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GALWAY HISTORIC LANDFILL

TIER 2 RISK ASSESSMENT HISTORIC LANDFILL AT TUAM, CO. GALWAY

Prepared for: Galway County Council

Comhairle Chontae na Gaillimhe
Galway County Council

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TIER 2 RISK ASSESSMENT HISTORIC LANDFILL AT TUAM, CO. GALWAY

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Abstract: This report represents the findings of a Tier 2 site investigation carried out at Tuam Historic Landfill, Co. Galway and conducted in accordance with the EPA Code of Practice for unregulated landfill sites. The site investigation was undertaken to determine the extent of the historic landfilling at the site.

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EXECUTIVE SUMMARY

Tuam Historical Landfill covers an area of c.3.4 ha and is located in the townland of Rinkippen to the south of Tuam. The landfill was operated by Galway County Council and post closure underwent remediation works. The historical landfill site adjoins an existing operational civic amenity site.

A Tier 2 study was conducted by Fehily Timoney and Company (FT) in accordance with the Environmental Protection Agency Code of Practice - Environmental Risk Assessment for Unregulated Waste Disposal Sites for Tuam Historic Landfill. The study consisted of a desktop study, topographical survey, geophysical survey, intrusive site investigation works and environmental monitoring. These works informed the development of the Conceptual Site Model (CSM) and risk screening model.

The findings of the site investigation work and geophysical surveying suggest the waste material is deposited in a single infill area estimated at ca.23,300 m^2.

An estimated waste volume of 145,407.7 m^3 based on a combination of the geophysical survey profiles and borehole logs for previously installed in waste boreholes (BH1 - BH3) was determined.

Trial pitting and site walkovers have confirmed the waste material is located close to the surface with a minimal soil cover underlain by a geocomposite clay liner (GCL) previously installed at the site.

Analysis of groundwater samples recovered from 8 No. monitoring wells reported ammoniacal nitrogen concentrations which exceed the European Communities, Environmental Objectives (Groundwater)(Amendment) Regulations, 2016 (S.I. No. 366 of 2016) threshold values and EPA Interim Guidelines Values (IGV) in all wells (upgradient and downgradient). The ammoniacal nitrogen concentrations measured at upgradient boreholes both in 2020 and 2022 could be considered representative of background levels as it unlikely that leachate migration to these locations is occurring based on groundwater flow direction.

Groundwater monitoring conducted in 2020, 2022 and historical groundwater monitoring results do indicate that leachate migration is impacting groundwater quality immediately downgradient of the site, to the west, however this impact has not been observed further from the site at monitoring locations further downgradient (>200m west). The impact on groundwater quality is likely to be localised.

Landfill gas monitoring from 11 No. perimeter boreholes and civic amenity borehole show that lateral migration of landfill gas is unlikely to be occurring. Despite low gas concentrations measured at the perimeter wells the proximity of the civic amenity (CA) site to the landfill site and the potential for the CA site to be underlain by waste material high risk scores of 70% have been calculated for SPR10 and SPR11.

Analysis of surface water samples taken from the River Killeelaun and River Clare showed several exceedances of the MAC and EQS surface water quality limit values as per the European Communities Environmental Objectives (Surface Waters) Regulations, 2009 (as amended). Elevated concentrations of dissolved metals such as Chromium and Nickel in downstream samples which weren't recorded in upstream samples indicate potential leaching of metals from the landfill and migration to the receiving drainage network and stream, downstream of the site. The additional round of monitoring undertaken in 2022 show one exceedance downstream of the site for the EQS threshold values for Ammoniacal Nitrogen, which could be an indicative of leachate migration from the landfill to surface water.

Based on the results of the Tier 2 site assessment, the site can be classified as a **High-Risk Classification (Class A)**. The principal risk identified on the site is the risk posed to the underlying aquifer from leachate migration and to human receptors from landfill gas migration.

1. INTRODUCTION

1.1 Background

Tuam Historical Landfill covers an area of c.3.4 ha and is located in the townland of Rinkippen to the south of Tuam. The landfill was operated by Galway County Council and closed in 1998. Since then closure and remediation works were carried out at the site. An active civic amenity site is located immediately adjacent to the site.

The landfill rises to a height of approximately 6-7m above the surrounding land and has relatively steep slopes along the north, west and southern boundaries. The topography of the surrounding area is generally relatively flat, with a gentle slope southward to the south-west towards the River Clare. The surroundings area is agricultural land and boglands.

Information provided by GCC states that the landfill operated from the 1950s to 1998 and during this period it is estimated that approx. 11,000 tons of waste was disposed each year. The landfill was subject to remediation post closure. Evidence suggests a geosynthetic clay liner (GCL) capping layer was placed over the landfill in 2001 and subsequently covered with a 300mm layer of soil. Routine surface water and groundwater monitoring was also carried out by Galway County Council up to 2013.

A Tier 1 Risk Assessment was previously completed by GCC. Based on the available information, the Tier 1 Assessment determined that the overall risk score for Tuam Landfill was 70%, resulting in a risk classification of High (Class A), with a score 70% being applied to SPR linkages SPR 10 and SPR11, referring to potential of landfill gas to human receptors via vertical and lateral migration.

A copy of GCC's Tier 1 risk assessment scoring is included in Appendix 1.

1.2 Scope of Works

FT's scope of work was to undertake a Tier 2 assessment of the site in accordance with the EPA Code of Practice (CoP) 2007: *Environmental Risk Assessment for Unregulated Waste Disposal Sites*. This approach required the completion of the following:

- Desk Study;
- Site Walkover;
- Geophysical surveying to estimate footprint and depths of waste;
- Intrusive Site Investigation;
- Groundwater, Leachate, Surface Water Sampling and Landfill Gas monitoring;
- Waste/made ground sampling and analysis;
- Development of a conceptual site model (CSM);
- Environmental Risk Assessment (ERA).

As part of the initial desk study, a review of available information was undertaken. This was followed-up with a site walkover by FT personnel on 20th May 2020. The desk study and site walkover were used to determine the locations for the intrusive site investigation.

The site walkover checklist and accompanying photolog are included in Appendix 2 to this report.

A Closure and Remediation Plan (1999) was also provided by GCC and was reviewed as part of the initial desk study. The Closure and Remediation Plan is included in Appendix 3 of this report for historical reference.

A topographical survey of the site was completed. A copy of the survey is included in Appendix 4.

Minerex were appointed by FT to undertake a geophysical survey of the site. Geophysical surveying included Electro Conductivity, Electro Resistivity and Seismic Refraction surveying methods. The purpose of the geophysical study was to attempt to define the vertical and lateral extents of any waste body.

The geophysical survey report is included in Appendix 5 to this document.

FT appointed Causeway Geotech Limited (CGL) to conduct the intrusive site investigation which included the installation of two groundwater monitoring wells (one shallow and one deep) and the excavation of five trial pits. Sampling and geotechnical analysis of capping material was also conducted.

The 2020 and 2022 geotechnical reports are included in Appendix 6 to this document.

Laboratory analysis of surface water and groundwater monitoring was conducted to assess and quantify any potential or ongoing environmental impacts. Laboratory analytical reports for surface and groundwater presented in Appendix 7 of this report.

The information gathered from the desk study, intrusive site investigation and geophysical survey were used to inform the development of the CSM and the Environmental Risk Assessment (ERA). This report presents the findings of the assessment.

2. DESK STUDY

2.1 Introduction

The desk study included the review of the following literature sources and websites:

- Geological Survey of Ireland, Groundwater Web Mapping: www.gsi.ie
- Environmental Protection Agency Maps: http://gis.epa.ie/Envision
- National Parks and Wildlife Service Map Viewer: www.npws.ie
- DoHPLG/EPA/Local Authority maps: www.catchments.ie
- BS 5930: 1999, Code of Practice for Site Investigations;
- BS 10175: 2000, Investigation of Potentially Contaminated Sites – Code of Practice;
- EPA - Assessing and Developing Natural Background Levels for Chemical Parameters in Irish Groundwater (2017);
- Closure and Remediation Plan for Tuam Landfill, (MCOSullivan, COWI) (1999).

2.2 Desk Study

This section of the report presents the findings of the desk study.

2.2.1 Site Description and On-Site Conditions

The site is located approximately 2km south of the town of Tuam and can be accessed via the R347, Athenry Road which runs between Tuam and Athenry. The site is in the ownership of Galway County Council and a civic amenity site is located in the south east corner of the site. The waste footprint area was previously estimated by GCC to be approximately 3.4Ha in size. There are no dwellings located within the site or in its immediate vicinity. Sheds and outbuildings (including a makeshift canteen area) form part of the civic amenity. There is a work/storage yard located 280m north-east, a farmyard located 350m east and a golf club also located 620m east of the site. The landfill is raised to a height of approximately 6-7m above adjacent lands and is capped with a GCL layer. The historic landfill can be more accurately described as a land raise.

The topography of the surrounding area is generally relatively flat, with a gentle slope southward to the south-west towards the River Clare. The surroundings lands comprise agricultural land and boglands.

A number of existing, offsite groundwater monitoring wells have also been identified at the site, some of which were used for the purpose of groundwater and landfill gas monitoring as part of this Tier 2 assessment.

The location of the site is shown in Figure 2.1.

2.2.2 Previous Studies

A Tier 1 Risk Assessment was previously completed by GCC in (Appendix 1). The Tier 1 assessment comprised the following:

- Identification of contaminant sources, pathways of contaminant migration and potential receptors which may be vulnerable if exposed to those contaminants, i.e. the identification of Source- Pathway-Receptor (SPR) linkages; and
- The prioritisation of sites and SPR linkages based on their perceived risk.

Based on the available information, the Tier 1 Assessment determined that the overall risk score for Tuam Landfill was 70%, resulting in a risk classification of **High (Class A)**.

In 1999, a Closure and Remediation Plan was prepared for the historic landfill in order to reduce the impacts on the surrounding environment and to re-integrate the landfill back into the surrounding landscape. Remediation measures contained in the Plan included the installation of surface water drains along the west and east boundary, re-grading the side slopes to a slope of 1:2.5 or 1:3 to ensure stability and allow for high water run-off. Capping consisting of a 200mm topsoil layer underlain by a 300mm low permeability clayey soil layer and followed by a 'regulation layer' between 100-1000mm placed directly above the waste material was also proposed. The purpose of the 'regulation layer' was to create an even surface for the application of the overlying low permeability soil layer and topsoil.

Three gas/leachate monitoring wells located within the waste body were also installed as part previous site investigations.

The proposed remediation measures aimed to:

- reduce leachate generation;
- separate leachate for surface water;
- control landfill gas migration;
- improve the overall appearance of the landfill;
- provide suitable conditions for plant and other vegetation growth.

In 1999, site investigations were carried out by Geotech Specialists Ltd. as part of a monitoring programme. The investigations included the installation of six boreholes (3 no. cable percussive boreholes (BH1, BH2 and BH3) located within the waste body and 3 no. rotary boreholes (RC1, RC2 and RC3 outside the waste body). Made ground consisting of landfill material with a thin covering of topsoil was encountered at BH1, BH2 and BH3, being located within the waste body. The made ground extended to depths of 4.8 - 9m and rested on soft brown peat to depths of 6-10m. Standpipes were installed in all six boreholes for the purpose of groundwater monitoring (RC1 - RC3) and leachate monitoring (BH1 - BH3)

In 2001, a GCL capping layer was installed as part of the implementation of the landfill remediation plan.

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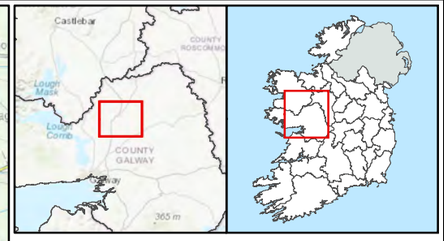
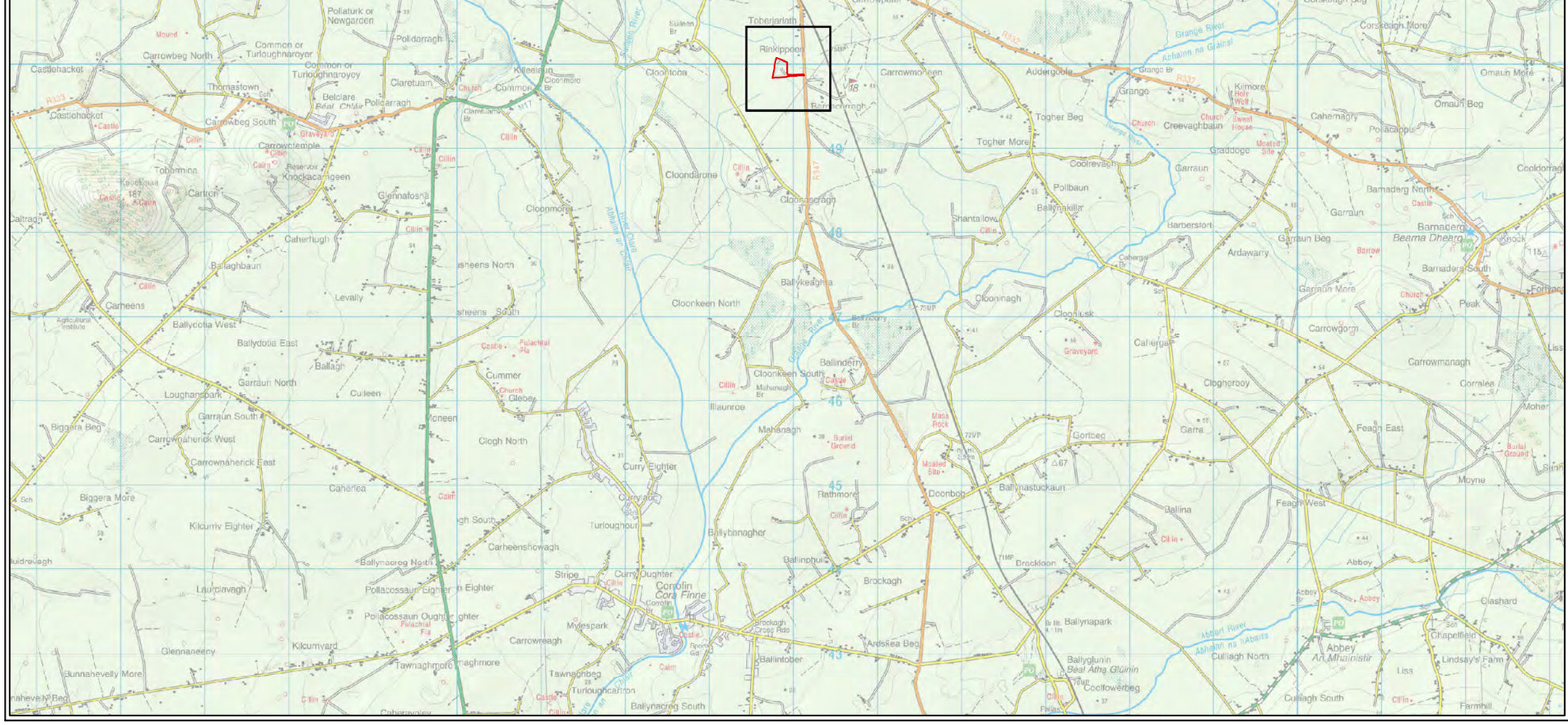


Site Boundary



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SCALE:	1:57795
REVISION:	0
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PAGE SIZE:	A3

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2.2.3 Topography

The site covers an area of 3.4 ha, located approximately 2km south of the town of Tuam. The landfill rises to a height of approximately 6-7m above the surrounding land and has relatively steep slopes along the north, west and southern boundaries.

The area surrounding the landfill is flat and low-lying, comprising agricultural land and cut-over bogland. A topographical survey of the site shows a maximum elevation of 47 mOD, within the centre of the landfill. The site is dome shaped with elevations decreasing in all direction from the centre of the site, with a minimum elevation of approximately 34 mOD at the south west corner of the site.

2.2.4 Geology

Geological and hydrogeological information on the site and surrounding area was obtained from the online GSI spatial mapping and database.

Drift/Quaternary Geology

The quaternary sediments at the site and estimated waste footprint area as 'Cut over raised peat (Cut)'. To the north and east and west of this, quaternary sediments are characterised as 'Till derived from limestones (TLs)'. Further west alluvium deposits are present following the River Clare. Drift/quaternary geology is shown in Figure 2.2.

