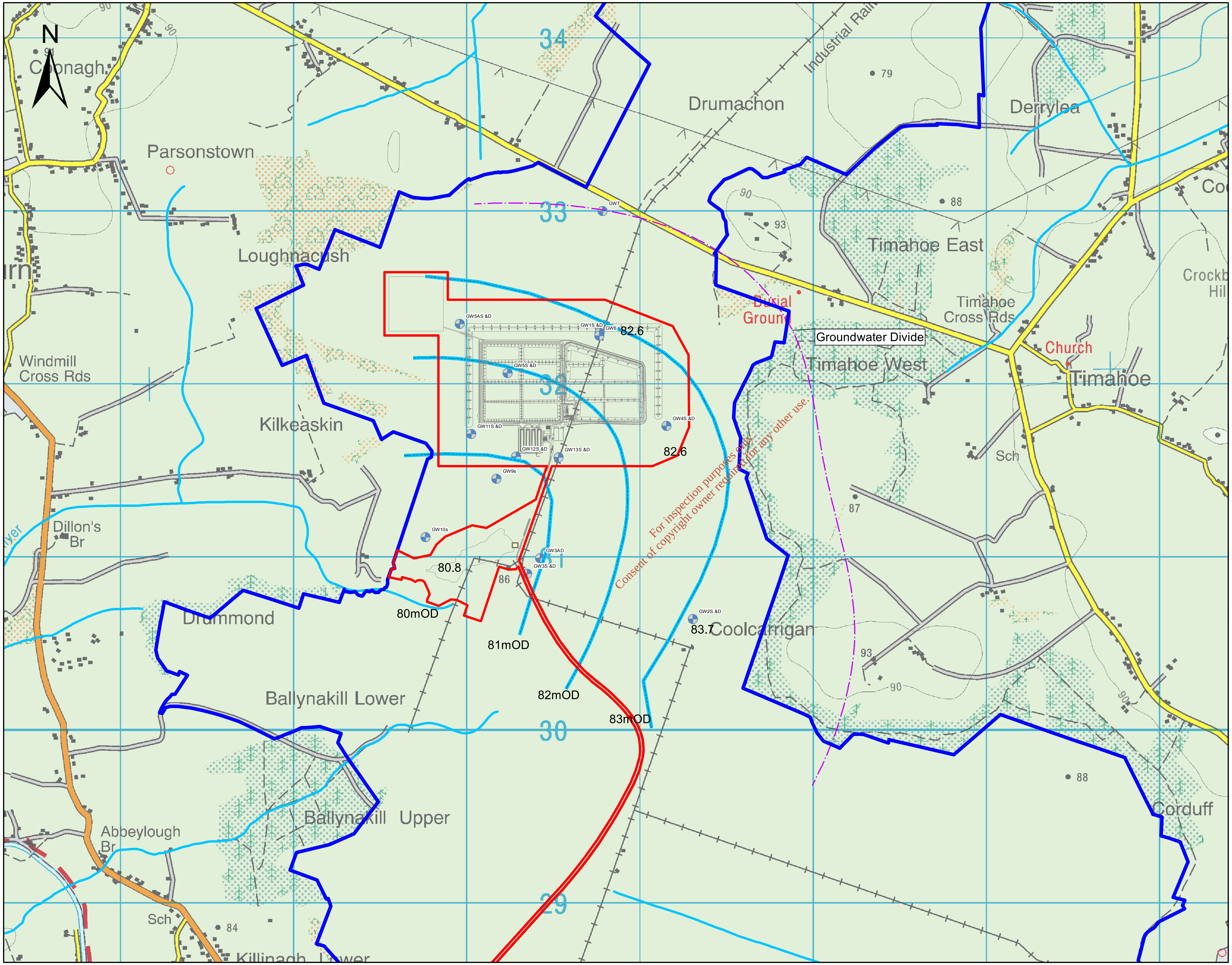

Legend

- Site Boundary
- Bord na Móna Ownership Boundary
- Existing MSW Landfill
- Groundwater Divide
- Rivers
- Groundwater Contours
- EPA Monitoring Wells

0 125 250 500 750 1,000
Metres

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
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D01	AUG '18	EIAR Issue	F.H.	J.D.
Issue	Date	Description	By	Chkd.

Client:
BORD NA MÓNA
Naturally Driven

Project:
EXISTING DREHID WASTE MANAGEMENT FACILITY

Title:
INFERRED GROUNDWATER CONTOURS

Scale @ A3: 1:20,000

Prepared by: F.Healy | Checked: J. Dillon | Date: August 2018

Project Director: D.Grehan

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Figure 6.8

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Table 6.10: Location and Elevation of Groundwater Monitoring Points and Piezometric Head

Reference	Grid Reference Easting, Northing	Ground Elevation (m OD)	Static Water Level – (m OD) winter water level	Static Water Level – (m OD) summer water level
GW1D	E274767, N232294	84.886	83.92	82.5
GW1S	E274773, N232292	84.852	84.28	82.6
GW2D	E275305, N230640	87.862	85.9	83.77
GW2S	E275312, N230650	87.37	86.07	84.9
GW3D	E274349, N230902	85.115	82.95	82.04
GW3S	E274354, N230907	85.018	83.2	81.8
GW4D	E275153, N231756	84.612	83.36	82.58
GW4S	E275159, N231740	84.213	83.17	
GW5D	E274236, N232062	85.85	83.39	82.68
GW5S	E274246, N232059	85.799	83.82	83.19
GW6	E274765, N232278	84.737	83.97	83.39
GW7	E274784, N232999	86.5 (approx)	-	
GW10	273836 230987	84.56	82.74	81.87
GW11s	274059 231737	84.97	84.2	82.57
GW11d	274058 231738	85.22	84.63	82.59
GW12s	274317 231583	83.79	83.44	82.56
GW12d	274317 231578	83.59	83.46	82.02
GW13s	274510 231554	84.74	82.71	81.8
GW13d	274507 231539	84.64	81.98	80.9

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Reference	Grid Reference	Ground Elevation	Static Water Level –	Static Water Level –
	Easting, Northing	(m OD)	(m OD) winter water level	(m OD) summer water level
BH3 - CG	274770, 231577	85.6		84.1[29]
R8	275326, 231517	85.7		82.3
R9	274758, 231308	84.23		81.1
R10	274717, 231035	83.67		81.05
R11	275176, 231096	86.75		82.3

The shallow subsoil piezometric levels and the deep bedrock piezometric levels differ across the Bord na Móna landholding. The shallow piezometric levels are considered to be heavily influenced by the artificial drains traversing the Bord na Móna landholding. These drains are excavated to the level of the mineral subsoil. Shallow flows are considered to discharge to the drains, with very short flowpaths. The fluctuation in water levels varies from 0.3 m to 0.5 m in the shallow subsoil environment.

Based on the piezometric levels, groundwater flow in the existing facility is from an east and northerly direction towards the west i.e. towards the River Cushaling Tributary. The summer piezometric levels vary from 82.5 m OD (GW4D) to 81.1 m OD (GW3D, R9), which is similar to the gradients observed during the winter surveys. The flow direction is consistent with the surface water drainage from the Bord na Móna landholding, which is towards the west/south-west and the Cushaling River and the former gravel borrow pit. The Cushaling emerges as a surface flow within the Bord na Móna landholding and continues to flow and gain groundwater baseflow further to the west of the Bord na Móna landholding.

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The piezometric head measurement for GW7 suggests that the groundwater flow pattern is different in this area. Although surface water collected in the drainage ditches is culverted to the south in this area, the groundwater flow appears to be to the north, towards the Fear English River, and ultimately to the River Boyne. Based on existing topographic maps for the area and site investigation data, the watershed between the River Boyne and the River Barrow occurs in the lateral distance between boreholes GW7 and GW1D, which are separated by approximately 725 m. No activities associated with the landfills will occur within the catchment of the River Boyne.

Groundwater Gradients

[29] Partially screened in the peat horizon

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The vertical groundwater gradient is assessed by calculating the vertical gradients between the observed Static Water Levels (SWLs) at locations with borehole pairs.

Monitoring of the groundwater levels from these boreholes was undertaken on a number of occasions during the environmental assessments in 2003, 2007 and 2016. Based on the groundwater monitoring surveys it is possible to determine the hydraulic gradients at these locations on a number of dates. The mean hydraulic gradients for these locations are presented in Table 6.11, with positive values representing an upward gradient (indicating a potential for flow from the bedrock to the overburden) and negative values representing a downward gradient (indicating potential for flow from the overburden to the bedrock).