The installation of boreholes during the 2020 site investigation, confirmed the presence of peat, silt, clay and limestone and is present at depths of 5.0 m bgl at borehole GW01 and 12.0 m bgl at borehole GW02, as referenced in the CGL 2020 borehole logs, Appendix 6.

Solid or Bedrock Geology

The bedrock beneath the site comprises two different formations the boundary of which transects the site. The site is underlain by a combination of undifferentiated Visean Limsetones (CDVIS) and pale grey clean skeletal limestone Burren Formation (CDBURR). Further to the south-west, the site is underlain by Knockmaa Formation. The closest bedrock outcrops recorded by GSI are located approximately 700m north of the site. The bedrock geology is presented in Figure 2.3.

Bedrock described as 'grey limestone' in the drillers logs, was encountered at 6.4 m BGL (27.95 mAOD) during the installation of borehole GW02 (drill depth 12.0 bgl) as referenced in the CGL 2020 borehole logs, Appendix 6.

Previous site investigation conducted in 1999 included the installation of 3 no. rotary core boreholes RC01, RC02 and RC03, located outside of the waste body, to the south-west, north-west and north-east of the site respectively. Bedrock was recorded at 4.4m bgl, 4.75m (c.30.78 mAOD) and 17.9m b.g.l (c.19.18 mAOD) at these boreholes respectively.

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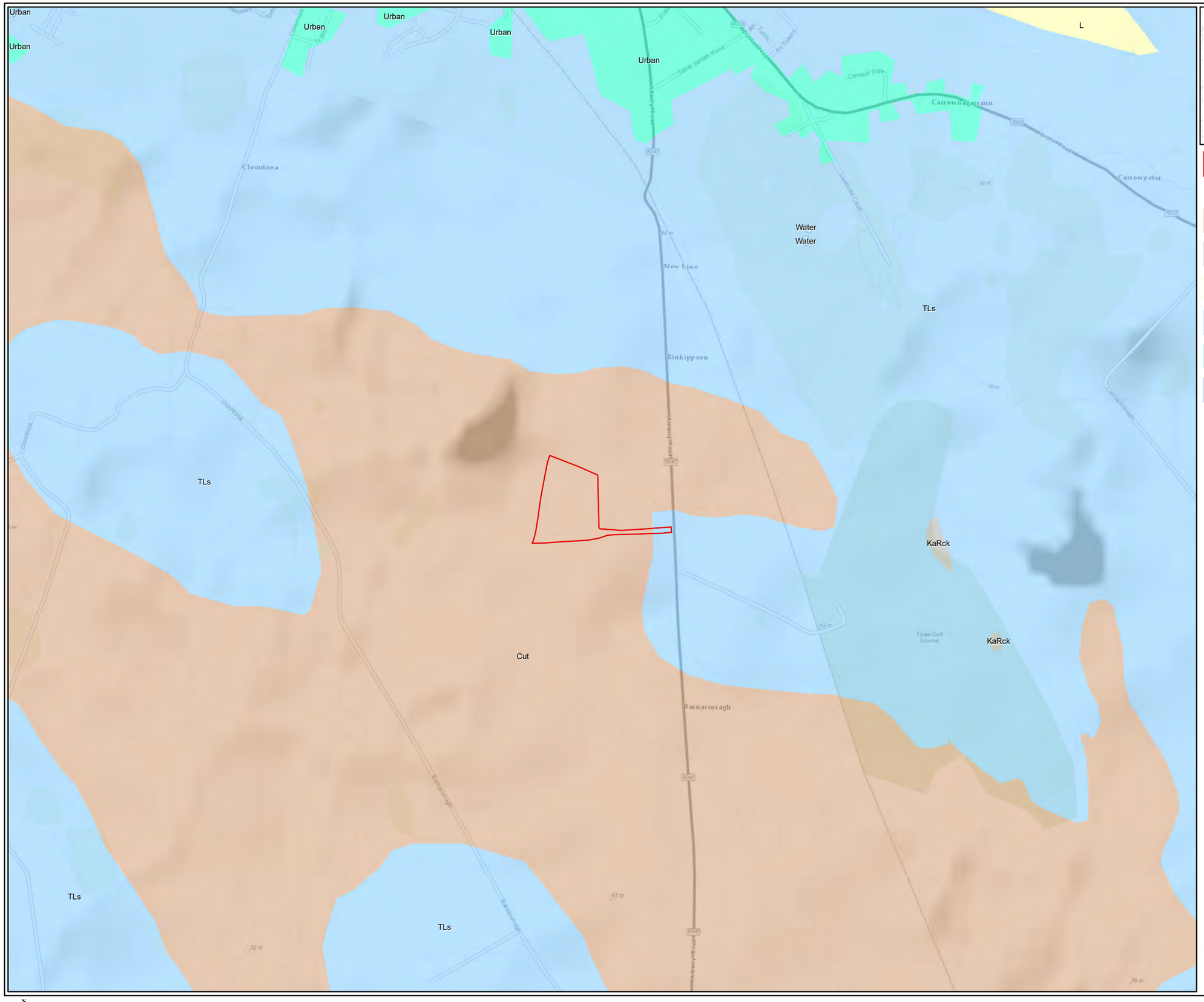

Site Boundary

Quaternary Sediments:

- Cut, Cut over raised peat
- KaRck, Kartsified bedrock outcrop or subcrop
- L, Lacustrine sediments
- TLs, Till derived from limestones
- Urban
- Water

N W E S

0 0.25 0.5 1 Kilometers

TITLE:	Quaternary Geology		
PROJECT:	Tuam Historic Landfill ERA		
FIGURE NO:	2.2		
CLIENT:	Galway County Council		
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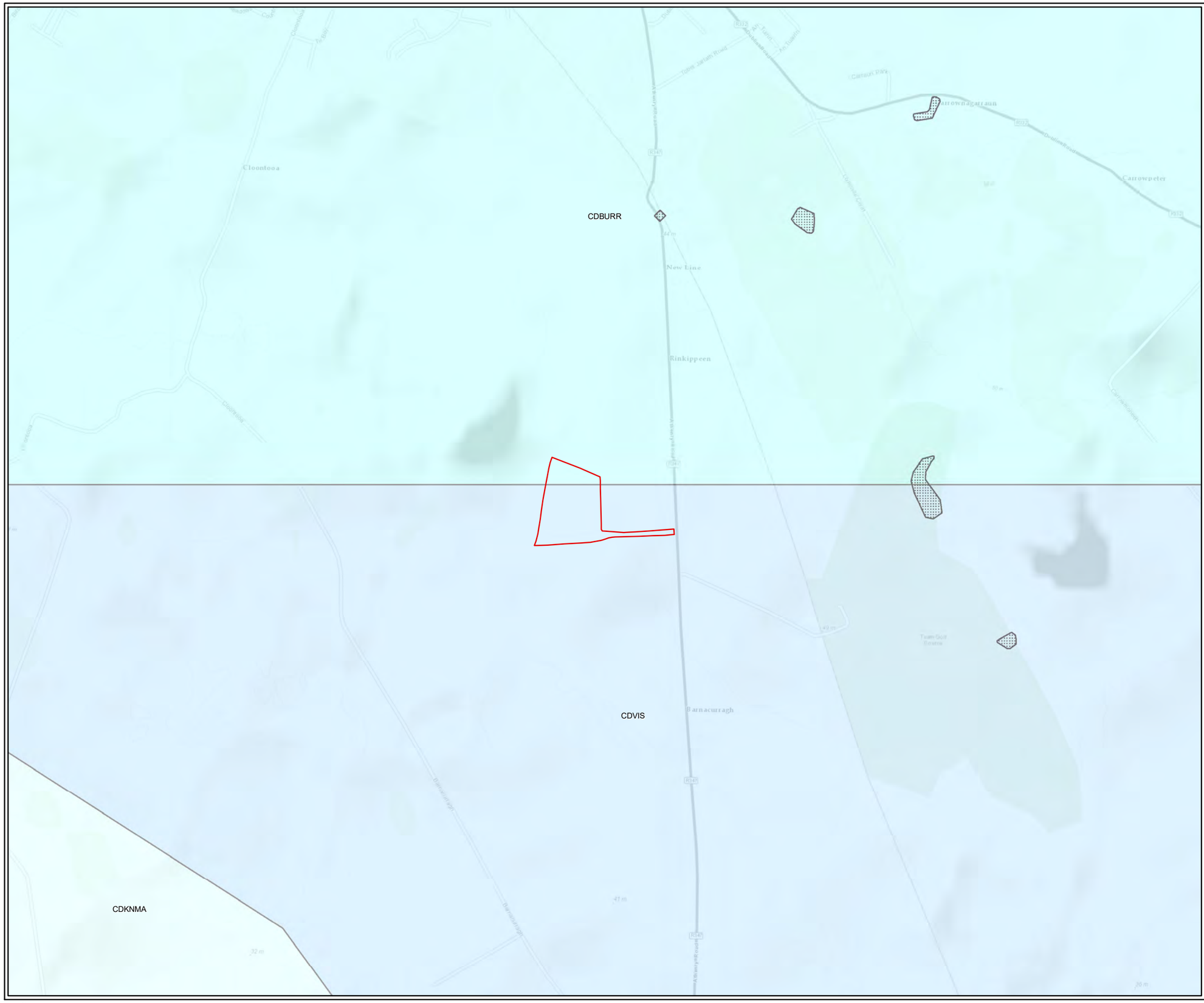

Site Boundary

Bedrock Outcrop

Bedrock Geology:

Burren Formation

Knockmaa Formation

Visean Limestones (undifferentiated

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TITLE: Bedrock Geology			
PROJECT: Tuam Historic Landfill ERA			
FIGURE NO:	2.3		
CLIENT:	Galway County Council		
SCALE:	1:10000	**REVISION:**	0
DATE:	18/10/2021	**PAGE SIZE:**	A3

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2.2.5 Hydrogeology

The underlying bedrock, groundwater aquifer is classified as a 'Regionally Important Aquifer - Karstified (conduit)'. The bedrock aquifer mapping is presented in Figure 2.4.

There are no recorded karst landforms within the site boundary. The nearest recorded karst landforms are located in the vicinity of Ballymoat approximately 2.4km to 2.7km north-east of the site boundary. These consist of a swallow hole, a spring and several enclosed depressions.

Historical mapping (1888-1913 and 1837-1842) for the area shows no springs in the immediate vicinity (<1km) of the site. The area immediately surrounding the site has a relatively low population density with a small number of farmyards within 500m of the site where unregistered private wells may be present.

Table 2.1 presents the details of the registered boreholes and springs within 2km of the site:

Table 2.1: Borehole and Spring Descriptions near the Project Site

BH/Spring	Yield class	Yield (m^3/day)	Use	Depth (m)	Depth to Rock confidence (m)	Distance from site (km)	Date
1425SWW025	Excellent	1310	Unknown	-	-	1.84	1899
1425SWW027	High Spring	3930	Public Supply (Co Co) Tobernanny PWS	-	-	1.98	1899
1423NWW014	Good	188	Group Scheme	116	-	2.9	

The GSI mapping showing approximate locations of known wells and springs is included in Figure 2.5.

Although GSI data shows records of water supply wells in the area (as per Table 2.1). There are no defined groundwater protection areas shown at these locations and the recorded wells may no longer be in use for group scheme water supplies. There are no Groundwater Drinking Water Protection Areas within the site boundaries according to GSI. The nearest defined groundwater protection zone is located approximately 4.6km west of the site near Belclare and is associated with the Claretuam Belclare Group Water Scheme. The Mid-Galway public water supply source protection zone is located approximately 11.1km south-east of the site near Derreen village.

The GSI shows that the underlying groundwater body (GWB) is named Clare-Corrib GWB and is defined as being at Good Status under the Water Framework Directive (WFD). The risk to groundwater quality is currently stated as 'At risk'.

GSI mapping shows groundwater recharge to be variable in the region. The annual recharge for the site is stated to be 152mm/yr based on the application of an effective rainfall 761 mm/yr for the area and a recharge coefficient of 20%.

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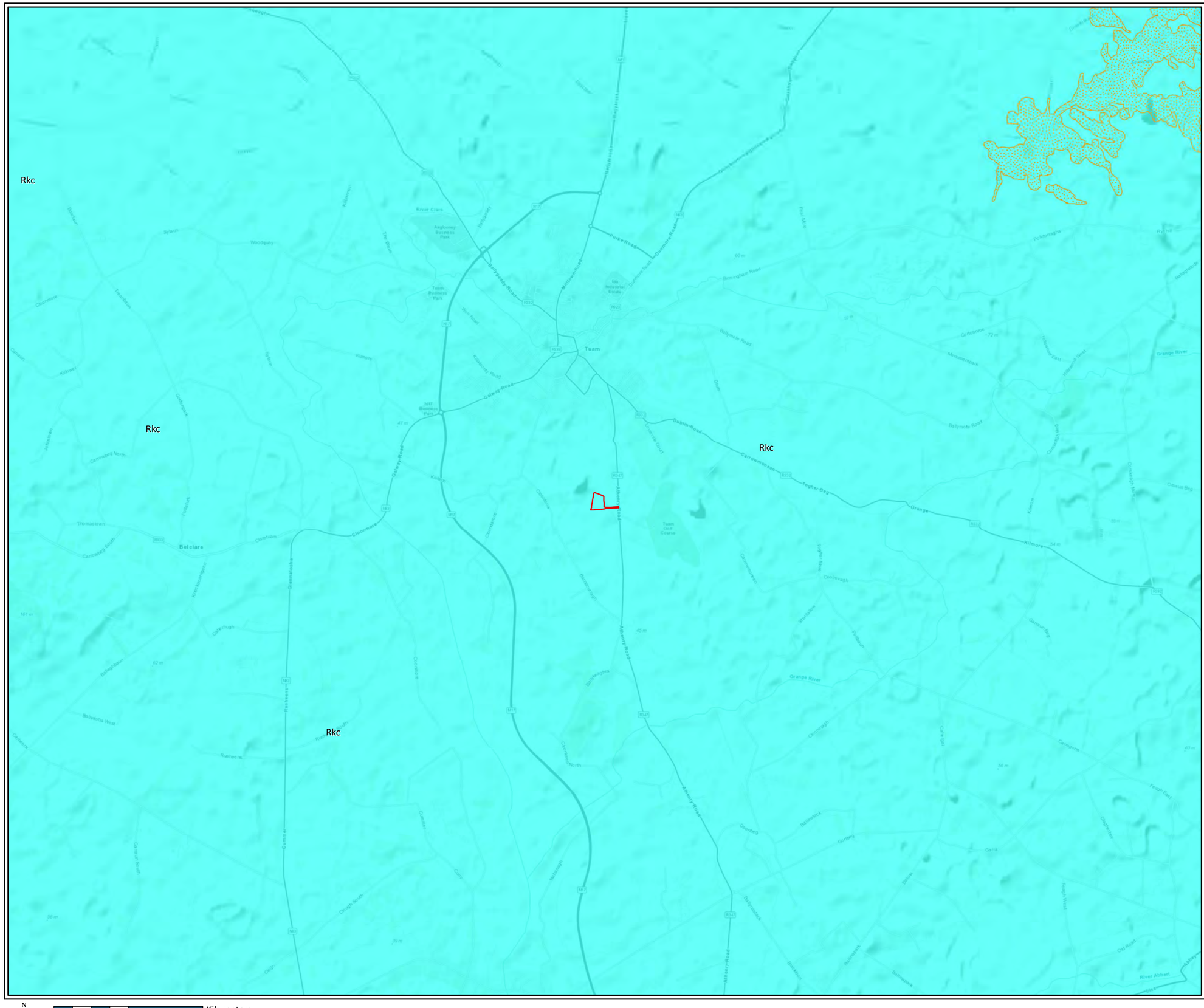

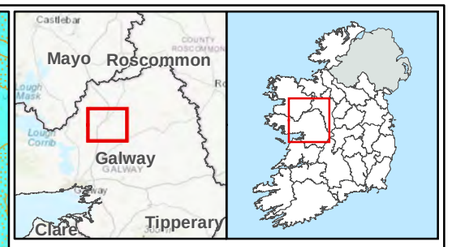

Site Boundary

Sand and Gravel Aquifers:

Locally important gravel aquifer

Bedrock Aquifers:

Rkc: Regionally Important Aquifer - Karstified (conduit)

TITLE:	Aquifer Classification		
PROJECT:	Tuam Historic Landfill ERA		
FIGURE NO:	2.4		
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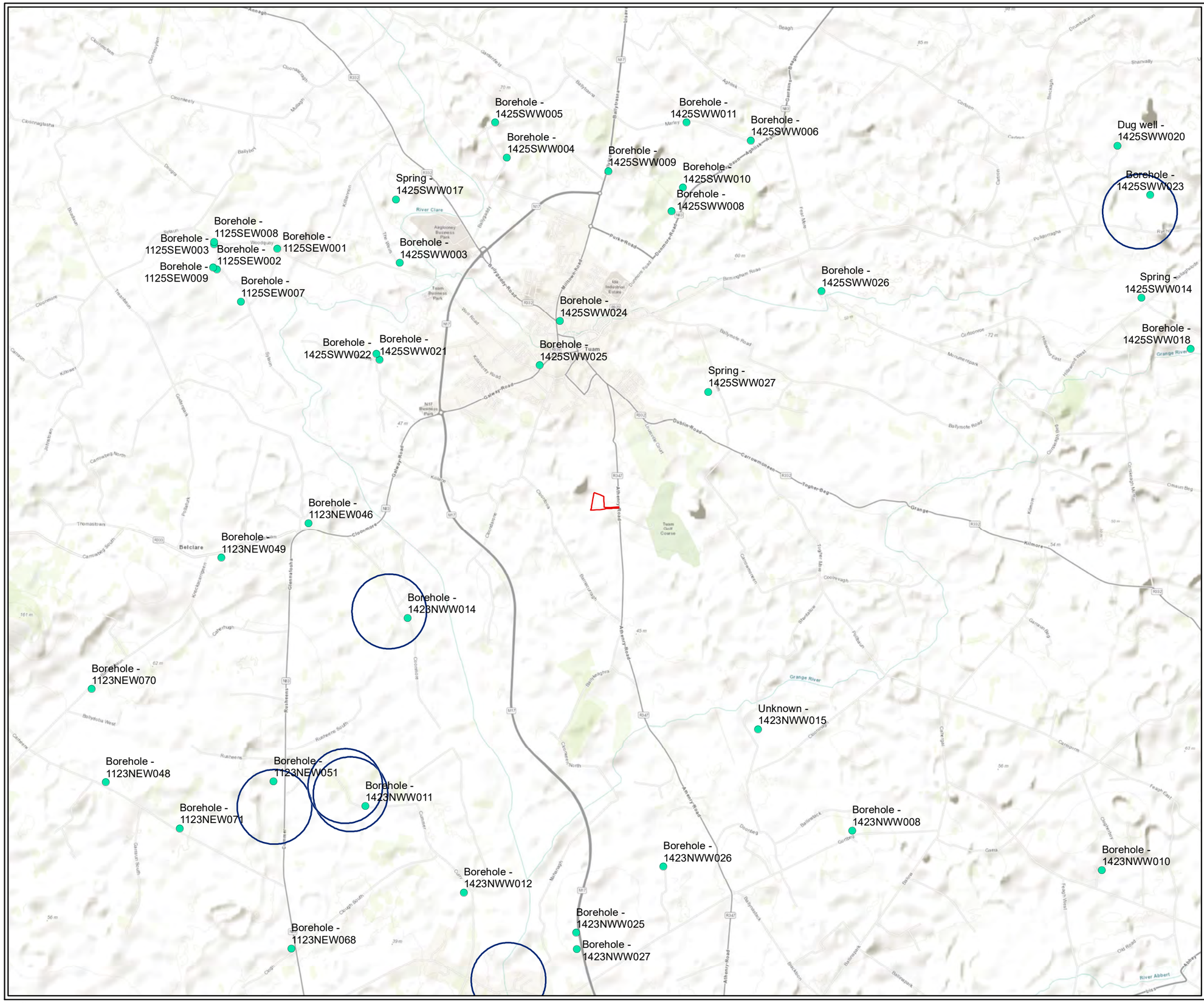

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2.2.6 Groundwater Vulnerability

Groundwater vulnerability, as defined by the GSI, is the term used to represent the intrinsic geological and hydrogeological characteristics that determine the ease with which groundwater may be contaminated by human activities.

The factors used in assessing groundwater vulnerability include subsoil type and thickness and recharge type as indicated in Table 2.2. The GSI procedure whereby groundwater protection is assessed is outlined in the EPA-GSI publication *Groundwater Protection Schemes* (DELG/EPA/GSI, 1999).

The GSI Online mapping data set identifies the vulnerability of groundwater to contamination within the site area is classified as being primarily high (H). The area towards the north-west of the site is classified as moderate (M), before becoming low (L). The groundwater vulnerability mapping is presented in Figure 2.6.

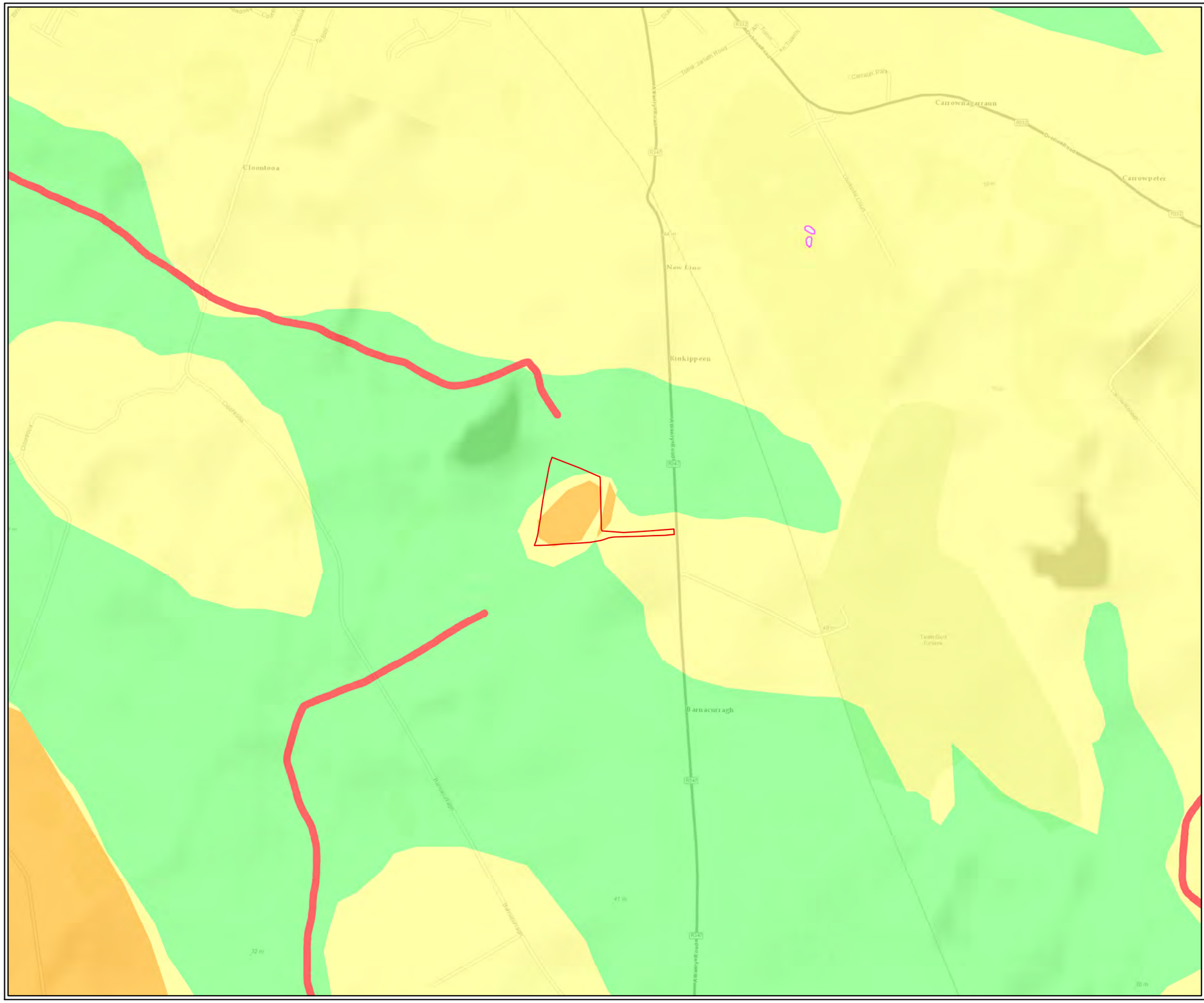
Table 2.2: GSI Guidelines – Aquifer Vulnerability Mapping

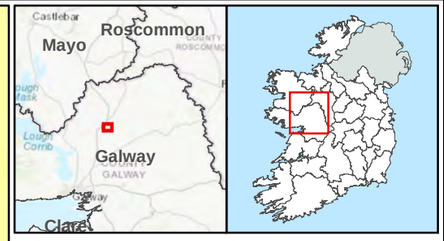
Vulnerability Rating	Hydrogeological Conditions		
	Subsoil Permeability (Type) and Thickness		
	High Permeability (Shallow Bedrock)	Moderate Permeability (e.g. Sandy soil)	Low Permeability (e.g. Clayey subsoil, clay, peat)
Extreme (E)	0 - 3.0 m	0 - 3.0 m	0 - 3.0 m
High (H)	>3.0 m	3.0 -10.0 m	3.0 - 5.0 m
Moderate (M)	N/A	>10.0 m	5.0 - 10.0 m
Low (L)	N/A	N/A	>10 m

Notes:

N/A = Not Applicable

Precise permeability values cannot be given at present





Site Boundary

Groundwater Vulnerability:

- H - High
- M - Moderate
- L - Low
- Water
- X - Rock Near Surface or Karst

N
W E
S

0 0.25 0.5 1 Kilometers

TITLE:	Groundwater Vulnerability		
PROJECT:	Tuam Historic Landfill ERA		
FIGURE NO:	2.6		
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2.2.7 Hydrology

The site is located within the Corrib catchment (Hydrometric Area: 30), Clare (Galway)_SC_040 sub-catchment and Clare (Galway)_060 sub-basin. Surface water drains have been constructed around the boundary of the landfill. The northern section of the landfill flows into the River Suileen(EPA Name: Killeelaun). This flows west before turning sharply south and subsequently converges with the River Clare downstream. The southern section of the site flows into a stream (EPA Name: the Clare (Galway)_060) which is a tributary of the River Clare and converges with the River Clare downstream just north of Corofin. The River Clare flows in a southernly direction past Tuam into Turloughmore then turns west before flowing into Lough Corrib.

Surface water quality monitoring has historically been conducted by GCC along the River Suileen to the north (c. 320m upstream) and at three locations along an unnamed stream/land drain to the south (at the southwest corner of the site, c. 170m downstream and c. 550m downstream). Water monitoring was carried out at these locations up until 2013.

The nearest downstream EPA surface water monitoring station is located c. 6km downstream of the site in Corofin. The most recent biological (Q-Rating) for surface water quality at this location (2018) was Q3-4, Moderate status. The nearest upstream EPA surface water monitoring station is located c. 3.5km upstream where the River Nanny converges with the River Clare, and the most recent Q-rating assigned was Q4, Good in 2018.

The catchments map is presented in Figure 2.7.

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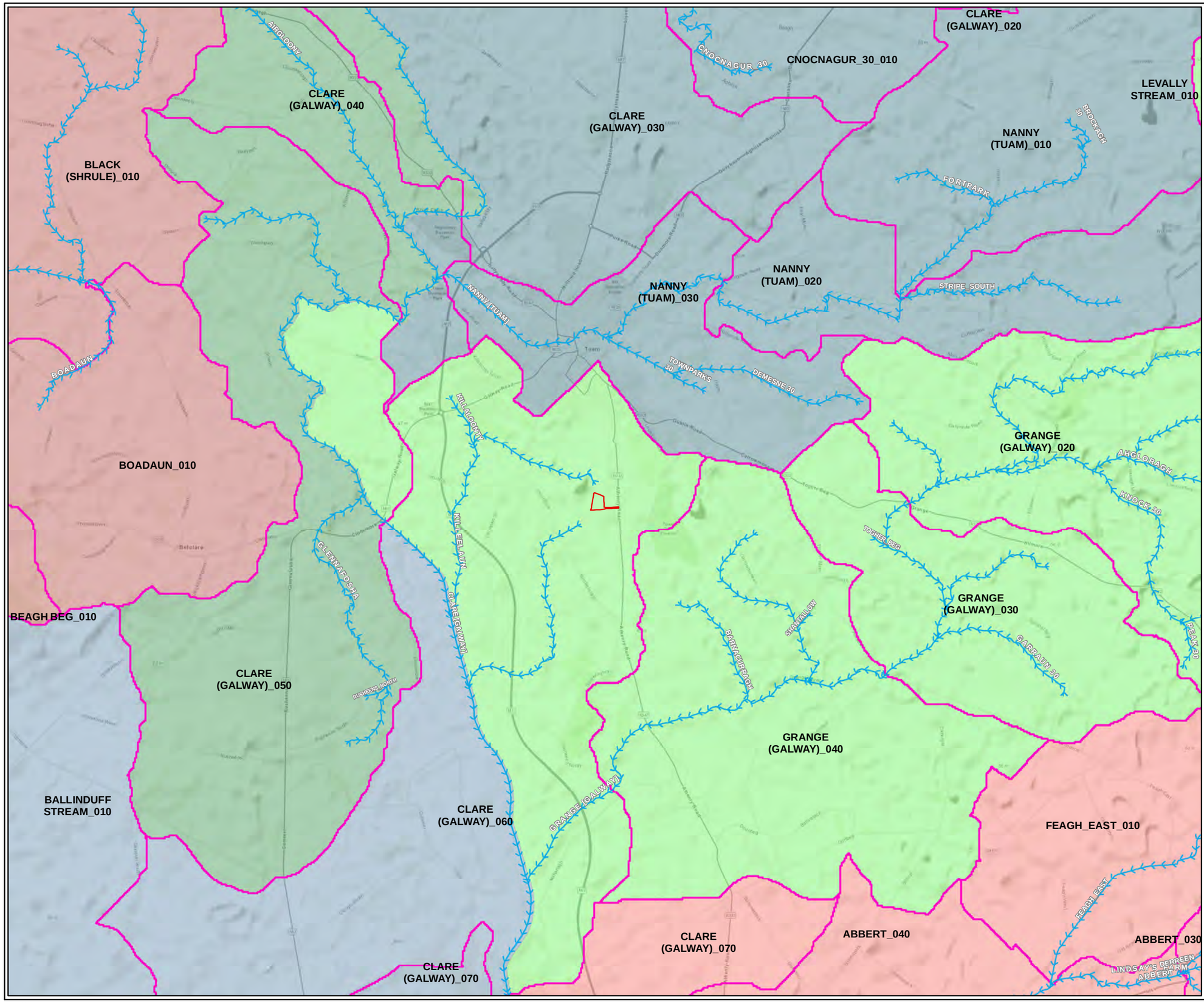

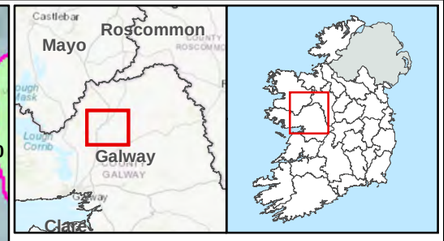

- Site Boundary
- Rivers
- WFD River Sub Basins

WFD Sub Catchments:

- Black[Shrule]_SC_010
- Clare[Galway]_SC_020
- Clare[Galway]_SC_030
- Clare[Galway]_SC_040
- Clare[Galway]_SC_050
- Clare[Galway]_SC_060

N W E S

0 0.5 1 2 Kilometers

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CLIENT:	Galway County Council		
SCALE:	1:50000	**REVISION:**	0
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2.2.8 Ecology

The site is not located within any Natural Heritage Area (NHA), proposed NHA (pNHA), Special Area of Conservation (SAC) or Special Protection Area (SPA). The River Clare is part of the Lough Corrib SAC (Site Code: 000297) and is located approximately 2km south-west of the site. Surface water drainage from the landfill flows into the River Clare c. 2km downstream, thereby creating a linkage between the site at the SAC.

Levally Lough is also part of the Levally Lough SAC (Site Code: 000295) which is located approximately 9.1km north-east of the site. Levally Lough is located upstream of the landfill hence it is not likely to be impacted by the landfill.