The calculated hydraulic gradients are quite low with the recorded gradients on the site ranging in magnitude from 0.129 to 1.154. The maximum upward gradient recorded is 1.129 and the maximum downward gradient recorded is -1.154. The presence of vertical gradients demonstrates that the overburden is low permeability and that the flow of water from the surface to the bedrock or from the bedrock to the surface is impeded (but not wholly prevented) by the low permeability till. Given that the gradients are low however, it would not be accurate to describe the bedrock aquifer as confined. Modest upward gradients are observed at the locations of: GW1D & GW1S (confirmed by GW6 and GW1S), GW3D & GW3S and GW4D & GW4S. However, a term such as "semi-confined" or "leaky" would best describe the hydrogeology of the site.

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Table 6.11: Vertical Groundwater Gradients

Borehole Pair	Date					Mean
	16/01/2003	03/02/2003	18/07/2003	10/01/2007	04/08/16	
GW1D						
GW1S	**0.129**	**0.139**	**1.129**	**0.364**	**0.27**	**0.40**
GW2D						
GW2S	**-0.463**	**-0.468**	**-0.438**	**-**	**-0.45**	**-0.45**
GW3D						
GW3S	**0.507**	**0.522**	**0.467**	**0.517**	**NA**	**0.503**
GW4D						
GW4S	**0.519**	**0.579**	**0.499**	**-**	**0.36**	**0.49**
GW5D						
GW5S	**-0.259**	**-0.214**	**-1.154**	**-0.431**	**NA**	**-0.515**
GW6	**0.055**	**0.43**	**0.37**	**-**		**0.285**

6.3.11 Groundwater Chemistry

Groundwater samples were obtained from the monitoring borehole network in February 2003 and in July 2006 to establish background groundwater quality at Drehid prior to development and results are

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presented in Table 6.12 and Table 6.13. Monthly and annual monitoring has been carried out during the operational phase of the existing landfill. Monitoring result trends for Conductivity and Ammonia for the period 2014 - 2016 are presented in Figures 6.9, 6.10 and 6.11. A brief interpretation of the chemistry is provided below and further details on the groundwater monitoring results are provided in the Site Condition Report. The locations of where the samples were taken are shown in Figure 3.4.

Prior to the water sampling survey, each borehole was purged to expel any groundwater standing within the standpipe and gravel pack. The purging of the standpipes was undertaken for over 90 minutes using an air compressor and a ½-inch air-line. The air-line was lowered gradually to the base of each borehole to expel the standing groundwater and to develop and clean the gravel pack surrounding the screened section of the borehole. The samples were obtained from the borehole standpipe immediately following the purging using a disposable bailer.

General Chemistry

The chemistry signature is one of a calcium bicarbonate groundwater. The pH of the groundwater varies within the range of pH 6.9 to pH 8.1. There is no significant difference in the pH between the shallow boreholes (average pH 7.4) and the deeper boreholes (average pH 7.5). Based on the site data, there is no trend in the groundwater data between preconstruction and operation of the existing landfill; however, some variability in conductivity concentrations is noted in the upgradient shallow wells. This is possibly due to the presence of construction berms on the western and northern section of the existing site. No significant variation occurs between upgradient and downgradient wells at the existing facility.

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Electrical Conductivity recorded at all monitoring locations were below the drinking water standards 2,500 µS/cm for groundwater and the Groundwater Threshold Values 1,875 µS/cm. Typically conductivity ranges from the deeper boreholes is 500 to 800 µS/cm. The highest concentrations are located in the upgradient wells GW 6 and GW 5AS (>1,000 µS/cm in June 2015). An increase in conductivity and corresponding increase in calcium concentrations was identified in 2014 at GW6 and GW5 and is attributed to the construction of subsoil berms and drainage ditches adjacent to the monitoring locations. Conductivity concentrations are significantly lower in the downgradient wells GW11D and GW12D of the landfill. Electrical Conductivity in GW11D and GW12D varies between 203 µS/cm to 554 µS/cm at these locations and may due to the installation within the tertiary clays.

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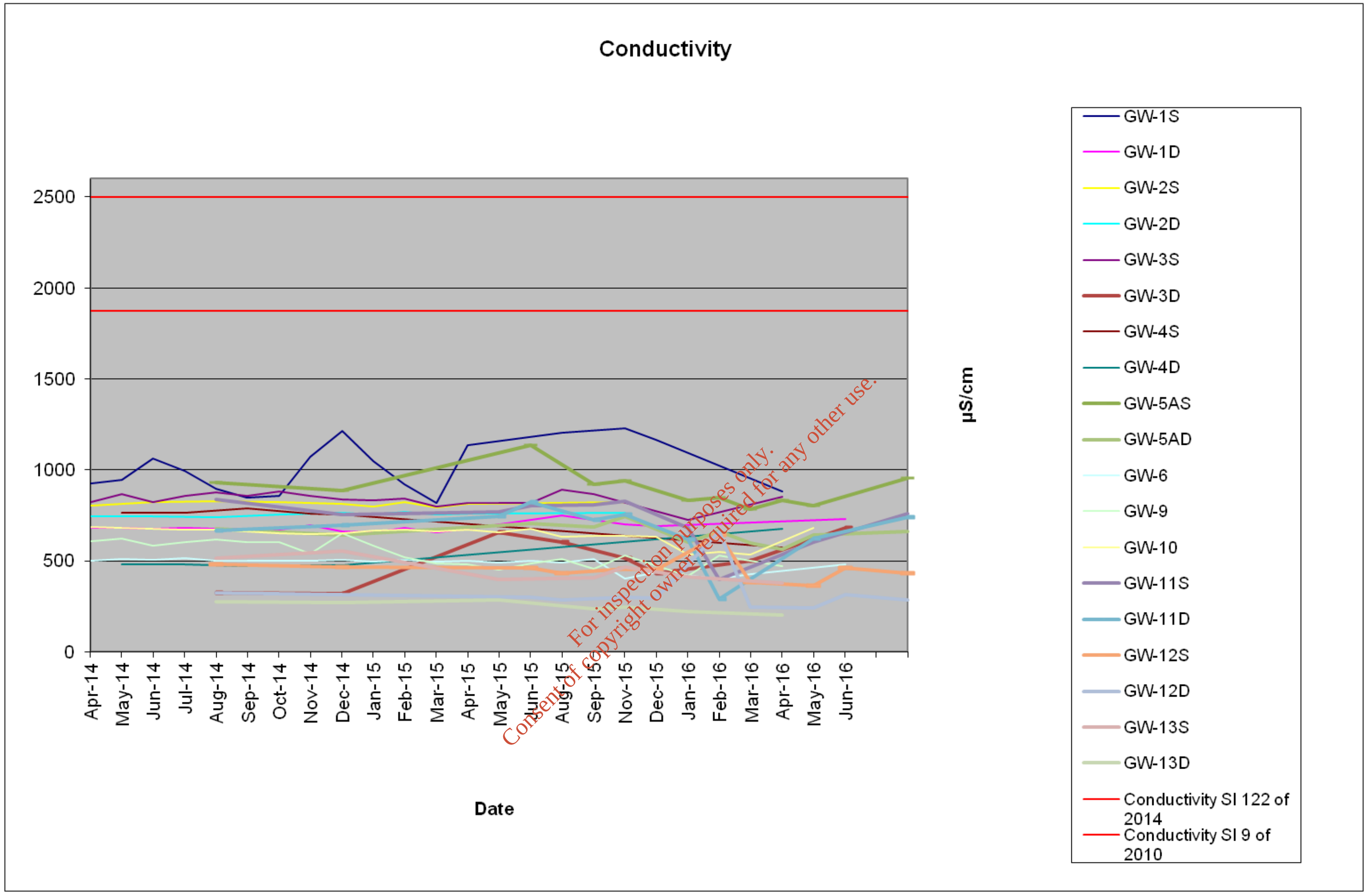

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Figure 6.9: Drehid Groundwater Monitoring - Conductivity Concentrations