The ecologically protected areas mapping is presented in Figure 2.8.

2.2.9 Existing Geological Heritage

The GSI holds no records of areas of Geological Heritage within the site boundary or in the immediate vicinity of the site.

The nearest recorded geological heritage site held by the GSI is approximately 5.3km west of the site boundary at a Knockmaa. This is described as an *" A large area of landscape with glacial deposits which have slightly modified a much older landscape"*. According to GSI mapping and records this site is also recommended as Geological NHA.

The geological heritage mapping is presented in Figure 2.9.

2.2.10 Existing Geotechnical Stability

The GSI landslides database indicates that there are no recorded geo-hazards within the site boundary. In 1909, a landslide event occurred 1.5km south-west of the site boundary at Kilmore. The landslide mechanism is recorded as undefined while the impact is described as '*No apparent impact'*.

2.2.11 Archaeological Heritage

Review of the 1837-1842 and 1888-1913 OSI historical maps for the area do not indicate the presence of any significant archaeological features. Review of the Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs' online historic environment viewer/database indicates no archaeological features within the site boundary. The database indicates the presence of a church, an ecclesiastical enclosure, a holy well and a lime kiln within c. 1km of the site. Archaeological features in the wider area include a burial ground, gravel/stone trackway, ringforts, lime kiln, holy well and an ecclesiastical enclosure.

Path: R:\Map Production\2020\P2282\Workspace\Tier2\P2282_GIS_Tuam_Tier2_A3.mxd

000263 (pNHA)

000289 (pNHA)

000282 (pNHA)

000234 (pNHA)

001288 (pNHA)

000297 (SAC)

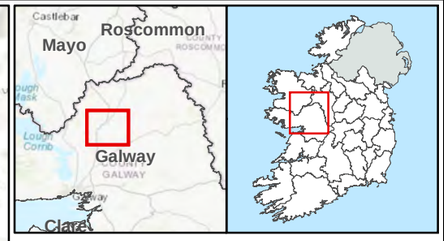
Tuam

Belclare

River Clare

Grange River

River Abbert



Site Boundary

Proposed Natural Heritage Area (pNHA)

Special Area of Conservation (SAC)

TITLE:	Ecologically Protected Areas		
PROJECT:	Tuam Historic Landfill ERA		
FIGURE NO:	2.8		
CLIENT:	Galway County Council		
SCALE:	1:50000	**REVISION:**	0
DATE:	18/10/2021	**PAGE SIZE:**	A3

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N W E S

0 0.5 1 2 Kilometers

Path: R:\Map Production\2020\P2282\Workspace\P2282_Tier2_ERA_Tuam_A3.aprx

World Topographic Map: Esri UK, Esri, HERE, Garmin, INCREMENT P, USGS, METI/NASA, NGA
World Topographic Map: Esri, HERE, Garmin, FAO, USGS
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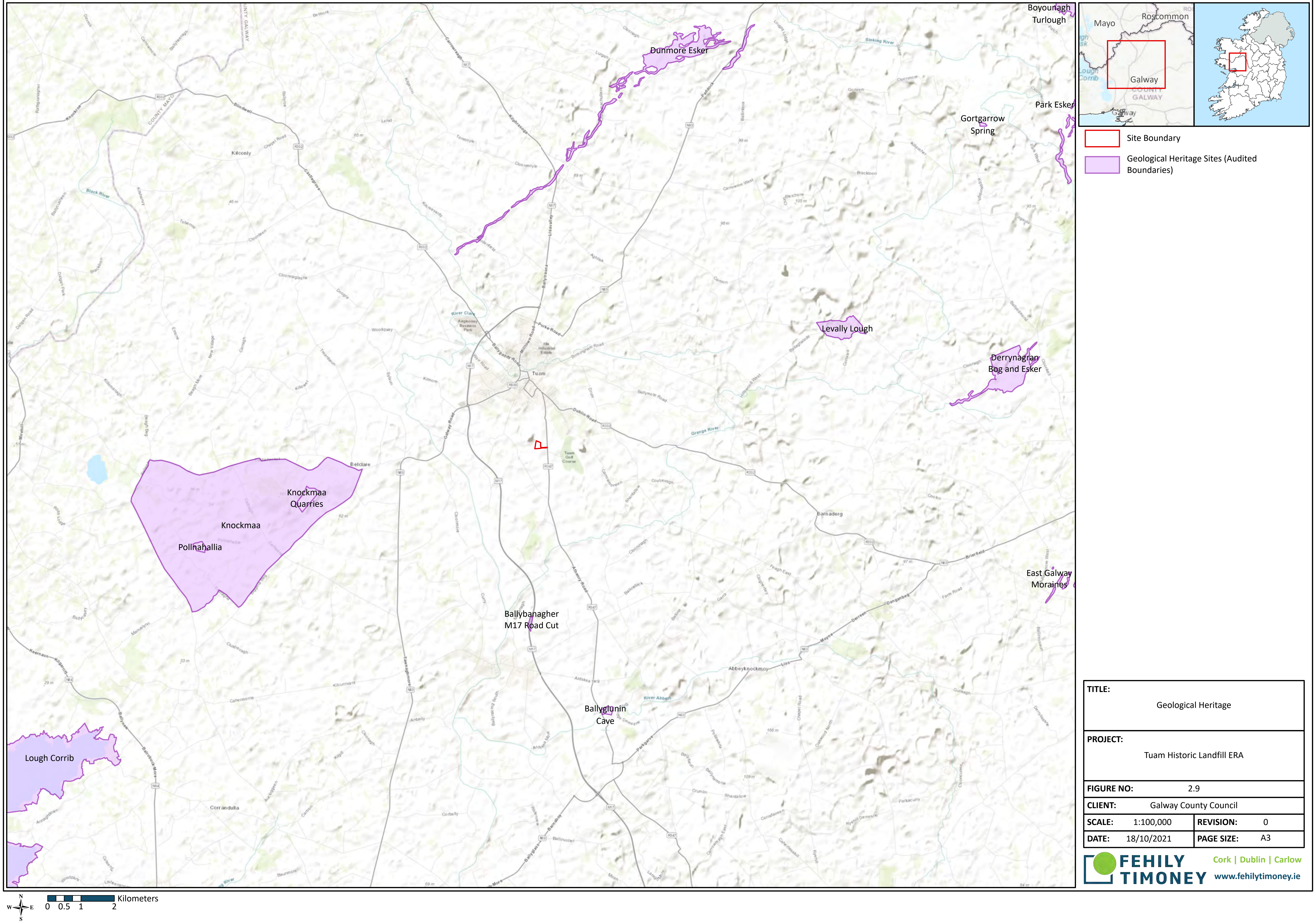

TITLE:	Geological Heritage
PROJECT:	Tuam Historic Landfill ERA
FIGURE NO:	2.9
CLIENT:	Galway County Council
SCALE: 1:100,000	REVISION: 0
DATE: 18/10/2021	PAGE SIZE: A3

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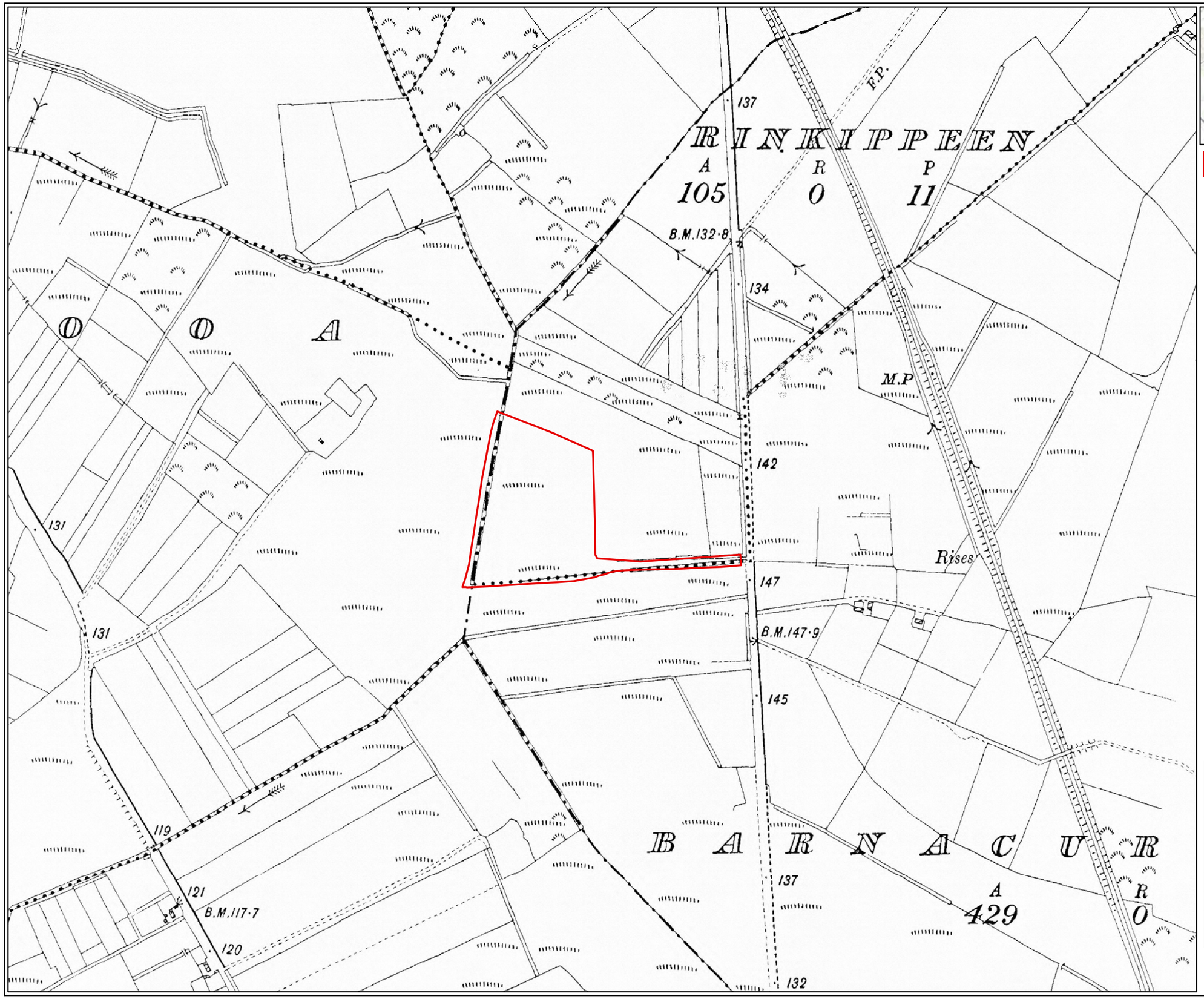
2.2.12 Site History

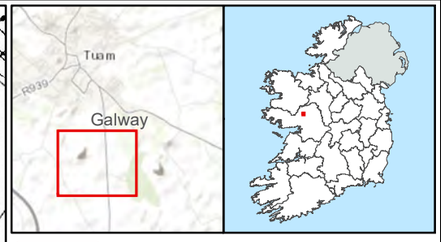
The earliest historical map available on the OSI website dates from 1837-1842. Review of this map shows that the site was historically marsh land. The latter 1888-1913 OSI historical mapping also displays previous use as marsh land. There are no distinct features noted within the site boundary or in the vicinity, on both map series.

More recent OSI historical imagery, from 1995 and 2000, show evidence of landfilling activities, while on imagery from 2005-2012 and 2011-2013 this activity seems to have ceased and capping completed. The images produced corresponds with the site closure and remediation plan which was developed in 1999 following closure of the site of the site in 1998. The aerial image from 1995 shows that the landfill of waste is still occurring while imagery from 2000 shows that some capping of the site has occurred or is ongoing at the time the image was produced. Information provided by GCC states that a GCL capping layer was constructed over 30,000 m^2 of the landfill in 2001. Imagery from 2005 shows that the site has been completely capped and grass has been established. Imagery also shows the development of the civic amenity site between 2000 and 2005.

OSI historical mapping presented in Figure 2.10 and Figure 2.11.

Path: R:\Map Production\2020\P2282\Workspace\Tier2\P2282_GIS_Fig2.10_Tuam_A3.mxd





Site Boundary

N W E S

Meters
0 50 100 200

TITLE:	OSI Historical Mapping		
PROJECT:	Tuam Historic Landfill ERA		
FIGURE NO:	2.10		
CLIENT:	Galway County Council		
SCALE:	1:5000	**REVISION:**	0
DATE:	18/10/2021	**PAGE SIZE:**	A3

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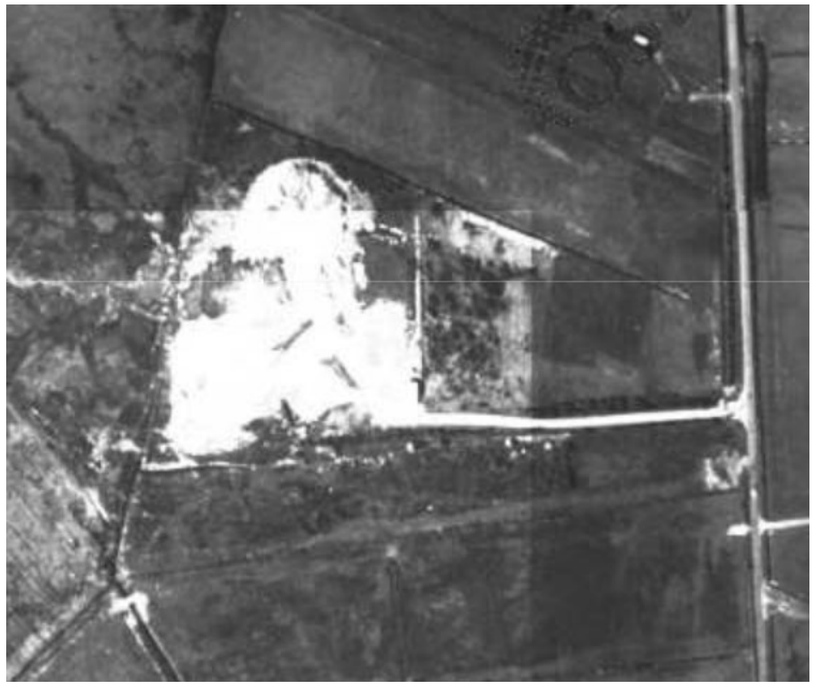

Historical Aerial Imagery (1995)

Historical Aerial Imagery (2000)

Historical Aerial Imagery (2005)

Historical Aerial Imagery (2005-2012)

Figure 2-11: Historical Aerial Imagery[1]

[1] *Source:* http://map.geohive.ie/

3. TIER 2 SITE INVESTIGATION

3.1 Site Investigation Works

A site investigation rationale was devised based on findings of the Tier 1 assessment, site walkover, historical aerial photography and desk study.

The scope of the 2020 site investigation works included:

- 1 no. Topographical Survey;
- 1 No. Geophysical survey (2D resistivity, EM31 Ground Conductivity and seismic refraction profiling);
- Installation of 2 no. groundwater monitoring wells;
- Excavation of 5 No. trial pits;
- Groundwater, Surface Water Sampling and landfill gas monitoring;
- Factual reporting.

Additional site investigations works were completed in 18th to the 20th of July 2022 by Causeway Geotechnical Ltd. in support of the RFI response.

The following works were completed:

- Four boreholes by light cable percussion (BH01 to BH03 and BHLFG1);
- Standpipe installation in four boreholes (BH01 to BH03 and BHLFG1);
- Permeameter test at two boreholes (BH01 and BH03);
- Triaxial permeability tests at 2 No. Boreholes (BH01 and BH03); and
- Environmental testing in 3 No. Soil samples (BH01 to BH03).

The locations of the intrusive site investigation works at the site are presented in Figure 3.1.

The site investigation methodology considered the following literature sources:

- EPA 2003, Landfill Manuals: Landfill Monitoring (2nd Edition)
- EPA 1999, Landfill Manuals: Site Investigations
- BS 5930: 1999, Code of Practice for Site Investigations
- BS 6068 Water Quality: Sampling (parts 6.1-6.6 and 6.11-6.12, 6.14)
- BS 8855 Soil analysis (all parts)
- CLM: Ready Reference 2002, Section 3.1 Soil sampling strategies
- CLM: Ready Reference 2002, Section 3.2 Groundwater sampling/monitoring strategies
- CLM: Ready Reference 2002, Section 3.3 Gas sampling/monitoring strategies.

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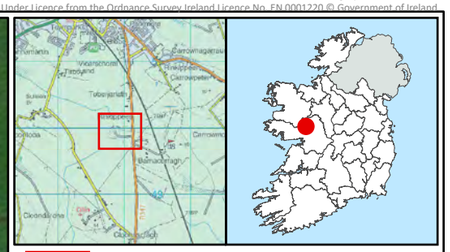

Site Boundary

Trial Pit

Groundwater Well

N
W E
S

0 50 100 200 Meters

TITLE: Site Investigation Location Plan			
PROJECT: Tuam Historic Landfill ERA			
FIGURE NO:	3.1		
CLIENT:	Galway County Council		
SCALE:	1:2,000	**REVISION:**	0
DATE:	18/10/2021	**PAGE SIZE:**	A3

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3.1.1 Geophysical Investigation

Minerex Geophysics Ltd (MGX) were instructed by FT to undertake a geophysical investigation of the site. The survey was carried out on the 21st May and 9th of June 2020. The MGX geophysical survey report is included in Appendix 5.

The geophysical survey consisted of reconnaissance EM Ground Conductivity Mapping with follow-up 2D Resistivity Profiling (RT) and Seismic Refraction Profiling. A total of 372m for Resistivity Profiling (RT) and 372m for Seismic Refraction Profiling of geophysical profiles were collected. The geophysical survey was used to estimate a general profile of the buried waste above the in-situ bedrock.

The survey located a waste body throughout the site. The extent of the historic landfill is estimated at 23,300 m^2, its depth is approximately 8m below ground level (bgl) which gives a total estimated waste volume of 186,400 m^3. The low resistivities and seismic velocities measured were noted as consistent with municipal solid waste (MSW) rather than Construction and Demolition (C&D) type waste.

MGX recorded RT profiles data along 2 designated profiles named R1 and R2, and two seismic refraction profiles (S1 and S2) were recorded across the site. See Figure 3.2.

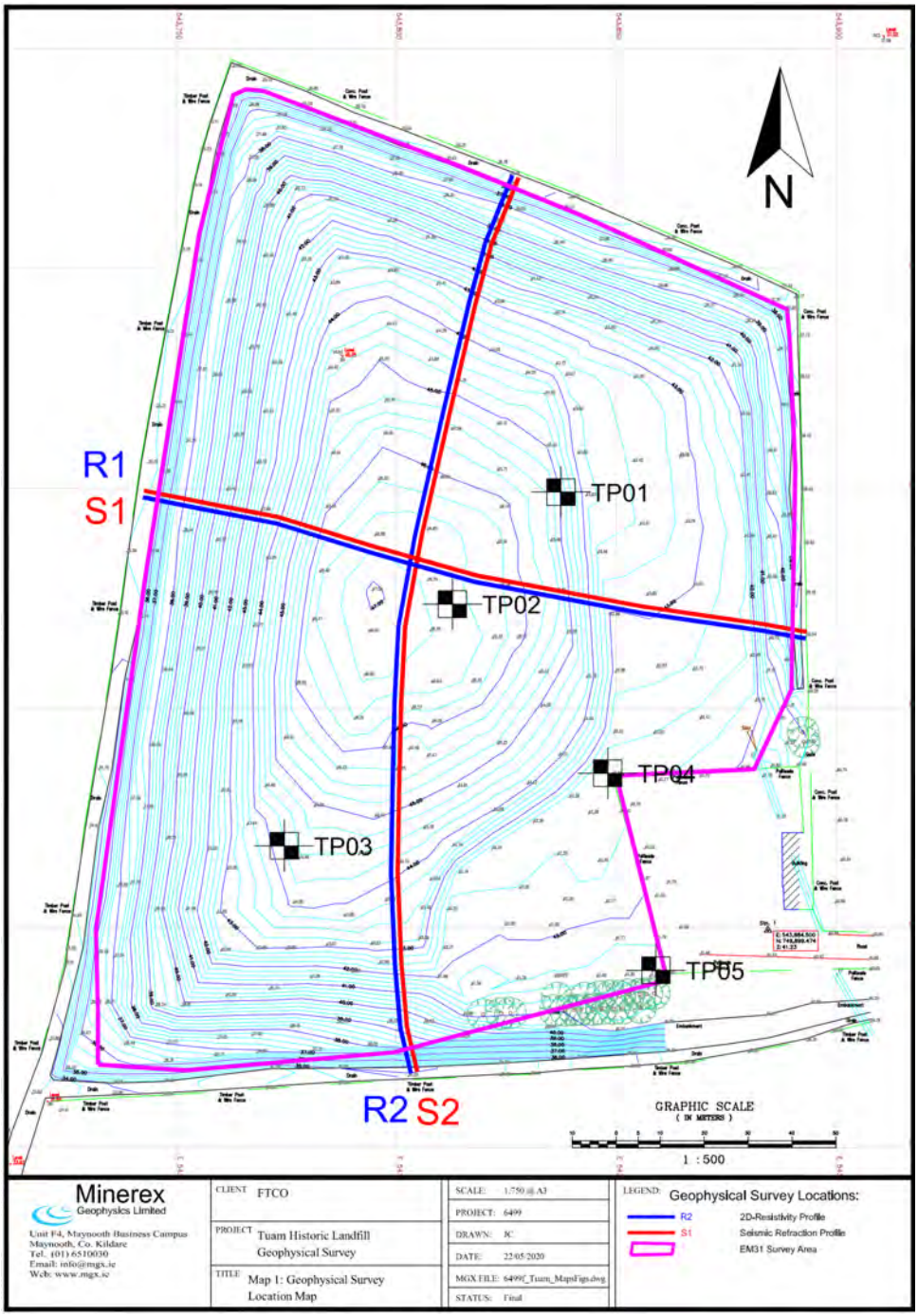


Figure 3-2: Geophysical Survey Location Map

Results

The geophysical survey succeeded in validating the general location of the waste material. Both the elevated EM conductivity readings show the waste to be present within most of the survey area.

The highest surface conductivities are found in the centre of the site where conductivities are typically above 60 mS/m. Very high conductivities indicate deep waste material. Around the edge of the site the conductivities begin to decrease.

Conductivities between 20 – 30 mS/m would indicate some waste material, while conductivities of less than 20 mS/m which are only found on the periphery of the site would usually indicate soil and rock fill, natural material or C&D waste.

Both profiles show a rapid change with depth from low resistivities to high resistivities at approx. 30 mOD. Low resistivities (<62.5 Ohm) indicate mainly waste material or leachate but may also indicate clay-rich or peat overburden. This is consistent with intrusive site investigation which confirmed the presence of peat beneath the waste. High resistivities (>500 Ohm) at depth indicate fresh limestone. Both profiles are laterally consistent which indicates waste throughout the site. Profile R1 has low – medium conductivities at depth. This may indicate a karst feature or leachate penetrating into the rock layer. It may also be an artificial effect of the very low resistivities above it and sharp topography along the surface.

A layered ground model was created from the modelled seismic data (See Figure 3.3):

Layer 1 has a seismic velocity range of 200 m/s and is found in most of the survey area. This velocity would represent landfill material, which has a lower velocity than the surrounding natural ground.

Layer 2 has a seismic velocity range of 700 m/s. This layer in interpreted as overburden material with leachate, and it is found in most of the survey area, below layer 1.

Layer 3a is interpreted as fresh Limestone and is found in most of the R2 profile and some areas of R1, under layer 2. This layer has N/A seismic velocity.

Layer 3b is interpreted as Karstified Limestone, Leachate within Limestone or Artificial Effect and is found in some areas of profile R1, under layer 2. This layer has N/A seismic velocity.

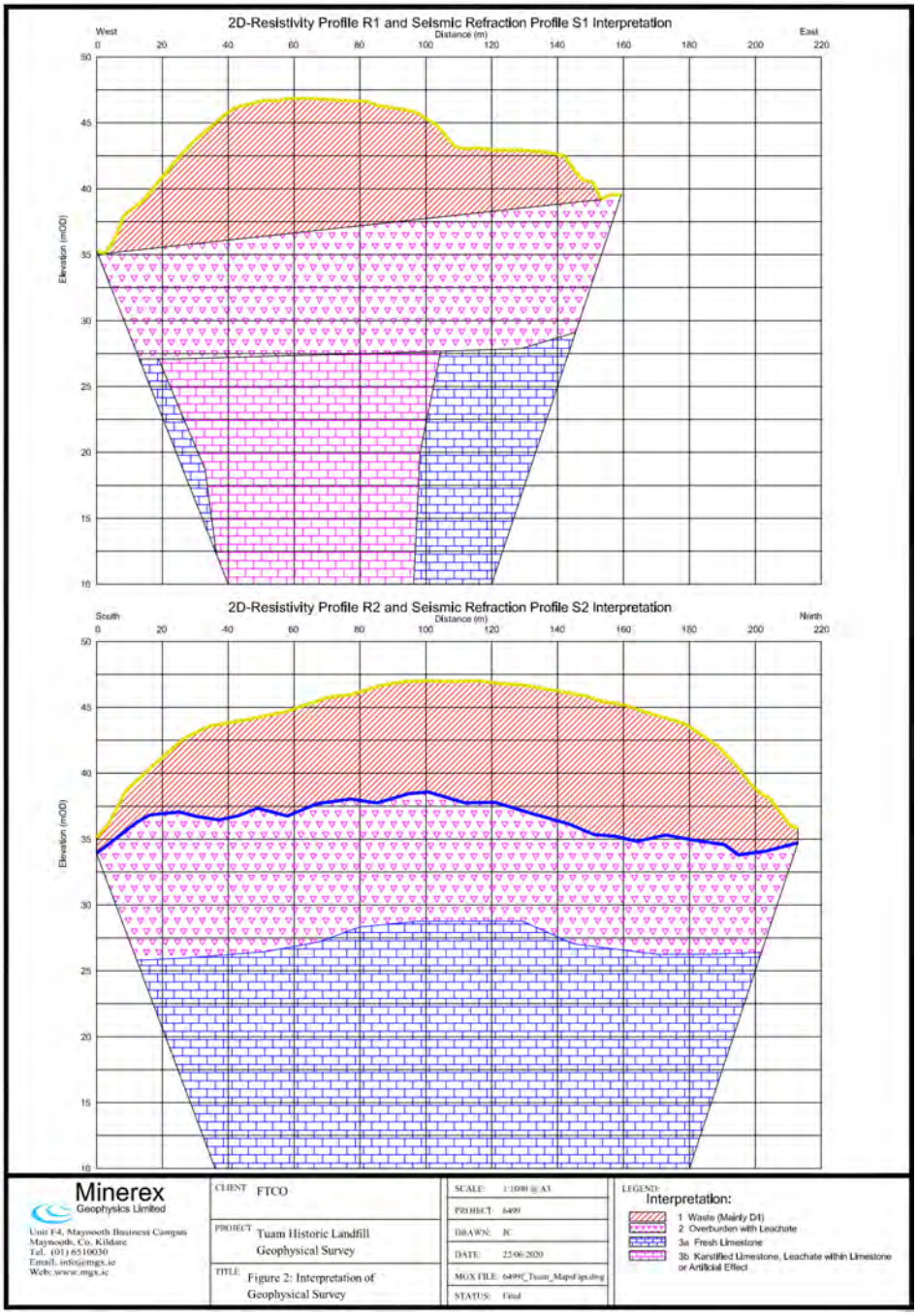


Figure 3-3: Integration of Geophysical Survey

3.1.2 Trial pits

A Causeway Geotech (CGL) Engineering Geologist supervised the advancement of 5 No. trial pits, shown in Figure 3.1, on the 7th July 2020.

The trial pits (TP01 to TP05) were advanced to depths of between 0.2m to 2.0m below existing ground level (bgl) using a 13t Tracked Excavator fitted with a 600mm wide bucket. The purpose of the shallow trial pits (TP01, TP02, TP03 and TP05) was to confirm the depths of soil capping above the waste and the presence and the extent of the GCL cap liner.

These trial pits were not advanced any further so as not to compromise the capping and GCL liner. TP04 was excavated adjacent to the civic amenity site to determine if waste deposition extended to this area and beyond the known capped landfill area. The geophysical survey used in conjunction with the profiles identified during trial pitting provided a picture of the underlying geology of the site and a general profile of the buried waste.

A summary of the ground conditions encountered at each trial pit is presented in Table 3.1 below with photographs and exploratory hole logs provided in the CGL 2020 site investigation report, Appendix 6.

Table 3.1: Summary of Ground Condition

Trial pit ID	Depth of cover material (m BGL)	Depth to base of made ground/waste (m BGL)	Profile Description
TP01	0.0 – 0.40 (Topsoil)	0.40 (base of excavation - terminated due to Geocomposite clay liner proven)	Topsoil.
TP02	0.0 – 0.20 (Topsoil)	0.20 (base of excavation – terminated due to Geocomposite clay liner proven)	Topsoil.
TP03	0.0 – 0.20 (Topsoil)	0.20 (base of excavation – terminated due to Geocomposite clay liner proven)	Topsoil.
TP04	0.0 – 0.05 (Topsoil) 0.05 – 0.25 (Made Ground) 0.25– 0.30 (Bitmac) 0.30 – 1.20 (Made Ground) 1.20 – 2.0 (Made Ground)	2.0 (base of excavation – terminated at scheduled depth)	Topsoil; Sandy GRAVEL of mixed lithologies; Bitmac; Sandy gravelly silty CLAY with fragments of timber, plastic, glass, steel, wire, brick and concrete; Sandy gravelly silty CLAY with fragments of plastic, glass, clothing, timber, brick and concrete.
TP05	0.0 – 0.05 (Topsoil) 0.05 – 0.20 (Made Ground)	0.20 (base of excavation - terminated due to Geocomposite clay liner proven)	Topsoil; Slightly gravelly silty SAND.

3.1.3 Evidence of Contamination

The trial pits excavation works identified waste material or liner throughout the site at depths ranging from 0.30 – 2.0m BGL. Where GCL capping was encountered trial pits were not advanced so as not to compromise the integrity of the existing landfill capping. The presence of the GCL liner at TP01, TP02, TP03 and TP05 confirms that waste was deposited at these locations and was subsequently capped following closure of the site.

Made ground comprising waste was encountered in 1 No. trial pit (TP04), indicating that waste deposition may also have occurred here. No GCL liner was encountered at this trial pit. The waste encountered was described as timber, plastic, glass, steel, wire, brick, concrete and clothing.

Previous site investigations included the installation of 3 no. cable percussion boreholes BH1, BH2 and BH3, located within the waste body in 1999. Waste material was recorded at BH1, BH2 and BH3 up to depths of 5.0m bgl (BH1), 5.0m bgl (BH2) and 9.0m bgl (BH3).

Bulk waste samples were obtained during the reinstallation of three no. dual leachate and landfill gas monitoring boreholes within waste body i.e. BH1, BH2 & BH3 during the additional site investigation undertaken in July 2022.

Waste samples were subject to WAC analysis. The results are shown in Table 2.2.

The results of this analysis indicate waste material encountered within the site are typically inert in terms of their leachate production, with the exception of Total Organic Carbon (TOC) and Loss on Ignition.