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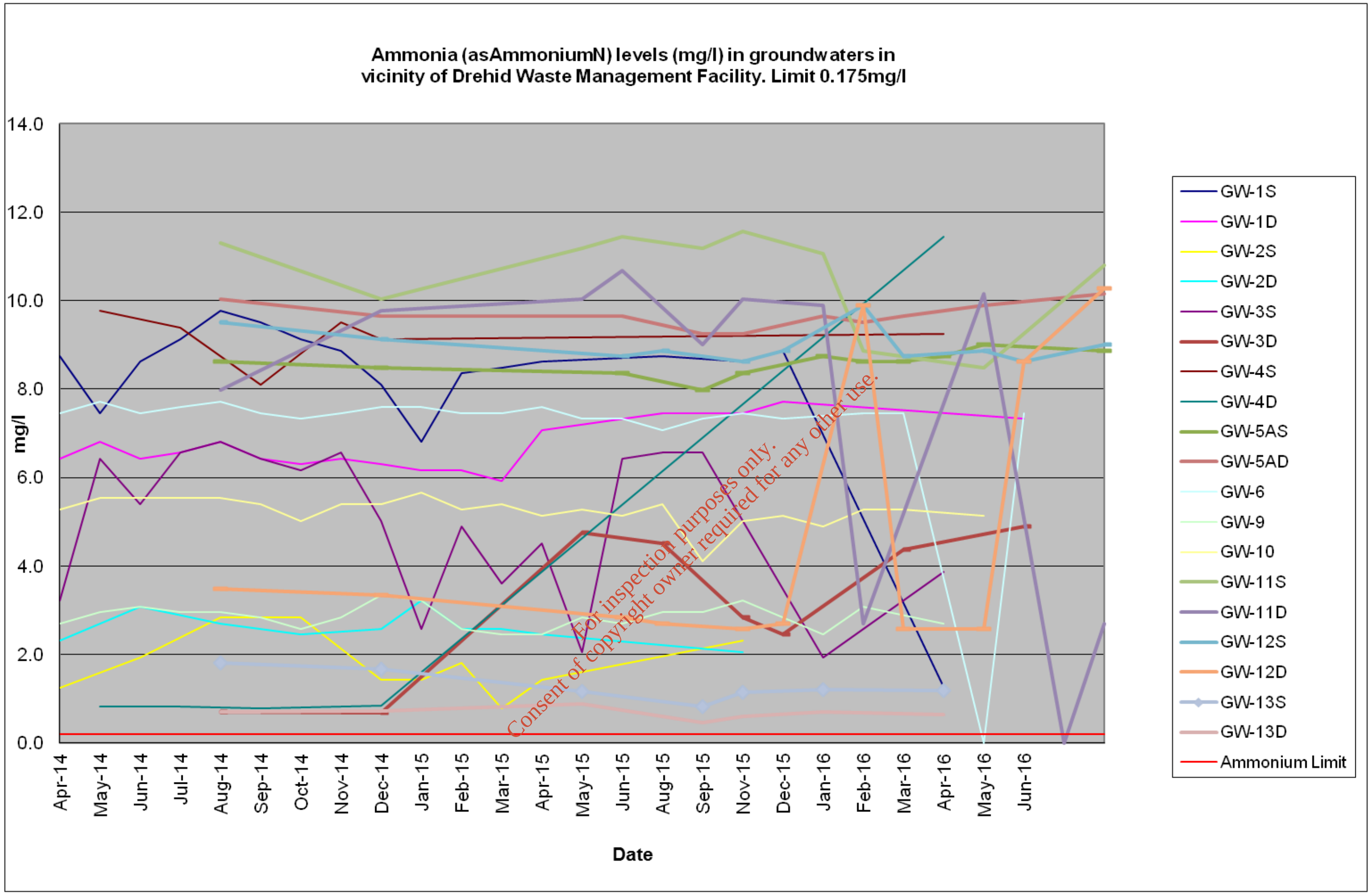

Figure 6.10: Drehid Groundwater Monitoring - Ammonia Concentrations

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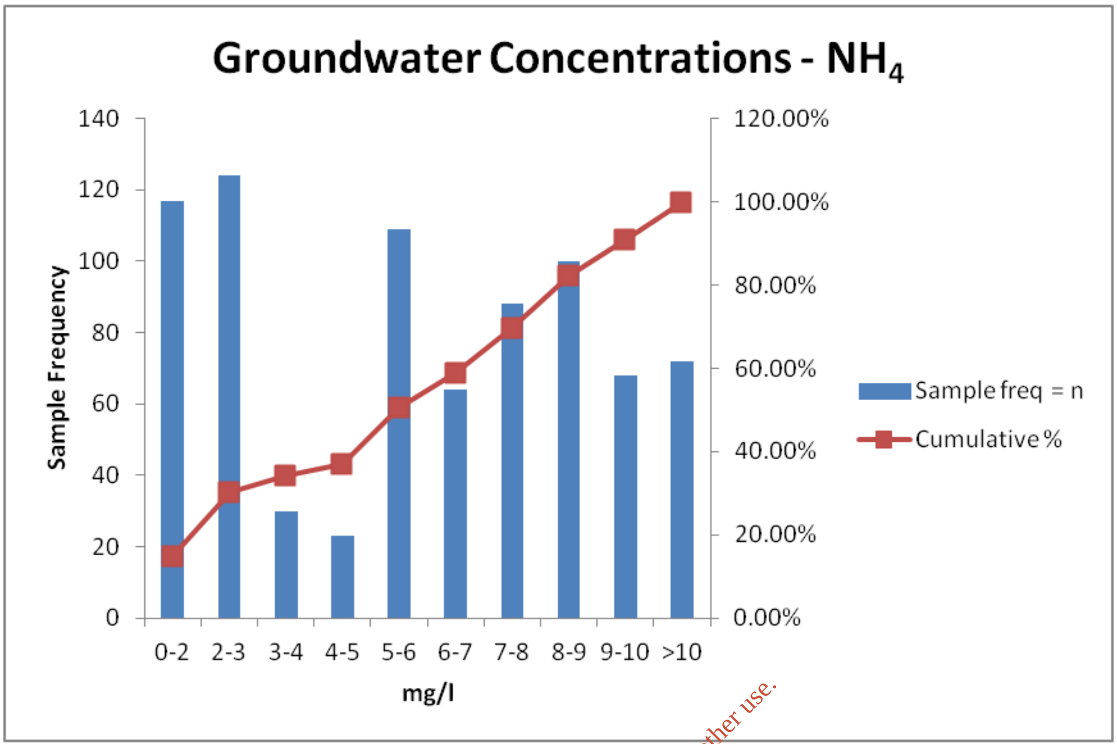

Figure 6.11: Drehid Groundwater Monitoring – Cumulative frequency Ammonia Concentrations

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Dissolved oxygen concentrations are considered low, with lower concentration detected in the deeper boreholes. This suggests that the oxygen saturation is depleted as the water percolates to the bedrock.

The total solids concentration is high for all samples; however, the suspended solids concentration appears to be the dominant factor. This is not unexpected as the wells are only periodically pumped and the sediment content would take a long time to clear.

Magnesium and sodium concentrations are variable but there were no exceedances of the drinking water standards for magnesium (50 mg/l) or sodium (150 mg/l). The highest sodium concentrations occurred in upgradient wells GW5AS (29 mg/l) and GW5AD (90 mg/l) (04/09/2015) and appear to be associated with the presence of tertiary clays. Concentrations in recently installed downgradient wells GW11S and GW11D appear to be significantly lower, again possibly due to the presence of variable tertiary clays. Magnesium concentrations across the Bord na Móna landholding are comparable to preconstruction concentrations.

Calcium concentrations in some shallow boreholes show an increase from 2003. Concentrations appear to increase in the vicinity of construction works at the existing facility or where drainage works are undertaken. The highest concentrations (>200 mg/l) were recorded in upgradient wells GW1S, GW2S and GW4S.

Potassium concentrations are variable across the Bord na Móna landholding, ranging from 1 mg/l to 36 mg/l. The highest concentrations were noted in the recently installed upgradient wells (GW5AS and GW5AD)

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and downgradient wells (GW11S and GW11D) between 2014 and 2016. Potassium concentrations at GW13D are higher than the adjoining wells, however this is possibly due to the installation of GW13D in the Tertiary clays underlying the site. No trend in Potassium concentrations or Potassium: Sodium ratio was identified between pre-construction and post construction at the existing long term monitoring locations (2003-2016).

Ammonia and Nitrate

Ammonia concentrations are elevated in all boreholes, ranging from 0.5 mg/l as N (GW4D) to 12 mg/l as N in GW1D (see Figure 6.10 above). The highest concentrations (>8 mg/l) are encountered in both upgradient wells (GW1S, GW4S, GW5S) and the recently installed downgradient well (GW11S) see Table 6.14 and Appendix 6.3. Concentrations in the recently installed downgradient wells GW11D, GW12S, GW12D, GW13S and GW13D are variable and reflect the natural variability in ammonium concentrations in the groundwater chemistry.

The reduction of free Nitrogen occurs due to the reducing environment of the peat, where there is a deficiency of available oxygen. The fact is borne out by the generally low concentration of Nitrite and Nitrate. The Drehid WMF is located within a cut-away peat land. Groundwater beneath peatlands has been found to be naturally high in Nitrogen and due to the nature of the peatlands the Nitrogen is present in the reduced form, Ammonia (the redox conditions - chemical oxidation and reduction conditions - being reducing conditions in this case). The Ammonia concentrations remain elevated as it is not oxidised to Nitrite or Nitrate. Reducing conditions also occur in the underlying blue grey silts and clays.

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The lowest concentrations of Ammonia (<1 mg/l) are typically encountered in GW4D, GW13S and GW13D, located upgradient and downgradient of the existing landfill. The lower Ammonia concentrations appear to be located in areas where Tertiary clays are present based on geophysical and site investigation data. Groundwater in these boreholes may not be in hydrogeological connection with the peat environment. Alternatively, localised anoxic/anaerobic reactions may remove Ammonium in the groundwater at these locations. No significant trend in Ammonium concentrations was identified between pre-construction and post construction at the existing licensed site. Concentrations are similar upgradient and downgradient of the landfill.

The Nitrate concentrations are low in all of the boreholes, similar to previous results. All concentrations are below 0.5 mg/l as N since 2008.

Chloride

The average chloride concentrations are less than 18 mg/l in all upgradient and downgradient wells at the Drehid facility. Chloride concentrations at the site are below the mean natural background level of 18 mg/l (Baker et al., 2007). The highest concentrations were detected in GW5AS (32 mg/l in June 2015) located upgradient and in GW11D (28 mg/l in August 2014) located downgradient of the facility. A significant decrease in Chloride concentrations was identified between pre-construction and operation of

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the existing landfill. Concentrations have decreased since the initial sampling of the wells (>30 mg/l in GW2S, GW2D, GW3S, GW4S, GW4D, GW5S, GW5D).

Sulphates

The Sulphate concentration is typically less than 10 mg/l since 2008. The highest recorded concentrations from recent monitoring was detected in GW2S (22 mg/l). The Sulphate concentrations show a reduction from those recorded in 2003 when 59 mg/l was detected in GW1D.

Orthophosphate

Ortho phosphate concentrations are generally low across the site showing only minor fluctuations between boreholes. With the exception of GW3S (0.63 mg/l in Aug 2007), results are typically between 0.05 mg/l to 0.14 mg/l. Concentrations of Orthophosphate were elevated pre-development in GW3S. A significant decrease in Orthophosphate has occurred in GW3S (0.63 mg/l in 2003) since the development of the facility (<0.1 mg/l since 2008).

Metals

The concentrations of trace metals are generally low in pre and post development monitoring for all upgradient and downgradient boreholes. However, arsenic and manganese are elevated both in predevelopment and post development monitoring results. The manganese concentration is consistently elevated and seems to be typical of groundwater in this area.

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Elevated concentrations of arsenic were detected in monitoring both pre-development and post development at the existing Drehid facility. Concentrations in both upgradient wells GW1S, GW1D, GW2S, GW2D, GW4D, GW6, GW9, and downgradient wells GW3S, GW3D, GW12S and GW12D are regularly above the drinking water standards. The highest concentrations are consistently encountered in upgradient wells GW1D and GW6. As both upgradient and downgradient wells are elevated, the concentrations are likely to represent background levels in the groundwater. The source of the arsenic is unknown, but it is noted that "*concentrations in groundwater in some areas are sometimes elevated as a result of erosion from natural sources"* (EPA 2001; Parameter of Water Quality). A literature review reveals several studies, which attribute arsenic concentrations to reducing conditions associated with peat deposits. Waste had not been deposited at the facility at the time of background sampling and as such these results represent the natural geochemistry beneath the peatland.

Recent sampling data indicates concentrations of Chromium, Cadmium, Copper, Tin, Antimony, Sliver, or Selenium are similar to the 2003 and 2006 background monitoring event. The occurrence of elevated concentration of trace metals in the groundwater is considered to result from the mobilisation of metals in the groundwater in an anoxic, reducing environment.

Barium concentrations vary greatly over the site but are generally higher within the shallow boreholes. Concentrations from 11th August 2006 (pre-development) recorded in GW1S (343 µg/l), GW4S (521 µg/l), GW1D (327 µg/l) and GW6 (123 µg/l) all lie above the IGV of 100 µg/l. These concentrations are similar to that detected in the 2003 monitoring event where concentrations ranged from 60 µg/l to 270 µg/l in the

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deeper boreholes and from 130 µg/l to 520 µg/l in the shallow boreholes and (as with arsenic concentration), are believed to be representative of the natural geochemistry beneath the peatlands. No significant trend is detected in the long term monitoring points. Concentrations are >500 µg/l in some newly installed upgradient (GW5AS) and downgradient wells (GW11S and GW11D).

Elevated concentrations of Nickel were detected in GW1S (27 µg/l), GW2S (30 µg/l), GW1D (27 µg/l) in 2006. Concentrations have decreased since 2006 to an average of 20µg/l.

VOC's, SVOC's and Pesticides

There were no concentrations of VOC's, SVOC's or pesticides detected in the operational phase of the existing landfill or the 2006 monitoring round. In the 2003 monitoring round, diesel range organics and mineral oil were detected. The interpretation of the compounds detected indicates that these related to lubricant oil used in the drilling of the boreholes. Polycyclic aromatic hydrocarbons were also recorded in GW2S and GW6, which are also related to the lubricant oil used in the drilling. The presence of microbial organisms in the groundwater is an external factor related to the drilling.

The chemistry of the deep groundwater encountered in GW7, GW11d and GW12d is significantly different to the other samples obtained within the site. The groundwater has a low level of mineralisation, which is often less than 50% of the average of the other samples. An explanation of the lower than expected level of dissolved minerals is the presence of tertiary clays overlying the area.

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Table 6.12: Groundwater Chemistry from Samples obtained on 04/02/2003