Table 2.2: Waste Sampling Results – Solid Waste Analysis

Parameter	Units	Inert Waste Acceptance Criteria	Non-Hazardous Waste Acceptance Criteria	Hazardous Waste Acceptance Criteria	Sampling Results - Sample ID		
					BH01	BH02	BH03
					(6.0m)	(2.5m)	(5.0m)
Total Organic Carbon	%	**3**	**5**	**6**	**11**	**5.8**	0.52
Loss On Ignition	%	--	--	**10**	**29**	**11**	10
Total BTEX	mg/kg	**6**	--	--	< 0.010	< 0.010	< 0.010
Total PCBs (7 congeners)		**1**	--	--			
TPH Total WAC	mg/kg	**500**	--	--	300	< 10	< 10
Total (of 17) PAHs		**100**	--	--			
pH		--	**>6**	--	8.1	8.1	8.3
Acid Neutralisation Capacity	mg/kg	--	**To evaluate**	**To evaluate**	0.013	0.032	0.02
Arsenic	mg/kg	**0.5**	**2**	**25**	0.13	0.036	0.028
Barium	mg/kg	**20**	**100**	**300**	0.22	0.43	0.32
Cadmium	mg/kg	**0.04**	**1**	**5**	0.0053	< 0.0011	< 0.0011
Chromium	mg/kg	**0.5**	**10**	**70**	0.098	< 0.0050	0.01
Copper	mg/kg	**2**	**50**	**100**	0.39	0.01	0.041
Mercury	mg/kg	**0.01**	**0.2**	**2**	0.00094	< 0.00050	< 0.00050
Molybdenum	mg/kg	**0.5**	**10**	**30**	0.26	0.18	0.12
Nickel	mg/kg	**0.4**	**10**	**40**	0.21	0.084	0.13
Lead	mg/kg	**0.5**	**10**	**50**	0.3	< 0.0050	0.1
Antimony	mg/kg	**0.06**	**0.7**	**5**	**0.19**	0.039	**0.15**
Selenium	mg/kg	**0.1**	**0.5**	**7**	0.025	0.015	0.013
Zinc	mg/kg	**4**	**50**	**200**	0.82	0.067	0.3

Parameter	Units	Inert Waste Acceptance Criteria	Non-Hazardous Waste Acceptance Criteria	Hazardous Waste Acceptance Criteria	Sampling Results - Sample ID		
					BH01	BH02	BH03
					(6.0m)	(2.5m)	(5.0m)
Chloride	mg/kg	**800**	**15000**	**25000**	130	670	790
Fluoride	mg/kg	**10**	**150**	**500**	9.4	1.3	2.1
Sulphate	mg/kg	**1000**	**20000**	**50000**	**1400**	**4800**	**1800**
Total Dissolved Solids	mg/kg	**4000**	**60000**	**100000**	**8400**	**8600**	**5800**
Phenol Index	mg/kg	**1**	-	-	< 0.30	< 0.30	< 0.30
Dissolved Organic Carbon	mg/kg	**500**	**800**	**1000**	**520**	310	**730**

* Hazardous Waste Landfill Criteria: >6% TOC

* Items in **bold** are in exceedance of the Inert WAC limit value

* Items shaded in **green** are in exceedance of the Non-Hazardous WAC limit value

* Items shaded in **orange** are in exceedance of the Hazardous WAC limit value.

3.1.4 Waste Delineation

The combined findings of the topographical and geophysical surveys and intrusive site investigation were used to interpret the lateral extent of the waste mass.

The maximum depth of waste encountered during the additional site investigation was 8m BGL (35.72 mAOD) in BH01, 9.3m BGL (36.6 mAOD) in BH02 and 7.0m BGL (36.3 mAOD) in BH03.

The findings of the ground conductivity and 2D-Resistivity show the area where landfill material is present. The interpreted landfill extent covers an area of approximately 23,300 m^2.

The maximum anticipated waste footprint (orange line) is presented in Figure 3.4.

The depth of waste has been estimated from 2D-Resistivity and the boreholes logs (BH01 to BH03), an average depth of waste of 36.3 m AOD has been assumed for the landfill material. The estimate excludes 300mm of capping material on top of the main waste body.

A 3D CAD volume calculation based on the topographical and geophysical surveys and the boreholes logs estimates an interred waste volume of approximately 145,407.7 m^3 at the site, applying an assumed waste density of 1.6 t/m^3 equates to 232,652 tonnes of waste present. Drawing no. P22-065-0600-0001 can be found in Appendix 8.

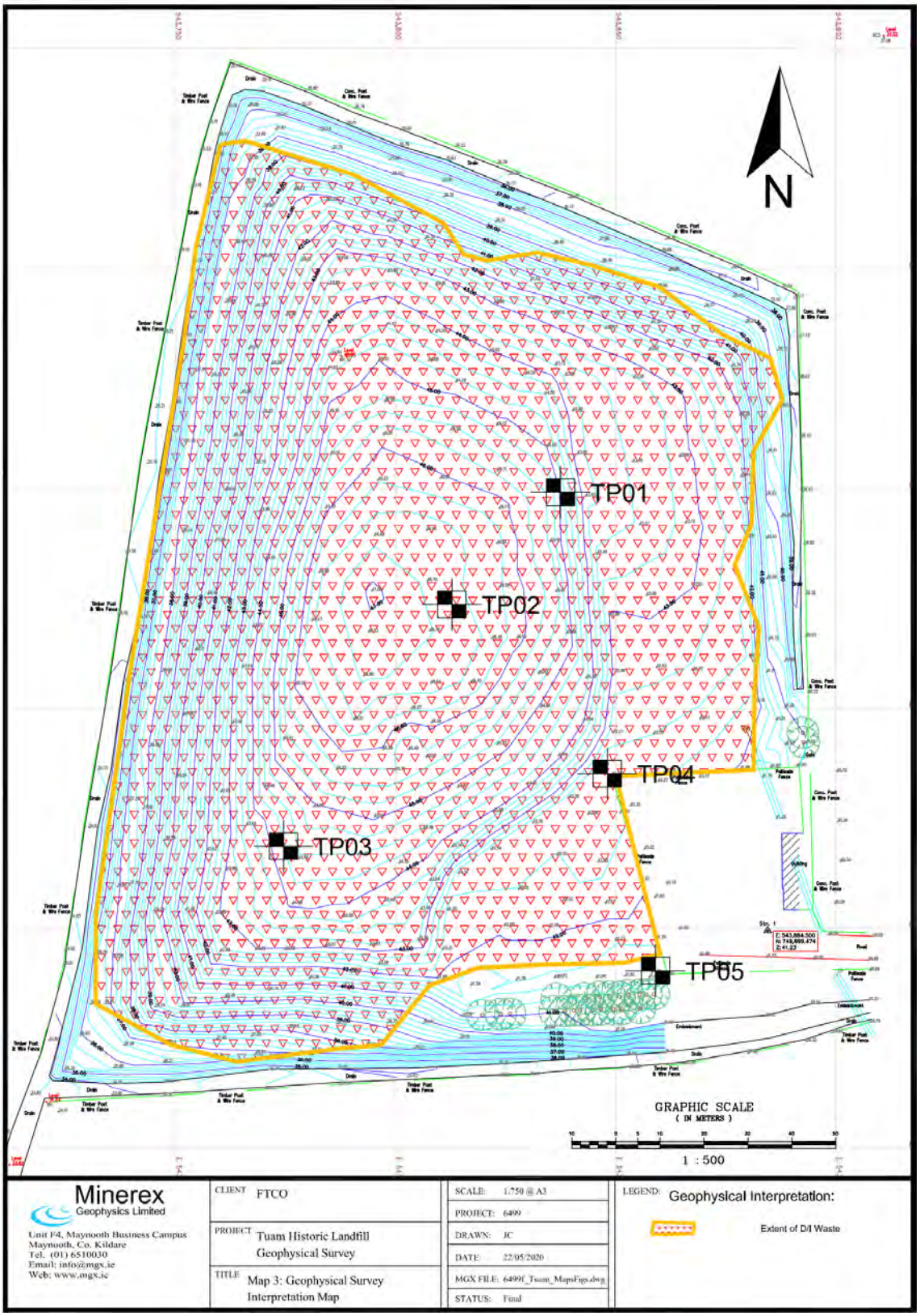


Figure 3-4: Geophysical Survey Estimated Waste Footprint

MGX note that low resistivities below the waste body is interpreted as likely leachate. The fresh limestone below this layer should generally restrict the leachate movement but there may be leachate penetration into the rock along profile R1.

3.1.5 Borehole Installation

Two boreholes (GW01 and GW02) were drilled to depths of 5.0m bgl and 12.0m BGL at the site. The addition of these groundwater monitoring wells was to replace existing wells/monitoring locations, downgradient of the site which were damaged and no longer fit for purpose.

Additional site investigations works were completed in 18th to the 20th of July 2022 by Causeway Geotechnical Ltd. in support of the RFI response.

Installation of 1 no. landfill gas monitoring borehole (BHLFG1) within the civic amenity site and Three no. dual leachate/gas boreholes (BH01 – BH03 inc.) were installed replacing the damaged/lost boreholes within waste body.

The log for these monitoring boreholes can be found in Appendix A of the 2022 geotechnical report, Appendix 6 of this report.

3.1.6 Groundwater Sampling

Groundwater monitoring was undertaken on the 1st July 2020 and 27th August 2020 at existing groundwater monitoring wells 5A, 8A, RC2, RC3, 3AP, 4AP, 5AP and 8AP.

All samples were appropriately bottled (using prepared laboratory bottle ware) and packaged for submission to the laboratory. The samples were submitted for laboratory testing to ALS Environmental Ltd. The analysis results are contained in Appendix 7 and are further discussed in the proceeding sections.

3.2 Geotechnical Analysis

3.2.1 In-situ Capping Permeability Testing

Bulk disturbed soil samples from TP01 and TP02 were submitted for geotechnical analysis by Causeway Geotech Ltd for analysis of moisture content, Atterberg limits and particle size distribution (PSD). The results of the geotechnical analysis are included in the 2020 Intrusive Site Investigation Report prepared by CGL in Appendix 6 of this report. Both samples were classified as '*Brown sandy gravelly clayey SILT'*.

Additional site investigations works were completed in 18th to the 20th of July 2022 by Causeway Geotechnical Ltd. in support of this RFI response.

A copy of the 2022 geotechnical report is included in Appendix 6 of this report.

Two number permeability by Triaxial Cell tests were undertaken on in-situ samples retrieved from BH01 and BH03. The results of the test are shown in Table 2.1 below.

Table 2.3: Triaxial Cell Test Results

Location	Permeability (m/s)
BH01	8.6×10^{-09}
BH03	2.0×10^{-09}

Additionally, two no. in-situ Hydraulic Conductivity by double ring infiltrometer assessments were undertaken at BH01 and BH03. The results of the test are shown in Table 2.1 below.

Table 2.4: Permeameter Test Results

Location	Hydraulic Conductivity (s^{-1})
BH01	0.0013279
BH03	0.0011363

The results of the permeability by triaxial cell and in-situ infiltrometer testing demonstrate that the landfill capping does not achieve a hydraulic conductivity of less than or equal to $1x10^{-9}$m/s however, it is high impermeable ranging from $2x10^{-9}$ to $8.6x10^{-9}$ m/s.

4. ENVIRONMENTAL ASSESSMENT

The results of the environmental assessment at the Tuam Historic Landfill site are presented in the following sections.

4.1 Chemical Assessment Criteria

In assessing environmental monitoring results, the following relevant documents and regulations were utilised.

- European Communities, Environmental Objectives (Groundwater)(Amendment) Regulations, 2016 (S.I. No. 366 of 2016).
- Interim Guideline Values (IGV) set out in the EPAs Groundwater *Towards Setting the Guideline Values for the Protection of Groundwater in Ireland*.
- European Communities Environmental Objectives (Surface Waters) Regulations, 2009 (S.I. No. 272 of 2009), as amended 2012 (S.I. No. 327 of 2012), 2015 (S.I. No. 386 of 2015), 2019 (S.I. No. 77 of 2019)
- European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989 (S.I. No. 294/1989).

4.2 Groundwater Analysis

Two rounds of groundwater quality monitoring were undertaken at the site in 2020, on the 1st July and 27th August. Groundwater monitoring was also conducted at newly installed wells GW01 and GW02.

An additional monitoring round was undertaken on the 31st May 2022.

The findings from the monitoring and an interpretation of the results are presented in the following sections.

4.2.1 Groundwater Depth Analysis

Groundwater depth analysis was undertaken on two occasions. Static groundwater levels from the 1st July 2020 and 27th August 2020 are calculated below:

Table 4.1: Groundwater Depth Analysis

Borehole ID	Location Gradient	Ground Level (mAOD)	Depth to Water (m bgl)	Groundwater Level (mAOD)
BH3	In waste	45.05	-	-
2AP	Cross-gradient	35.49	-	-
3AP	Cross-gradient	35.53	1.46	34.1
4AP	Downgradient	35.21	0.905	34.3

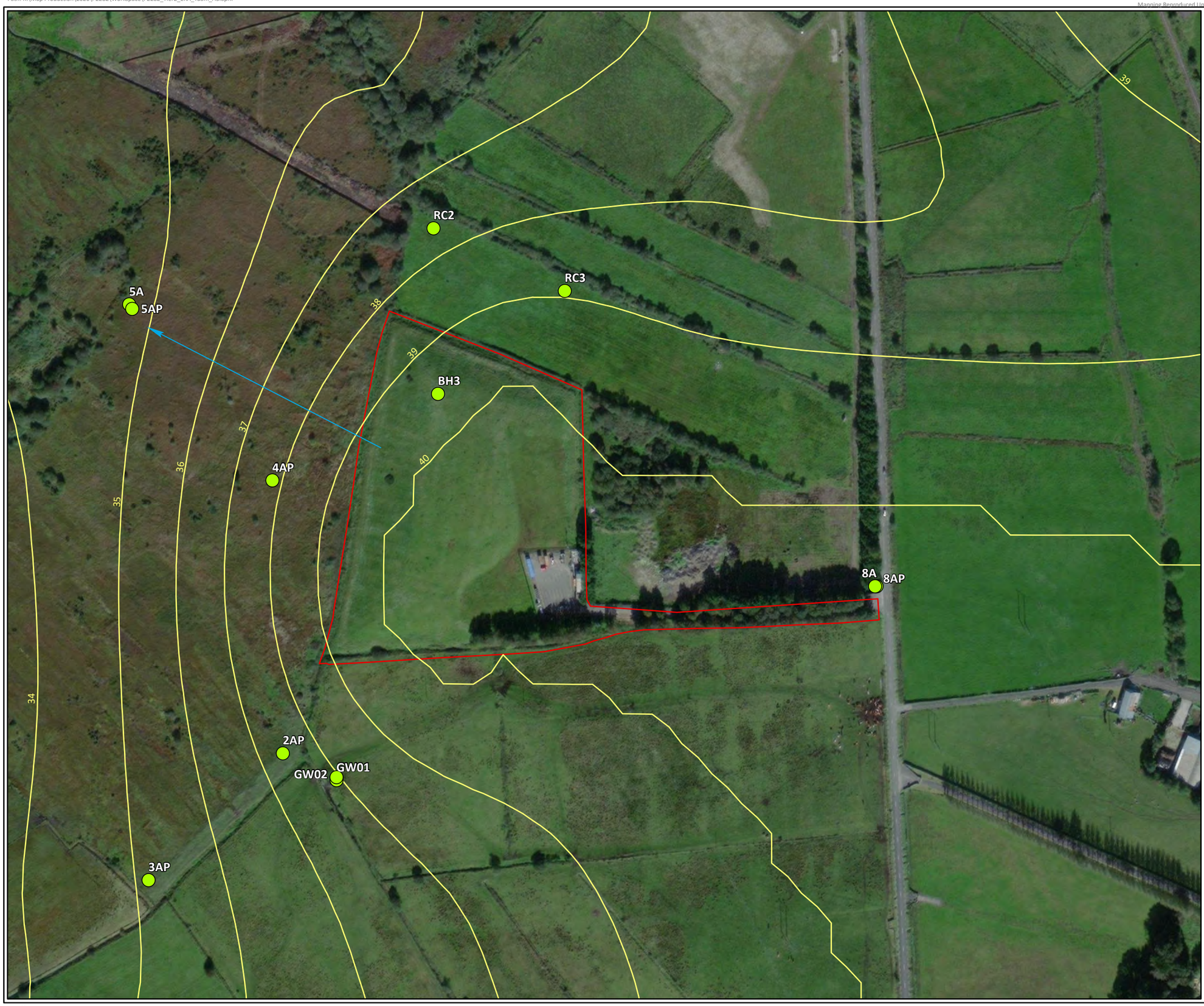
Borehole ID	Location Gradient	Ground Level (mAOD)	Depth to Water (m bgl)	Groundwater Level (mAOD)
5A	Downgradient	34.52	1.42	33.1
5AP	Downgradient	34.54	1.42	33.1
8A	Upgradient	42.13	4.55	37.6
8AP	Upgradient	42.16	2.845	39.3
RC2	Cross-gradient	35.53	1.245	34.3
RC3	Cross-gradient	37.08	1.775	35.3

Based on the above groundwater level measurements, the groundwater flow direction is defined to be east to west. Previous site investigation as described within the closure and remediation plan (Appendix 3) also states that groundwater flow is in a westerly and south-westerly direction.