Parameter	Units	*M.A.C.*	*Detection Limit*	GW1D	GW1S	GW2D	GW2S	GW3D	GW3S	GW4D	GW4S	GW5D	GW5S
pH			*0.01*	7.51	7.17	7.46	6.93	7.66	7.16	7.75	7.55	7.56	7.53
Electrical conductivity EC	mS/cm	*6.5<pH<9.5*	*0.014*	0.835	1.043	0.755	0.983	0.319	0.936	0.493	0.722	0.9	0.71
Dissolved oxygen (DO)	mg/l	*2500*	*0.1*	4.9	6.1	7.6	6.8	5.4	6.6	8.8	7.5	7.9	8.4
Redox potential	mV	*n/a*		121	14	120	124	102	126	110	119	128	128
COD	mg/l	*n/a*	*10*	178	176	166	193	87	167	95	133	107	114
Total solids	mg/l	*n/a*	*1*	18579	34946	8693	48647	3152	16635	1557	22710	80762	14169
Total suspended solids	mg/l	*n/a*	*10*	16476	31904	10616	43392	2916	15050	1270	18930	73980	11390
Total hardness (as CaCO3)	mg/l	*60 MRC*	*5*	320	520	266	478	300	312	366	258	300	220
Total alkalinity (as CaCO3)	mg/l	*30 MRC*	*1*	380	570	460	520	210	240	290	380	370	350
Ammonia as NH4-N	mg/l	*0.3*	*0.2*	8	1.9	2	2.1	0.5	6.6	0.8	6.1	3.2	7.6
Nitrate NO3	mg/l	*50*	*0.3*	0.3	0.3	2.6	25.6	0.05	0.3	<0.3	<0.3	<0.3	<0.3
Nitrite NO2	mg/l	*0.5*	*0.05*	0.07	0.18	0.39	0.68	0.18	0.1	<0.05	0.11	<0.05	0.3
TON	mg/l	*n/a*	*0.3*	<0.3	<0.3	0.7	6.1	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Chloride Cl	mg/l	*250*	*1*	31	21	44	37	20	39	36	31	37	41
Fluoride F	mg/l	*1*	*0.01*	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sulphate SO4	mg/l	*250*	*3*	59	31	14	45	10	4	4	13	<3	55
ortho-Phosphate PO4	mg/l	*5*	*0.03*	0.2	0.3	0.2	0.2	0.2	0.2	0.3	1.2	0.2	2.6
Potassium K	mg/l	*12*	*0.2*	3.2	0.8	1.8	4.1	1.3	2.9	1.4	2.4	3	2.1
Sodium Na	mg/l	*200*	*0.2*	39.5	9.2	32	16.8	12.4	17	15.5	40	64	12.2
Calcium Ca	mg/l	*200*	*0.05*	124.9	156	128.2	152	48.51	161.7	81.74	108.5	117.8	119.1
Magnesium Mg	mg/l	*50*	*0.05*	11.11	44.06	9.17	34.72	7.56	11.33	13.68	17.14	11.81	9.64
Aluminium Al	mg/l	*0.2*	*0.05*	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zinc Zn	mg/l	*1*	*0.005*	0.007	0.011	<0.005	0.008	0.017	0.006	<0.005	<0.005	0.006	0.006
Iron Fe	mg/l	*0.2*	*0.001*	0.008	0.023	0.005	0.02	0.003	0.014	0.002	0.002	0.003	0.004
Manganese Mn	mg/l	*0.05*	*0.001*	0.006	0.242	0.084	0.409	0.082	0.151	0.006	0.142	0.383	0.26
Barium	mg/l	*0.5*	*0.05*	0.12	0.13	0.27	0.18	0.09	0.52	0.17	0.13	0.1	0.4
Boron	mg/l	*1*	*0.05*	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead Pb	µg/l	*10*	*5*	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Copper	µg/l	*2000*	*5*	<5	7	<5	<5	<5	<5	<5	<5	<5	<5
Mercury Hg	µg/l	*1*	*0.05*	0.12	0.11	<0.05	<0.05	0.1	0.05	0.23	0.11	0.08	0.27
Nickel Ni	µg/l	*20*	*10*	<10	11	<10	<10	14	14	<10	<10	18	13
Arsenic	µg/l	*10*	*5*	19	<5	<5	<5	22	6	8	<5	<5	<5
Cyanide CN	µg/l	*50*	*50*	60	<50	<50	<50	<50	<50	<50	<50	170	<50
Cadmium Cd	µg/l	*5*	*0.4*	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Chromium Cr	µg/l	*50*	*1*	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Silver Ag	µg/l	*10*	*10*	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Selenium	µg/l	*10*	*5*	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Phenols (HPLC)	mg/l	*0.0005*	*0.01*	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01
Diesel Range Organics (DRO)	µg/l	*10*	*10*	<10	<10	<10	3303	<10	4441	<10	1649	5533	2731
Mineral Oil	µg/l	*10*	*10*	<10	<10	<10	1486	<10	1776	<10	<10	1383	956
Petrol Range Organics C4-C10	µg/l	*10*	*10*	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Petrol Range Organics C10+	µg/l	*10*	*10*	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
BTEX (MTBE) Compounds	µg/l	*10*	*10*	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
PAH (16 EPA Compounds)	ng/l	*100*	*10*	<10	<10	<10	1332	<10	<10	<10	<10	<10	<10
Semi-Volatile Organic Compounds	µg/l		*1*	<1	<1	<1	<1	<1	<1	<1	7	<1	<1
Volatile Organic Compounds	µg/l		*1*	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total Coliforms	c.f.u./100ml	*0*	*1*	1450	2880	4130	34480	1480	81640	28	310	4590	1460
Faecal Coliforms	c.f.u./100ml	*0*	*1*	6	2	<1	<1	<1	<1	<1	<1	<1	1
Ionic Balance	%			4.22%	14.14%	5.10%	9.19%	0.19	37.97	8.43	15.97	26.72	2.21

Legend
M.A.C = Maximum Admissable Concentration under S.I. No. 439, 2000(European Communities Drinking Water Regulations).
< = Less than

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Table 6.13: Results of Chemical Analysis of Groundwater (11/7/2006)

Parameter	Component	Units	M.A.C	Detection	GW-1S	GW-1D	GW-2S	GW-3S	GW-3D	GW-4S	GW-4D	GW-6	GW-7
pH	-	pH units	≥ 6.5 & ≤ 9.5	-	7.7	7.8	8	7.6	8	7.7	7.8	7.9	7.7
Conductivity @ 25ºC	-	µS/cm	1000	-	722	742	820	577	313	782	489	615	286
Ammonia (NH3-N)	-	mg/l	0.3	<0.02	8.1	8.7	2.7	5.6	0.41	7.2	0.74	7	1.19
Total Phosphorous	-	mg/l	-	<0.05	0.57	0.57	0.31	0.56	0.14	0.46	0.1	<0.05	0.08
Anions	Chloride	mg/l	250	<0.5	14.4	14.4	15.6	16.6	12.5	15.1	13	14.1	14.1
	N03-N	mg/l	11.3	<0.05	<0.05	<0.05	0.21	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	P04-P	mg/l	-	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16
	SO4	mg/l	250	<0.5	<0.5	<0.5	14.9	1.4	<0.5	1.1	<0.5	<0.5	<0.5
Boron (Dissolved)	-	µg/l	1000	<2	3	18	28	25	17	23	22	18	13
Comb Pesticide Suite	All Components	µg/l	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury	-	µg/l	1	<1	<1	<1	<1	<1	<1	<1	<1	15	<1
Metals (Dissolved)	Arsenic	µg/l	10	<2	25	142	3	8	24	5	15	27	5
	Silver	µg/l	10	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Aluminium	µg/l	200	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Beryllium	µg/l	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Barium	µg/l	500	<2	343	327	521	471	53	206	65	123	29
	Chromium	µg/l	50	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Cadmium	µg/l	5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Cobalt	µg/l	-	<2	3	8	5	<2	<2	<2	<2	7	<2
	Copper	µg/l	2000	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Manganese	µg/l	50	<2	118	72	307	221	88	330	91	59	213
	Tin	µg/l	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Nickel	µg/l	20	<2	27	27	30	10	4	5	4	16	<2
	Lead	µg/l	25	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Antimony	µg/l	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Selenium	µg/l	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
	Zinc	µg/l	100	<2	<2	3	34	81	2	<2	2	10	9
Metals Scan	Calcium	mg/l	200	<0.1	151	151	202	203	50	156	78	112	38
	Iron	mg/l	0.2	<0.1	0.1	0.1	0.3	0.3	<0.1	0.1	0.1	0.1	<0.1
	Potassium	mg/l	12	<0.1	1.3	1.4	1.1	1.6	0.6	1.9	1.1	1.7	2.9
	Magnesium	mg/l	50	<0.1	7.4	7.6	23	12	7.8	16	<2	9	7.1
	Sodium	mg/l	200	<0.1	9.9	13	12	14	9.1	12	<2	17	13
SVOC's	All Components	µg/l	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
VOC's USEPA 524.2 µg/l	All Components	µg/l	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
VOC's by GC-FID	All Components	mg/l	-	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Total Coliforms	-	MPN/100mls	0/100mls	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
e.Coli	-	MPN/100mls	0/100mls	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

M.A.C = Maximum Admissable Concentration under S.I. No. 278, 2007 (European Communities Drinking Water Regulations).

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Table 6.14: Average groundwater quality from 2014 – Q2 2016

Borehole - GW	Units	GW 1S	GW 1D	GW 2S	GW 2D	GW 3S	GW 3D	GW 4S	GW 4D	GW 5S	GW 5D	GW 6	GW 9	GW 10	GW 11S	GW 11D	GW 12S	GW 12D	GW 13S	GW 13D
Analyte																				
pH	Ph units	7.2	7.3	7.2	7.3	7.1	7.3	7.5	7.6	7.2	7.3	7.6	7.5	7.3	7.4	7.5	7.7	7.9	7.5	7.9
Conductivity	µS/cm	903.4	723.9	847.8	750.6	826.6	504.0	743.1	540.4	897.2	653.4	520.7	527.8	654.2	723.8	667.4	456.9	324.9	446.3	248.4
Chloride	mg/l	13.2	11.8	12.2	15.4	14.6	13.3	14.4	12.7	17.3	11.2	12.1	12.4	11.4	14.6	14.5	10.8	10.7	12.9	11.9
Ammonia as NH3	mg/l	6.6	6.7	1.6	2.1	4.0	2.4	7.1	1.1	6.7	7.5	6.1	1.8	4.1	8.2	6.5	7.0	3.6	1.0	0.5
Ammonium	mg/l	8.4	8.6	2.1	2.7	5.1	3.1	9.1	1.3	8.6	9.7	7.9	2.3	5.3	10.6	8.3	9.0	4.7	1.3	0.7
Sulphate	mg/l	2.1	0.8	11.7	2.0	7.2	1.4	1.0	0.7	8.2	1.0	0.7	3.2	0.9	5.5	7.5	0.8	0.7	7.4	1.0
Nitrate as NO3	mg/l			0.3				0.1	0.1	0.1	0.0	0.1	0.2	0.3	0.0		0.1	0.1	0.1	0.1
Orthophosphate	mg/l	0.0	0.0	0.1		0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1		0.0	0.0	0.0	0.1	0.0
Total Phosphorus	mg/l	0.8	1.2	0.3	0.1	0.4	0.1	0.1	0.1	0.0	0.0	0.2	0.3	0.2			0.1	0.1	0.1	0.1
Metal Scan																				
Calcium	µg/l	195.7	155.8	205.5	125.5	164.0	72.0	235.0	69.0	132.0	54.4	77.5	140.0	122.7	128.5	69.0	76.5	32.5	83.0	31.0
Magnesium	µg/l	18.0	5.8	27.7	7.9	19.4	8.4	18.7	15.7	3.4	3.7	9.2	8.5	9.7	3.2	9.8	6.0	7.5	6.8	4.5
Potassium	µg/l	1.4	1.2	0.9	1.3	1.5	0.3	2.3	1.2	14.5	5.4	1.7	2.3	1.5	12.4	19.4	8.7	9.0	5.3	8.3
Sodium	µg/l	13.8	11.2	8.7	16.5	12.4	11.0	14.0	14.3	15.2	45.6	11.5	11.7	7.1	7.9	8.5	8.8	8.5	4.8	4.2
Iron	µg/l	137.7	5.7	16.8	3.0	6.7	0.2	2.5	1.4	0.1	0.1	30.0	2.4	36.4	<LOD	<LOD	0.1	0.1	1.4	0.2
Boron	µg/l	13.8	9.6	47.1	12.5	21.6	12.0	17.0	13.7	16.0	8.5	12.8	11.0	5.9	15.0	24.0	17.0	12.5	11.0	9.0
Arsenic	µg/l	29.4	126.8	12.6	28.0	12.9	18.0	5.0	22.7	2.0	6.0	131.0	12.2	5.6	2.0	5.0	18.5	7.5	3.0	3.0
Barium	µg/l	377.2	350.9	479.4	351.5	395.0	135.0	323.0	85.7	395.5	859.5	129.9	147.8	112.3	485.5	339.5	202.0	62.0	80.5	37.0
Cadmium	µg/l	<2	4.5	2.0	<2	<2	<2	<2	2.0	2.0	2.0	<2	<2	<2	<2	<LOD	2.0	2.0	2.0	2.0
Cobalt	µg/l	3.0	9.4	4.7	4.0	<LOD	<LOD	3.0	2.0	3.0	2.0	8.0	3.3	<LOD	2.0	3.0	2.0	2.0	2.0	2.0
Chromium	µg/l	3.0	7.5	6.0	<LOD	2.5	<LOD	<LOD	2.0	2.0	2.0	<LOD	3.8	3.5	<LOD	<LOD	2.0	2.0	2.0	2.0
Copper	µg/l	3.8	192.2	5.8	<LOD	2.8	<LOD	<LOD	2.0	2.0	2.5	268.5	6.0	3.5	<LOD	4.0	3.0	2.0	2.0	2.0
Mercury	µg/l	0.1	84.5	0.1	0.1	0.1	0.1	0.1	1.0	1.0	1.0	28.0	0.1	0.1	0.1	0.1	1.0	1.0	1.0	2.0

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Borehole - GW	Units	GW 1S	GW 1D	GW 2S	GW 2D	GW 3S	GW 3D	GW 4S	GW 4D	GW 5S	GW 5D	GW 6	GW 9	GW 10	GW 11S	GW 11D	GW 12S	GW 12D	GW 13S	GW 13D
Analyte																				
Manganese	µg/l	420.0	194.8	455.6	161.5	218.1	277.0	882.0	95.3	237.5	175.0	27.6	312.8	208.8	205.0	294.5	50.0	55.0	274.0	322.0
Beryllium	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Nickel	µg/l	18.6	34.6	22.3	12.5	5.1	6.0	7.0	3.7	30.5	23.0	20.1	12.2	3.9	30.0	30.5	7.5	5.0	2.0	2.5
Lead	µg/l	4.2	5.6	7.0	<LOD	5.3	<LOD	<LOD	2.0	2.0	2.0	5.2	5.0	3.3	<LOD	<LOD	2.0	2.0	2.0	2.0
Antimony	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	3.0	2.0	2.0	2.0	2.0	<LOD	2.0	<LOD	<LOD	3.0	2.0	2.0	2.0
Selenium	µg/l	3.0	3.0	2.0	<LOD	1.0	<LOD	<LOD	2.0	2.0	2.0	<LOD	1.5	2.0	<LOD	11.0	2.0	2.0	2.0	3.5
Aluminium	µg/l	76.7	108.7	184.2	2.5	107.1	<LOD	10.0	2.7	2.0	2.0	39.4	135.9	70.6	<LOD	<LOD	2.0	2.0	5.0	2.0
Zinc	µg/l	31.7	54.0	24.8	8.0	31.0	<LOD	23.0	5.0	2.0	2.0	36.1	42.4	14.6	<LOD	<LOD	2.0	2.0	2.0	2.0
Organics Scan	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
USEPA	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Dichloromethane (µg/l)	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
GC-FID	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Acetone	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Methanol	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Ethanol	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Isopropanol	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Acetonitrile	µg/l	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

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Note: the averaging period from 2014 to Q2 2016 is used to maintain consistency with the Proposed Development EIAR.

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6.3.12 Likely Future Receiving Environment / Do Nothing Scenario

In the Do Nothing Scenario the existing conditions detailed in Chapter 3 will remain. The site will continue to be managed in accordance with the IED licence. The potential for agricultural land use is negligible while the potential for commercial forestry is low except where peat depths are less than 0.5m. As the water level is managed at the site and in the surrounding area by a large number of drains, the potential for peatland restoration is low.

6.4 POTENTIAL EFFECTS ON GEOLOGY AND HYDROGEOLOGY

6.4.1 Construction Phase

Potential effects during the construction phase of the existing facility include activities associated with the movement, excavation and disposal of soils, contaminated materials (if present) and compaction of soils. This can result in temporary and permanent impacts on the geological environment.

In order to minimise any potential impact on the environment, including the soil, geological and hydrogeological environment (natural resource), avoidance of impact was incorporated into the design of the development.

Shallow soil removal along the landfill footprint and hardstand areas is almost completed with the exception of some works at Phase 15 required. However, the natural soil and geological environment has been impacted by past industrial activity undertaken within the property. The existing facility is approximately 179 ha of land within an overall landholding of 2,544 ha. The existing facility area of approximately 179 ha has resulted and will continue to result in a permanent change from industrial cutover peatland to industrial/commercial and low intensity grassland use. The geological and hydrogeological environment over the remaining area within the landownership boundary (2,544 ha) will therefore remain unaffected by landfill activities.

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Earthworks and excavations are likely to cause the greatest impact on the soil environment during the construction phase. Imported material required for the construction of the additional landfill capacity will require appropriate handling during the construction phase. Mitigation measures are included in Section 6.5.

All excavations within the site will be terminated in the unconsolidated material; potential impact on the bedrock environment will be negligible. All peat was progressively cleared from the footprint in order to achieve formation levels for construction. The peat and subsoil material is utilised on site and used to screen the facility as outlined in Chapter 3.

The operation of plant and machinery during construction poses a potential risk of soil and groundwater contamination, through the potential spillage of fuel, lubricants or chemicals directly onto exposed surfaces.

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The potential impact associated with exposed soil surface principally relates to sediment laden run-off to watercourses. The greatest risk of sediment run-off will occur during wet weather. Management and control of water falling on worked areas is an important aspect in minimising the impact of construction. Mitigation measures are outlined below in Section 6.5 to reduce the impact on the soil environment. The implementation of such measures will ensure that surface water discharges will be of good quality.

The baseline assessment indicates that there are no groundwater abstraction wells for potable supply within approximately 1 km of the landfills (based on distance to nearest sensitive receptors).

Due to the low permeability of the natural subsoil and the thickness of this unconsolidated material, the potential effects on any domestic wells or boreholes in the broad vicinity of the existing facility are considered to be low. Based on the groundwater and surface water monitoring, no impact has occurred on the subsoil environment. Based on hydrogeological conditions in this region, the zone of contribution to domestic wells is small and do not extend to the existing facility.

The facility will not impact upon the quality or abstraction rate of any supplies in the area. The facility is outside of the source protection zones of both the Robertstown well field and the Johnstown Bridge well field (over 5 km from the Facility). Therefore, the facility will not impact upon these abstractions.

6.4.2 Operational Phase

Due to the nature of the existing facility, machinery is present and operational on the facility. This may lead to occasional accidental emissions, in the form of oil, petrol or diesel leaks, which could cause contamination if the contaminants entered the soil environment. Similarly, there is the potential for leakage of process water from the existing facility which could cause contamination of the soil and groundwater environment.