Based on waste depth estimates and groundwater level measurements it is expected that the static groundwater level may be slightly below the base of the landfill waste, however groundwater levels can fluctuate seasonally, and groundwater may intersect the landfill depending on weather conditions.

A potentiometric map illustrating the hydraulic gradient and the direction of groundwater flow is presented in Figure 4.1.

Path: R:\Map Production\2020\P2282\Workspace\P2282_Tier2_ERA_Tuam_A3.aprx



Site Boundary

Borehole Locations

1m Ground Elevation Contours

Indicative Groundwater Flow Direction

TITLE:	Groundwater Flow Direction		
PROJECT:	Tuam Historic Landfill ERA		
FIGURE NO:	4.1		
CLIENT:	Galway County Council		
SCALE:	1:2,500	**REVISION:**	0
DATE:	18/10/2021	**PAGE SIZE:**	A3

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4.2.2 Groundwater Quality Monitoring

The results of groundwater samples analysed from the 10 No. existing wells (BH3, 2AP, 3AP, 4AP, 5A, 5AP, 8A, 8AP, RC2 and RC3) and the newly installed wells (GW01 and GW02) at the site have been assessed against the EPAs Interim Guideline Values (IGVs) and S.I No. 9 of the European Communities Environmental Objectives (Groundwater) Regulations 2010 (amended) overall threshold values (OTV).

Boreholes BH3, 2AP, 3AP, 4AP, 5AP and 8AP were dry during the first round of monitoring while boreholes BH3, 2AP, 5A and 8A were dry during second round of monitoring, and 2AP, BH3 and 8AP were dry during the third round of monitoring, therefore samples could not be taken from these wells at that time.

A summary of the results reported for each parameter for the monitoring rounds is outlined in Table 4.2, only results found to be above the limit of detection (LOD) are presented below while the complete results and laboratory reports are presented in Appendix 7.

Table 4.2: Groundwater Sampling Results

Parameter	Units	S.I. No. 9 of 2010 [1]	EPA IGV [2]	Round 1 (01/07/2020)				Round 2 (27/08/2020)								Round 3 (31/05/2022)								
				5A	8A	RC2	RC3	3AP	4AP	5AP	8AP	RC2	RC3	GW01-S[4]	GW01-D[4]	3AP	5A	8A	4AP	5AP	GW01	GW02	RC2	RC3
				DG	UG	CG	CG	CG	DG	DG	UG	CG	CG	DG	DG	CG	DG	UG	DG	DG	DG	DG	CG	CG
Inorganics																								
Conductivity @ 20 deg.C	mS/cm			0.666	0.87	0.769	0.423	0.525	0.966	0.568	0.866	0.762	-	0.765	0.763	0.608	0.698	0.898	0.953	0.566	0.7	0.805	0.679	0.141
Fluoride	mg/l	1	1	<0.5	0.693	<0.5	<0.5	<0.5	<0.5	<0.5	0.768	<0.5	<1	0.629	0.664	<0.5	<0.5	0.61	0.701	<0.5	0.922	0.564	0.977	<0.5
Oxygen, dissolved	mg/l		NAC	7.57	6.76	5.98	8.56	11.2	3.21	6.34	9.13	10.1	-	10	10.4	4.56	7.18	2.98	6.18	5.78	5.36	3.36	2.22	9.11
Sulphate	mg/l	187.5	200	<2	18.2	<2	<4	<10	<2	2.1	42.5	<2	<4	<1	<1	<2	<2	7.3	3.7	<2	<2	<2	<2	<10
Chloride	mg/l	24	30	12.5	**57.3**	20.1	17.2	14.7	**48.5**	13.1	**90.2**	21.8	14.8	**45.1**	**33.9**	14.9	13	**66**	**45.6**	12.2	**31.2**	**44.4**	18.2	28.2
Ammoniacal Nitrogen as N (low level)	mg/l	0.065 - 0.175	0.15	**1.31**	**1.8**	**3.48**	**1.62**	**0.361**	**2.04**	**1.24**	**0.854**	**3.56**	0.1	**3.33**	**1.6**	**0.74**	**1.15**	**11.9**	**0.984**	**0.21**	**2.01**	**1.77**	**2.72**	0.142
Alkalinity, Total as HCO3	mg/l		NAC	967	485	783	641	383	666	994	439	610	16.5	628	523	438	545	528	655	424	683	28400	548	30.5
Filtered (Dissolved) Metals																								
Arsenic (diss.filt)	µg/l	7.5	10	2.84	4.98	2.58	5.08	1.02	4.33	4.35	**31.2**	2.74	2.88	1.93	4.7	0.889	3.7	**64.7**	4.48	2.63	3.14	5.96	1.37	1.66
Barium (diss.filt)	µg/l		100	53.1	51.5	59	29.1	9.75	**138**	53.7	63.4	53.5	25.4	91.3	82.8	13.7	74.8	41.9	**217**	65.8	83.7	64.9	35.9	4.9
Boron (diss.filt)	µg/l	750	1000	<10	11.2	17.1	<10	<10	13.9	10.4	25.6	18	<10	29.7	18.4	<10	<10	34.6	10.9	<10	17.7	<10	16.5	<10
Cadmium (diss.filt)	µg/l	3.75	5	<0.08	<0.08	<0.08	0.103	0.172	<0.08	0.115	0.17	0.519	1.68	<0.08	0.335	0.0915	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	0.619
Chromium (diss.filt)	µg/l	37.5	30	<1	<1	2.29	1.17	<1	2.37	3.72	<1	5.33	1.3	1.05	<1	<1	1.2	1.14	2.99	<1	1.35	<1	3	1.39
Copper (diss.filt)	µg/l	1500	30	0.357	<0.3	0.579	6.59	5.2	0.397	1.2	11.7	2.31	11.3	2.99	1.1	0.858	<0.3	<0.3	0.553	0.397	<0.3	<0.3	<0.3	6.41
Lead (diss.filt)	µg/l	7.5	10	<0.2	<0.2	0.584	1.52	<0.2	1.58	0.668	2.48	1.52	4.88	<0.2	<0.2	0.359	0.28	<0.2	0.235	<0.2	<0.2	<0.2	0.364	1.79
Manganese (diss.filt)	µg/l		50	**91.9**	**231**	**128**	34.3	**181**	**876**	**146**	**204**	**179**	12.8	89.1	109	**327**	**170**	**364**	**926**	**439**	**112**	**90.1**	**119**	8.42
Nickel (diss.filt)	µg/l	15	20	7.98	19.4	11.7	15.3	5.92	7.66	8.89	**22.2**	12	9.3	**17.4**	**44.2**	3.33	12.9	3.58	4.08	1.56	8.22	13.7	3.25	8.03
Zinc (diss.filt)	µg/l	75	100	2.38	2.81	2.53	8.86	3.36	4.13	6.5	18.4	8.67	37.9	19.7	16.3	4.98	12.9	2.18	5.84	2.76	3.61	5.14	3.7	10.5
Sodium (Dis.Filt)	mg/l	150	150	10.4	27.2	13.3	8.34	6.46	88	10.3	47.1	12.7	12.7	32.2	24.5	7.5	9.29	34.4	93.2	7.67	21.5	18.2	11.1	8.36
Magnesium (Dis.Filt)	mg/l		50	4.92	9.41	8.65	3.64	4.37	11.9	5.26	9.1	11	3.25	11.6	12.1	4.74	4.93	8.55	14.7	4.64	14.3	16.2	7.73	2.61
Potassium (Dis.Filt)	mg/l		5	0.865	1.56	2.99	1.13	0.466	**53.7**	0.916	1.64	3.12	0.237	2.77	2.69	0.325	0.733	**6.56**	**54**	0.649	2.26	2.17	2.44	1.9
Calcium (Dis.Filt)	mg/l		200	160	187	177	97	107	91.4	169	154	**355**	35.9	148	137	139	160	142	107	134	130	106	166	22.8
Iron (Dis.Filt)	mg/l		0.2	**0.33**	**1.32**	**1.87**	**3.04**	**0.657**	**30.2**	**7.79**	**16.9**	**11.1**	**1.9**	0.0349	0.0314	**4.22**	**3.53**	**16.4**	**38.8**	**6.05**	**5.86**	**2.71**	**8.49**	**0.941**
Combined Pesticides / Herbicides																								
Dieldrin	µg/l	0.075	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	<0.1	<0.02	<0.02	**0.141**	**0.527**	<0.1	<0.2	<0.02	<0.02
Simazine	µg/l	0.075	1	0.082	<0.01	0.132	0.133	<0.05	<0.1	<0.1	<0.01	<0.01	<0.05	<0.02	<0.02	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.05	<0.1
Microbiological																								
Coliforms, Total*	MPN/100ml		0	**914**	-	**>2420**	**>2420**	**17300**	**15.5**	**74.9**	**64.2**	**817**	**52000**	**>2419.6**	**>2419.6**	-	-	-	-	-	-	-	-	-
Coliforms, Faecal*	CFU/100ml		0	**12**	-	<1	<100	**740**	**1**	**7**	**4**	**9**	**2**	**69**	**>100**	-	-	-	-	-	-	-	-	-
Miscellaneous Organics																								

Parameter	Units	S.I. No. 9 of 2010 [1]	EPA IGV [2]	Round 1 (01/07/2020)				Round 2 (27/08/2020)								Round 3 (31/05/2022)								
				5A	8A	RC2	RC3	3AP	4AP	5AP	8AP	RC2	RC3	GW01-S[4]	GW01-D[4]	3AP	5A	8A	4AP	5AP	GW01	GW02	RC2	RC3
				DG	UG	CG	CG	CG	DG	DG	UG	CG	CG	DG	DG	CG	DG	UG	DG	DG	DG	DG	CG	CG
Mecoprop	µg/l	0.075	10	<0.04	<0.08	<0.04	<0.04	<0.4	2.64	<0.2	<0.08	<0.4	<0.2	<0.4	<0.4	<0.4	<0.2	<0.2	1.01	<0.2	<0.4	<4	<0.04	<0.4

[1] OTV-Overall threshold value, European Communities Environmental Objectives (Groundwater) Regulations, 2010 (S.I. No. 9 of 2010) as amended in 2011, 2012, 2016.

[2] IGV-Interim Guideline Values, from EPA, Towards Setting Guideline Values for the Protection of Groundwater in Ireland, 2003.

[3] UG = upgradient, DG=downgradient, IW = in waste, CG=cross-gradient

[4] GW01-S (shallow) refers to GW01, GW01-D (deep) refers to well GW02 (See Causeway 2020 site investigation report Appendix 6)

* Items shaded in **orange** are in exceedance of the Drinking Water Regulations

* Items shaded in **bold** are in exceedance of the EPA IGV Standards

4.2.3 Groundwater Analysis Discussion

The results of the groundwater monitoring from the 8 No. existing boreholes (3AP, 4AP, 5A, 5AP, 8A, 8AP, RC2 and RC3) and the newly installed monitoring boreholes (GW01 and GW02) include several exceedances of the EPA IGVs and groundwater regulations OTVs in all 3 rounds of monitoring in 2020 and 2022.

Samples recovered from monitoring wells in 2020 and 2022 reported ammoniacal nitrogen concentrations from 0.1 mg/l to 11.9 mg/l, exceeding threshold values for all boreholes. Ammoniacal nitrogen concentrations at 8A and 8AP, being upgradient of the landfill may represent background levels. The elevated concentrations detected at these wells may be attributed to other anthropogenic sources such as agricultural activities. Additionally, the presence of peat in the area may also be a source of ammonia, and the elevated ammoniacal nitrogen concentrations detected upgradient of the site could be naturally occurring.

Elevated concentrations of chloride above the OTV and EPA IGV are observed in 5 No. boreholes 8A, 4AP, 8AP, GW01-S (GW01) and GW01-D (GW02) in 2020 and 4 No boreholes 8A, 4AP, GW01 and GW02 in 2022. Landfill leachate has the potential to contain high concentrations of chloride ions and may be source of the concentrations observed offsite and downgradient of the site at borehole 4AP, GW01 and GW02.

Arsenic concentrations of 31.2 mg/l borehole 8AP in 2020 and of 64.7 mg/l borehole 8A in 2022 exceed the IGV and groundwater regulation limit values however as both boreholes 8AP and 8A are located upgradient of the landfill is not likely that these arsenic concentrations due to leachate migration from the landfill.

Potassium at a concentration of 53.7 mg/l and 54 mg/l was detected at groundwater monitoring well 4AP in 2020 and 2022, respectively, and of 6.56 mg/l at monitoring well 8A in 2022, all of which exceed the IGV limit. Potassium concentrations at this level may be an indication of impact on groundwater quality from the landfill as potassium concentrations are significantly lower at all other wells, cross-gradient and upgradient of the landfill.

In 2020, Nickel was elevated above the groundwater quality threshold values (S.I No. 9 of 2010) at wells 8A, 8AP, GW01 and GW02. The elevated concentrations at 8A and 8AP, upgradient of the landfill suggest that the concentrations of nickel measured are naturally occurring. Both 8AP and GW02 (GW01-D) yielded the highest concentrations of nickel again indicating that the nickel concentrations may be naturally occurring and attributable to the underlying geology at these monitoring locations.

Faecal coliforms were detected in 9 No. boreholes on both monitoring rounds. However, the presence of faecal coliforms in groundwater is not likely attributed to the historical landfill, but more likely present from agricultural or domestic sources i.e. human/animal waste, slurry, septic tanks etc. Samples were not tested for coliforms on Round 3 in 2022.

The results of groundwater monitoring are below the laboratory limit of detection for List 1 and List 2 substances (SVOCs, pesticides, herbicides, organics) with the exception of 3 No. offsite boreholes (5A, RC2 and RC3) in 2020 which exceed the threshold values for Simazine and 2 No. off site boreholes (4AP and 5AP) which exceed the threshold values for Dieldrin in 2022. Simazine and Dieldrin are commonly used herbicides, and their presence at these locations are not expected to be attributed to leachate migration from the landfill.

Results of historical groundwater monitoring at the site (as included within the Closure and Remediation Plan), upgradient and downgradient also showed evidence of migration of leachate from the site and leachate impacting on groundwater quality at monitoring locations downgradient e.g. at locations 4AP and 10AP. Pollutant concentrations do decrease however further downgradient at the site i.e. at monitoring location 3AP, c.200m west of the site.

The results of this assessment suggest that the migration of leachate from the site and contamination of groundwater downgradient of the site is more likely to be a local issue and is not likely to significantly impact on groundwater quality further from the (>200m).

4.2.4 Leachate monitoring

Three no. dual leachate/gas boreholes (BH01 – BH03 inc.) were installed replacing the damaged/lost boreholes within waste body.

Leachate monitoring was undertaken on 9th August 2022.

A summary of the results is included in Table 4.3 below. Only results that were shown to be above the limit of detection were included. Complete results of the leachate monitoring are included in Appendix 7.