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However, given that the existing facility is underlain with low permeability subsoil, the potential for migration offsite is low/negligible. Potential spillages that may directly or indirectly impact on the surface water environment in the area of the development, operational impacts are considered in more detail in Chapter 7 (Water). The natural soil and geological environment has been impacted by past industrial activity undertaken within the existing facility. Since the cessation of peat harvesting, the lands have largely remained unaffected by human activity or development. Some small scale, localised peat cutting still occurs at the margins of the existing bog to meet local requirements.

The greatest potential impact associated with the operation of the facility is the potential discharge of hazardous substances to the bedrock aquifer. A hydrogeological risk assessment (HRA) prepared in support of the Proposed Development EIAR (which includes the existing MSW Landfill) is included in Appendix 6.8.

At present the Drehid WMF is permitted for the deposition of treated MSW up to 2028.

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The avoidance of impact was incorporated into the design of the landfill to have as low impact as possible on the groundwater environment. Laboratory testing of the mineral subsoil, based on tri-axial constant head permeability tests, indicates that the in-situ natural vertical permeability of the quaternary overburden varies between 2.2 $x10^{-10}$ m/s (lower limit) to 1.5 x 10^{-9} m/s (upper limit), with an average vertical permeability of 6.78 x 10^{-10} m/s.

The low permeability natural mineral subsoil is overlain by a 0.5 m thick barrier layer of Bentonite Enhanced Soil (BES), which is processed to achieve a permeability of less than or equal to 5 x 10^{-10} m/s. The BES is in turn overlain by a geomembrane HDPE liner, to prevent leakage of leachate. Leachate from the landfill is fully contained and collected in process waste water tanks. Leachate generated from the landfill is collected through a leachate collection system. This system is designed in accordance with the Landfill Design Manual. The leachate is collected and pumped to the leachate storage tanks prior to export by tanker to an appropriate licensed WWTP.

The composting process generates wastewater in the form of leachate and condensate. Leachate is generated by the leaching of moisture from feedstock within the composting tunnels (particularly in the early stages of the process) to the floor of the tunnels. Condensate is generated by the cooling of high humidity process air (exhausted from the tunnels) in aeration system ductwork. This collected leachate is used in a closed loop system and will not generate surplus leachate.

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The excavation of the peat material and mineral subsoil is required to allow the landfill to be constructed in such a manner as to create a groundwater hydraulic trap. A minimum of 7 m subsoil will remain beneath the design formation level in the landfill.

In addition, an undercell drainage network will be installed comprising a network of drains or 300 mm of drainage stone with a groundwater pump sump which will prevent hydraulic uplift and facilitate the construction of the landfill footprint. This methodology is already applied at the Drehid Waste Management Facility.

A Hydrogeological Risk Assessment (HRA) was undertaken as part of the application and is included in Appendix 6.8. The LandSim model (v2.5.17) was developed by Golder Associates for the Environment Agency in England and Wales to provide probabilistic quantitative risk assessments of specific landfill site performance in relation to groundwater protection.

The HRA has been carried out using conservative assumptions regarding the source, pathways and receptors. The Environment Agency's LandSim software (version 2.5.17) and the Environment Agency's Contaminant Fluxes from Hydraulic Containment Landfills Worksheet Version 1.0 have been used to estimate of the potential risks associated with the site as they both use audited and verified model code that is widely accessible.

The LandSim software was used for the following reasons:

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- it uses stochastic techniques and so allows a probabilistic appreciation of the site's performance;
- it provides a consistent approach to the estimation of hydrogeological risks for landfills;
- it aids comprehensive reporting of input values, assumptions and results; and
- It allows several landfill phases to be modelled simultaneously.

The LandSim model has been assessed in a stochastic manner and throughout this assessment the acceptable probability of an undesirable outcome occurring has been set at the 95%ile confidence level. In addition, the 95%ile is commonly selected as a reasonable worst case, against which it is acceptable to make decisions taking into account the assumptions and limitations of the modelling process.

The Water Framework Directive requires technical precautions (i.e. appropriate landfill liner, capping layer, etc.) must be undertaken to prevent the discharge to groundwater of hazardous substances (formerly List I substances) and to ensure that any discharge of List II substances does not cause pollution and to limit the discharge of non-hazardous pollutants (List II substances). This means that the HRA must demonstrate that hazardous substances will not reach the aquifer at discernible concentrations at the compliance point and that non-hazardous pollutants will not be present at a compliance point above a level that may constitute pollution.

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The compliance point in this case is the base of the subsoil material (bedrock aquifer prior to dilution in the aquifer) for hazardous substances (List 1) and the River Cushaling tributary (Code: 14_352), located west of the site for non-hazardous substances (List 2). Input parameters are based on the site design (refer to Chapter 3), including engineered containment, phase areas, waste thickness, and leachate drainage and collection facilities.

Leachate quality data from the existing landfill and published data[30] were used to provide ranges of input concentrations into the LandSim model for the Landfill.

Waste input for the Landfill comprises C&D waste including fines, soil & stone, and treated MSW. Ammoniacal nitrogen and chloride are two of the major constituents of Landfill leachate and have been selected as indicators of likely levels of contamination. Chloride is not attenuated other than by dilution, whilst ammoniacal nitrogen, a List II substance and other hazardous substances are retarded by processes such as ion exchange. In addition, metals such as mercury and cadmium (List I) were included as input parameters for modelling. Hydrophobic and hydrophilic organics were also assessed.

The LandSim modelling results indicate that, with the landfill designed and constructed as described in Chapter 3, it is unlikely that any significant impact to groundwater will occur. There are no predicted exceedances of Hazardous Substances in the underlying aquifer prior to dilution.

[30] Improved definition of leachate source term from landfills. (EA, 2004) LandSim version 2 (Golders, 2007)

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The 95th percentile values are used as outputs from the model, which are representative of the reasonable worst-case performance of the landfill. The compliance point for List I substances is considered to be the base of the in-situ clay subsoils or in the limestone aquifer unit.

The compliance point for List II substances is considered to be the River Cushaling tributary (Code: 14_352), located downgradient of the waste footprint within the application boundary. There are no current or proposed drinking water abstractions located between the facility and the River Cushaling tributary.

For both the advective / dispersion and diffusive modelled scenarios, no breakthrough of hazardous substances is predicted during the theoretical managed lifetime of the site i.e. during the operational and post closure managed phases of the landfill (60 and 100 years). Hazardous and non-hazardous substances do not exceed the relevant Environmental Assessment Limits (EALs) during the operational and post closure managed phases of the landfill.

Cadmium is the only hazardous substance to record breakthrough at the compliance point (base of the subsoil material) within the modelled lifetime of the site of 20,000 years. The predicted 95th percentile concentration of <0.00001 mg/l, is not detectable with current laboratory methods and <1% of the minimum reporting value of 0.001 mg/l.

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None of the non-hazardous (List II) substances record peak concentrations greater than 50% of their respective guidelines within the modelled lifetime of the site of 20,000 years for either an advective/dispersion or diffusive modelled pollutant-transport scenario. The predicted concentrations are sufficiently low that none of these contaminants will have a discernible impact upon groundwater quality within the aquifer unit.

Inorganic anions and cations i.e. (Sodium and Chloride) are the only determinands which may record detectable concentrations down-gradient of the landfill during the theoretical managed lifetime of the existing facility. The predicted concentrations are above groundwater guidelines and background concentrations in the downgradient groundwater. However, there are no potential or existing potable groundwater abstractions between the landfill sites and the River Cushaling. Chloride concentrations are within the Surface Water Regulations in the River Cushaling based on the HRA. The predicted 95th percentile concentration of 60 mg/l, is 25% of the drinking water parameter value (250 mg/l). Again, no groundwater abstractions occur downgradient of site between the existing facility and the Cushaling River.

As part of the development of the existing facility, avoidance of impacts was incorporated into certain designs, to minimise or significantly reduce potential effects.

Earthworks and excavations are likely to cause the greatest impact on the soil environment during the construction phase. It should be noted that the vast majority of the material required for the construction of the facility infrastructure is available within the confines of the site activity boundary, therefore

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construction disruption will not impact on the surrounding environment, i.e. the general public will not be impacted during the construction of the facility.

All excavations within the site are terminated in the unconsolidated material; therefore, there is no potential effect on the bedrock environment. Peat material was removed from the landfill footprint and the borrow areas in order to win construction material or achieve formation levels for landfill construction. Peat was removed from the administrative area, sand and gravel borrow pit and the existing landfill. Further excavations will be limited and phased over the remaining 10 year lifetime of the existing facility and therefore the potential impact of such activity will also be phased.

The potential impact associated with exposed soil surface principally relates to sediment laden run-off to watercourses. The greatest risk of sediment run-off occurs during wet weather. Management and control of water falling on worked areas are an important aspect in minimising the impact of construction. The implementation of such measures at the existing facility has ensured that surface water discharges have been of good quality. Much of the infrastructure and mitigation measures outlined herein have already been put in place for the construction and operation of the existing facility, with the remaining measures to be implemented on a phased basis.

Mitigation measures are outlined in Section 6.5 below to reduce the impact on the soil environment. The landfill design is cognisant of the hydro geological setting of the existing facility and the recommendations of the GSI Groundwater Response Matrix for Landfills.

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The regional hydrogeological setting of the site, in terms of aquifer potential and groundwater vulnerability, does not preclude the siting of a residual landfill at the site. The Response Matrix for Landfill Selection indicates that the site falls within the R1 and R2 zone. The R1 and R2 zones are the lowest risk categories in the matrix for landfill selection. Therefore, in terms of land-use zoning the siting of a landfill is acceptable, subject to guidance outlined in the EPA Landfill Design Manual or conditions of an IED Licence.

The baseline assessment indicates that there are no groundwater abstraction wells for potable supply within 1 km of the landfill footprint. There are no groundwater abstraction wells located down gradient of the existing or landfills. The landfills will not impact upon the quality or abstraction rate of any supplies in the area. The landfills are outside of the source protection zones of both the Robertstown well field and the Johnstown Bridge well field. The landfills will not impact upon these proposed major abstraction areas.

6.5 MITIGATION MEASURES

6.5.1 Construction phase

The following mitigation measures have been employed on site for initial stages of construction of the permitted Drehid WMF. These mitigation measures will also be employed for the remaining phases of the existing landfill operations and for the existing facility which is the subject of this EIAR.

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Occasional construction activities carried out at the facility which are deemed Specified Engineering Works are required to be notified to the EPA. Construction works carried out at the facility are and will continue to be carried out in accordance with a Construction Environmental Management Plan (CEMP) which the Contractor is required to supply to Bord na Móna. The CEMP outlines measures to ensure compliance with the IED emission limit values for the site during the construction works.

During the construction of the facility, and especially when excavation of unconsolidated material is required, standard approved working methods have been and will continue to be employed to reduce the risk to the surrounding environment. Exposed soil surfaces have the potential to flow from the site to surface water channels. Temporary and permanent water control measures, including sediment control measures and the attenuation lagoons will control the quality of any water discharged from the Drehid WMF as a whole. Details of the water control measures are included in Chapter 7 (Water).

During the progressive ground clearance for the landfill footprint, the excess soil material was used to create visual berms. To mitigate soil erosion, all exposed soil surface will be anchored by vegetation and/or by use of ground stabilisation geogrids. During construction work and until vegetation has anchored the embankments, any water accumulating on exposed soil is diverted through the attenuation lagoons.

All potentially polluting materials, including hydraulic fluid, engine oil and fuel, are and is stored in bunded areas to ensure total containment in the unlikely event of failure of a storage tank. This reduces the risk of soil contamination due to activity of plant and equipment.

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In order to provide assurance that the landfill is constructed in accordance with intended design and technical specifications, a comprehensive Construction Quality Assurance (CQA) plan is implemented during the construction stage. The CQA plan will include Construction Quality Control (CQC) procedures to ensure that materials and workmanship meet defined specifications.

CQC procedures include the integrity testing of all surface water, foul water, process water pipe work, landfill liners and underground structures in accordance with industry accepted standards and procedures.

All integrity testing is inspected and witnessed by an appropriately qualified person acting on behalf of Bord na Móna. Integrity test certificates are signed by both the Contractor's Engineer and the engineer representing Bord na Móna.

Following the completion of construction and testing of the landfill cells and prior to the acceptance of waste, the CQA Report is prepared by a third party in compliance with good industry practice.

6.5.2 Operational Phase

Any standing water accumulating within the landfill footprint, where waste has not been placed, is diverted to the attenuation lagoons, where suspended solids fall out of suspension prior to discharge of water to

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the adjoining surface water network. The mitigation measures described refer only to the stabilisation of exposed soil surfaces as there will be little or no disturbance of the geological environment.

The leachate storage tanks are located in a fully bunded area of the site. Surface water from this area is captured in a sump and pumped to the leachate storage tanks, where it is stored prior to being tankered from site and disposed of at a licensed facility as discussed in Chapter 3. No run-off from the leachate storage area is discharged or connected to the surface water network.

The engineering measures utilised in the construction of landfill capacity are aimed at the containment of leachate within the landfill liner system and the collection of landfill leachate for treatment, recirculation or disposal to a licensed WWTP, as discussed in Chapter 3.

The design has also taken account of the groundwater protection response matrix and the protection of this natural resource. The design of the containment system is in accordance with the EU Landfill Directive. A composite basal lining system was developed to maximise the protection offered. This basal liner has already been installed for the existing landfill and will be utilised for the remaining phases of the landfill. The landfill is founded on stiff gravelly clay. The existing geotechnical design and slope stability assessment programme will continue to be implemented at the Drehid facility.

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The primary containment system in the existing facility is the HDPE liner. The second protection layer, an engineered low permeability layer of 500 mm of Bentonite Enhanced Soil (BES), with a permeability value of less than or equal to 5 x 10^{-10} m/s, which forms a low permeability barrier to impede vertical percolation at the landfill.

The low permeability of the natural overburden material (vertical permeability varying between 2.2 x 10^{-10} m/s to 1 x 10^{-9} m/s) offers further protection to the groundwater environment, in addition to those measures employed in the engineering of the facility.

The leachate management system is described in more detail in Chapter 3 of this EIAR. A leachate collection system, comprising a permeable drainage layer with leachate collection pipework, has been installed on top of the basal liner in the existing landfill, with a gradient towards a leachate sump. Leachate from the existing landfill is pumped to the leachate storage tanks. The leachate storage tanks are emptied periodically and tankered off-site to approved wastewater treatment facilities. Leachate from the composting facility is recirculated within the composting process, insofar as is possible, or transferred to the leachate storage tanks for tinkering off-site.

Four existing attenuation lagoons (No. 1 to No. 4) serve the existing landfill. All surface water collected from the landfill, and their subsequent capping, will discharge to surface water swales where it will flow by gravity to the existing surface water attenuation lagoons as shown on Drawing No. 10369-2001, thereby limiting recharge to the landfill mass.

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Overflow from the attenuation lagoons is diverted through integrated constructed wetlands (ICWs) to provide an additional step in the treatment train, prior to discharge to the peatland drainage system.

All effluent from the proprietary wastewater treatment plant serving the administration building (i.e. liquid fraction) is diverted to the leachate storage tanks. Therefore, the contaminant loading on the area will be minimal as there is no direct discharge of potentially polluting material to the groundwater environment.

The run-off from internal roads and the low risk hardstanding areas in the existing facility is collected centrally, from where the accumulated water is diverted through a sediment grit trap, a three-chamber oil interceptor and finally discharged to surface water attenuation lagoons, and wetland areas.

A fixed rate outfall is maintained from the surface water attenuation lagoons to the adjoining site drainage network, which eventually drains to the Cushaling River via the existing Bord na Móna surface water pond which services the southern portion of the Timahoe Bog. The fixed rate outfall from the facility surface water attenuation lagoons will ensure that during extreme rainfall events peakflows are retained within the site.

Given the above mitigation measures and the landfill design employed to contain the leachate within the landfill and the results of the HRA, it is considered that the impact on the geological and hydrogeological environment will not be significant.

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6.6 MONITORING

Sampling of groundwater, from the monitoring boreholes installed within the site, is undertaken in accordance with the existing IED Licence to demonstrate the quality of the groundwater. The groundwater sampling results previously provide detailed information on the existing groundwater quality. These groundwater wells will continue to be sampled during the operational lifetime of the facility in accordance with the IED Licence. The quality of the groundwater samples is compared to the samples obtained as part of the baseline study to determine if the site operations are having an effect on the surrounding environment.

6.7 RESIDUAL EFFECTS

The existing facility is resulting in a permanent change from industrial cutover peatland to industrial/commercial and low intensity grassland use.

Due to the low magnitude of impact and low sensitivity of the surrounding environment, the residual impacts on the surrounding geological and hydrogeological regime at the site are considered to be minor and mainly long term in nature. Detailed mitigation measures have been provided with regard to the design, construction, and maintenance of the existing facility. It is considered that there will be no significant residual impact on the geological environment as a result of this facility.

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