Table 4.3: Leachate Sampling Results August 2022

Parameter	Units	BH1	BH2	BH3
Carbon				
Organic Carbon, Total	mg/l	91.8	47.2	233
Inorganics				
Oxygen, dissolved	mg/l	1.87	7.99	<0.3
pH	pH Units	8.06	7.79	7.56
Sulphate	mg/l	176	133	513
Chloride	mg/l	440	70.2	739
COD, unfiltered	mg/l	2380	1420	1860
Ammoniacal Nitrogen as N (low level)	mg/l	68	96.2	255
Conductivity @ 20 deg.C	mS/cm	3.12	1.98	6.33
BOD, unfiltered	mg/l	60.5	42.8	166
Alkalinity, Total as HCO3	mg/l	7130	2340	3310
Filtered (Dissolved) Metals				
Mercury (diss.filt)	µg/l	<0.01	0.0531	<0.01
Arsenic (diss.filt)	µg/l	3.01	2.54	6.35
Barium (diss.filt)	µg/l	261	215	233
Boron (diss.filt)	µg/l	904	456	1470
Cadmium (diss.filt)	µg/l	<0.08	0.163	<0.08
Chromium (diss.filt)	µg/l	3.22	3.03	27.1
Copper (diss.filt)	µg/l	<0.3	8.49	<0.3
Lead (diss.filt)	µg/l	0.644	14.6	0.224
Manganese (diss.filt)	µg/l	141	1790	3390

Parameter	Units	BH1	BH2	BH3
Nickel (diss.filt)	µg/l	13.2	10.7	57.5
Phosphorus (diss.filt)	µg/l	290	118	320
Selenium (diss.filt)	µg/l	8.45	1.88	3.99
Zinc (diss.filt)	µg/l	4.25	149	4.47
Sodium (Dis.Filt)	mg/l	1090	87.5	740
Magnesium (Dis.Filt)	mg/l	64.9	55.6	184
Potassium (Dis.Filt)	mg/l	120	59.4	227
Calcium (Dis.Filt)	mg/l	56.7	210	165
Iron (Dis.Filt)	mg/l	3.3	2.01	6.48
Semi-Volatile Organic Compounds (SVOCs)				
bis(2-Ethylhexyl) phthalate (aq)	µg/l	541	86.2	31
Butylbenzyl phthalate (aq)	µg/l	59.7	<10	<10
Benzo(b)fluoranthene (aq)	µg/l	21.6	<10	<10
Chrysene (aq)	µg/l	23.1	<10	<10
Volatile Organic Compounds (VOCs)				
Carbon disulphide	µg/l	1.48	<1	1.67
Benzene	µg/l	1.84	<1	3.39
Toluene	µg/l	1.11	<1	1.8
1,1,1,2-Tetrachloroethane	µg/l	<1	5.23	<1
Ethylbenzene	µg/l	<1	5	2.51
m,p-Xylene	µg/l	<1	51	1.77
o-Xylene	µg/l	<1	1.42	1.09
1,3,5-Trimethylbenzene	µg/l	<1	1.52	<1
1,2,4-Trimethylbenzene	µg/l	<1	1.89	<1
4-iso-Propyltoluene	µg/l	<1	<1	1.21

The leachate monitoring results show elevated concentrations of pollutants commonly encountered within MSW landfill leachate i.e. ammoniacal nitrogen, chloride and COD. The results shown are typical of MSW landfill leachate.

4.3 Landfill Gas Monitoring

In 2020, FT carried out two rounds of monitoring of landfill gas (LFG) parameters at each monitoring well locations (BH3, 2AP, 3AP, 4AP, 5A, 5AP, 8A, 8AP, RC2 and RC3) as indicated on Figure 3.1. Methane, carbon dioxide, oxygen and atmospheric pressure were analysed at the 9 No. groundwater monitoring wells located outside the waste body and one well within the waste body (BH3) using a landfill gas analyser.

An additional monitoring round was carried out in 2022, after the reinstallation of the damaged/lost boreholes (BH01 to BH03) within the waste body and the installation of a landfill gas monitoring borehole (BHLFG1) within the civil amenity site.

4.3.1 Monitoring Results

As per the EPA Landfill Manuals - Landfill Monitoring, 2nd Edition, the trigger level for methane outside the waste body is 1% v/v and for carbon dioxide, 1.5% v/v. The monitoring results for methane, carbon dioxide and oxygen levels for the perimeter borehole are summarised in Table 4.3.

Table 4.4: Gas Monitoring Results

Date: 01/07/2020						
Sample Station	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Atmospheric Pressure (mbar)	Staff Member	Weather
BH3	0	0.6	22.3	1005	Daniel Hayden	Overcast, Warm, 16-18°C
2AP	0	0.9	21.9			
3AP	0	0.3	22.1			
4AP	0	0.6	22.4			
5A	0	1.2	20.8			
5AP	0	1	21.2			
8A	0	**1.8**	20.4			
8AP	0	**1.7**	20.5			
RC2	0	0.9	21.2			
RC3	0	**1.5**	21.5			
Date: 27/8/2020						
Sample Station	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Atmospheric Pressure (mbar)	Staff Member	Weather
BH3	0	0.2	20.8	998	Daniel Hayden	Overcast, Rain, 14-16°C
2AP	0	0.4	20.6			
3AP	0	0.1	21.8			
4AP	0	0.9	22.4			
5A	0	0.8	20.8			
5AP	0	0.6	21.2			
8A	0	1.4	19.8			
8AP	0	0.8	20.5			
RC2	0	0.6	21.2			
RC3	0	0.4	21.5			

As can be seen in Table 4.3, no methane was detected in all monitoring wells in both the first and second round of monitoring. Carbon dioxide is only detected at or slightly above the trigger value of 1.5% v/v at wells 8A, 8AP and RC3 in the first round of monitoring. This indicates that no or very minimal migration of landfill gas is occurring at the site, however monitoring well 8A and 8AP are located c.200m east of the historic landfill, and it is not expected that landfill migrate this distance from the site.

Additional site investigations works were completed in 18th to the 20th of July 2022 by Causeway Geotechnical Ltd. in support of this RFI response.

Three no. dual leachate/gas boreholes (BH1 – BH3 inc.) where installed replacing the damaged/lost boreholes within waste body. A landfill gas monitoring borehole (BHLFG1) was installed within the civic amenity site as per proposed remediation plan.

Landfill gas monitoring was undertaken on 9th August 2022 and results can be found in Table 4.5 and Table 4.6.

Table 4.5: Civic Amenity Gas Monitoring Results – August 2022

Sample Station	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Atmospheric Pressure (mbar)	Staff Member	Weather
BHLFG1	0.2	0.8	19.3	1026	Sean Foley	Sunny, Warm, 22°C

Table 4.6: Landfill Footprint Gas Monitoring Results – August 2022

Sample Station	CH_4 (% v/v)	CO_2 (% v/v)	O_2 (% v/v)	Atmospheric Pressure (mbar)	Staff Member	Weather
BH01	25.6	9.8	1.0	1026	Sean Foley	Sunny, Warm, 22°C
BH02	41.2	11.5	1.1			
BH03	67.7	17.2	0.5			

As can be seen in Table 4.5, only small traces of methane and carbon dioxide were detected in the monitoring well located within the civic amenity, below the trigger levels set by the EPA. This indicates that no or very minimal migration of landfill gas is occurring at the site.

Table 4.6 shows the continued production of landfill gas within the landfill footprint.

4.4 Surface Water Monitoring

4.4.1 Monitoring Locations

The surface water monitoring locations were selected upstream and downstream of the landfill footprint, as shown on Figure 4.2. Monitoring locations SW1 to SW4 were selected as the upstream and downstream locations on River Killeelaun to the north of the landfill and River Clare to the south of the landfill.

Two rounds of surface water monitoring were carried out in 2020, on the 1st July and 26th August. An additional round was carried out in 2022, on the 31st May. The surface water sampling locations at the site are presented in Figure 4.2.

4.4.2 Monitoring Parameters

The results of surface water sampling analysed from the 4 No. sampling locations (SW1 to SW4) at the site have been assessed against the Maximum Admissible Concentration (MAC) and the Environmental Quality Standard (EQS) as per S.I. No. 77/2019 - European Union Environmental Objectives (Surface Waters) (Amendment) Regulations 2019.

A summary of the results from the monitoring round is outlined in Table 4.4, while the laboratory reports are presented in Appendix 7.

Path: R:\Map Production\2022\P22-065\Workspaces\P22_065_Tuam.aprx

Site Boundary

Surface Water Monitoring Locations

Surface Water Flow Direction

N W E S

0 50 100 200 Meters

TITLE:	Surface Water Sampling Locations		
PROJECT:	Tuam Historic Landfill ERA		
FIGURE NO:	4.2		
CLIENT:	Galway County Council		
SCALE:	1:3,500	**REVISION:**	0
DATE:	26/10/2022	**PAGE SIZE:**	A3

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Table 4.7: Surface Water Sampling Results

Parameter	Units	EQS[1]	MAC[2]	Round 1 (01/07/2020)				Round 2 (26/08/2020)				Round 3 (31/05/2022)			
				SW1	SW2	SW3	SW4	SW1	SW2	SW3	SW4	SW1	SW2	SW3	SW4
Inorganics															
Fluoride	mg/l	0.5		<0.5	<0.5	<0.5	<0.5	0.562	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
pH	-	6.0<pH<9.0		7.59	7.99	8.08	7.85	6.94	7.37	7.12	7.23	7.79	7.84	7.88	8.07
Ortho-phosphate (as PO_4)	mg/l	≤0.075 (95%ile)		1.01	<0.05	<0.05	<0.05	2.18	0.169	0.074	0.374	-	-	-	-
Ammoniacal Nitrogen as N (low level)	mg/l	≤0.140 (95%ile)		1.86	0.174	0.123	0.16	3.42	4.79	-	0.0791	0.0537	0.139	0.0285	0.0297
Cyanide, Total	mg/l	0.01		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Biochemical Oxygen Demand (BOD)	mg/l	2.6		2.25	6.27	5.94	9.4	13.5	18.3	-	5.85	<1	<1	<1	<1
Filtered (Dissolved) Metals															
Mercury (diss.filt)	µg/l		0.07	<0.01	0.0131	<0.01	<0.01	<0.01	**0.114**	<0.01	0.0178	<0.01	<0.01	<0.01	<0.01
Arsenic (diss.filt)	µg/l	25		1.4	1.35	1.28	2.14	2.63	2.75	1.32	2.07	0.863	1.12	1.04	1.15
Cadmium (diss.filt)	µg/l	0.15	0.9	<0.08	<0.08	<0.08	<0.08	0.448	<0.08	0.136	0.476	<0.08	<0.08	<0.08	<0.08
Chromium (diss.filt)	µg/l	4.7	32	1.94	6.63	6.74	7.33	1.39	1.27	1.18	2.13	<1	<1	<1	<1
Copper (diss.filt)	µg/l	30		1.96	3.9	3.7	3.71	3.32	5.26	2.47	4.8	6.16	0.4	0.442	0.731
Lead (diss.filt)	µg/l	1.2	14	<0.2	<0.2	<0.2	<0.2	0.223	0.681	0.231	0.65	<0.2	<0.2	<0.2	<0.2
Nickel (diss.filt)	µg/l	4	34	3.64	4.33	3.88	6.18	7.04	3.4	4.36	9.3	3.95	2.71	2.89	2.78
Zinc (diss.filt)	µg/l	100		1.88	5.54	6.44	8.16	9.81	16.6	10.8	20.9	3.55	2.1	4.06	2.72
Semi-Volatile Organic Compounds (SVOCs)															
1,2,4-Trichlorobenzene (aq)	µg/l	0.4	not applicable	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Anthracene (aq)	µg/l	0.1	0.1	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
bis(2-Ethylhexyl) phthalate (aq)	µg/l	1.3	not applicable	<2	<2	<2	<2	<8	<16	<20	<8	<2	<2	<2	<2
Benzo(b)fluoranthene (aq)	µg/l		0.017	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Benzo(k)fluoranthene (aq)	µg/l		0.017	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Benzo(a)pyrene (aq)	µg/l	0.00017	0.27	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Benzo(g,h,i)perylene (aq)	µg/l		0.0082	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Diethyl phthalate (aq)	µg/l	1.3	not applicable	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Fluoranthene (aq)	µg/l	0.0063	0.12	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Hexachlorobenzene (aq)	µg/l		0.05	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Hexachlorobutadiene (aq)	µg/l		0.6	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Pentachlorophenol (aq)	µg/l	0.4	1	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Phenol (aq)	µg/l	8	46	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Naphthalene (aq)	µg/l	2	130	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Indeno(1,2,3-cd)pyrene (aq)	µg/l		not applicable	<1	<1	<1	<1	<4	<8	<10	<4	<1	<1	<1	<1
Combined Pesticides / Herbicides															
Dieldrin	µg/l	0.01	not applicable	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0386	<0.015

Notes:

1. Environmental Quality Standard (EQS) as per European Communities Environmental Objectives (Surface Waters) Regulations 2009 (S.I No. 272 of 2009). Refers to Annual-Average (AA) EQS for relevant parameters.
2. Maximum Admissible Concentration (MAC), as classified by European Communities Environmental Objectives (Surface Waters) Regulations 2009 (S.I No. 272 of 2009).

** Items shaded in **orange** are in exceedance of the 2009 EQS Regulations

*** NAC – no abnormal change

4.4.3 Surface Water Analysis Discussion

The results of the surface water laboratory analysis as presented in Table 4.5, when assessed against the MAC and EQS quality standards reported several exceedances of threshold values in 2020. However, results show little variation in parameter levels observed between upstream and downstream sampling locations.

Fluoride slightly exceeds the EQS threshold value one occasion at upstream monitoring location SW1.

Elevated concentrations of ortho-phosphate were detected at all sampling locations during the second round of sampling and at SW1 during the first round. Upstream location SW1 yielded the highest ortho-phosphate concentrations for both rounds, suggesting the elevated concentrations of phosphate measured downstream of the site may not be attributed to the landfill.

Exceedances of the EQS limit values for ammoniacal nitrogen (as N) was recorded in all sampling locations on both rounds except for SW3 during sampling round 2. The presence of ammoniacal nitrogen at these levels may be an indication of agricultural runoff from the surrounding fields or due to the presence of peat and bog in the area rather than direct impact from the landfill.

Biochemical oxygen demand (BOD) concentrations were also elevated above the EQS value at almost all sampling locations during both rounds. BOD is a broad indicator of water quality and provides a measurement of the organic matter that is biologically available for bacteria present in a sample or waterbody to consume. Organic matter present in the waterbody is likely to be naturally occurring.

The presence of elevated dissolved metal concentrations such as Chromium and Nickel in downstream samples which weren't recorded in upstream samples indicates potential leaching of metals from landfill and migration to the receiving drainage network and stream.

In the additional monitoring round undertaken in 2022 results for SW1 to SW4 show only 2 no. exceedances for the EQS threshold values. SW2 exceeds the threshold value for Ammoniacal Nitrogen, which could be an indicative of leachate migration from the landfill to surface water; and SW3 exceeds the threshold value for Dieldrin.

5. RISK ASSESSMENT

5.1 Introduction

Risk assessment considers the likelihood of occurrence and the consequence of occurrence of an event (Royal Society, 1992[2]). ERA (Environmental Risk Assessment) is based on the development of a Conceptual Site Model (CSM) which is used to determine the potential exposure of a vulnerable receptor to a contaminant. The CSM is used as the basis for the risk assessment. It is used to identify all possible sources (S), pathways (P) and receptors (R) as well as the processes that are likely to occur along each of the source-pathway-receptor (S-P-R) linkages and uncertainties.

Based on the desktop investigation and completed site investigation, this CSM assumes the source to be the made ground containing waste deposit, the pathway to involve the migration of landfill gas, surface water and groundwater and the ultimate receptors to be the surface water features, groundwater, groundwater abstraction well and all human presence near the waste material.

5.2 Potential Pathways and Receptors

A pathway is a mechanism or route by which a contaminant encounters, or otherwise affects, a receptor. Contaminants associated with deposited waste may include leachate generated from groundwater/rainwater infiltration into the waste material and/or the lateral or vertical migration of landfill gas to human receptors.

The potential pathways associated with the Tuam site are:

- Groundwater migration;
- Surface water migration.

5.2.1 Groundwater/Leachate Migration

According to the EPA CoP, there are three main pathways for leachate migration. These are:

- Vertically to the water table or top of an aquifer, where groundwater is the receptor;
- Vertically to an aquifer and then horizontally in the aquifer to a receptor such as a well, spring, stream or in this case, the adjacent coastline;
- Horizontally at the ground surface or at shallow depth to a surface receptor.

The migration and attenuation of leachate from the site depends on the permeability and thickness of subsoil and on both the bedrock permeability value and type. These elements are encompassed in groundwater vulnerability, groundwater flow regime and surface water drainage.

[2] Royal Society 1992, Risk: Analysis, Perception and Management. The Royal Society, London (ISBN 0-85403-467-6).

The main receptors to leachate migration from this site are:

- Aquifer;
- Surface water features.

5.2.2 Landfill Gas Migration

According to the EPA CoP, there are two main pathways for landfill gas migration. These are:

- Lateral migration via subsoil;
- Vertical migration via subsoil.

The migration of landfill gas from the site depends on the nature of the material deposited and the nature, permeability and thickness of the surrounding subsoil or bedrock.

The main receptors to potential landfill gas migration from this site are:

- Human Presence/Buildings nearby the waste body (civic amenity site).

5.3 Conceptual Site Model

Based on the review of the Tier 1 assessment and site investigation works undertaken for Tuam Historic Landfill, an assessment of the risk is made to confirm the source – pathway – receptor (S-P-R) linkages identified in the preliminary investigation. The results and analysis of the investigation has enabled a revised conceptual model to be produced for the site, which is presented in Figure 5.1, overleaf.

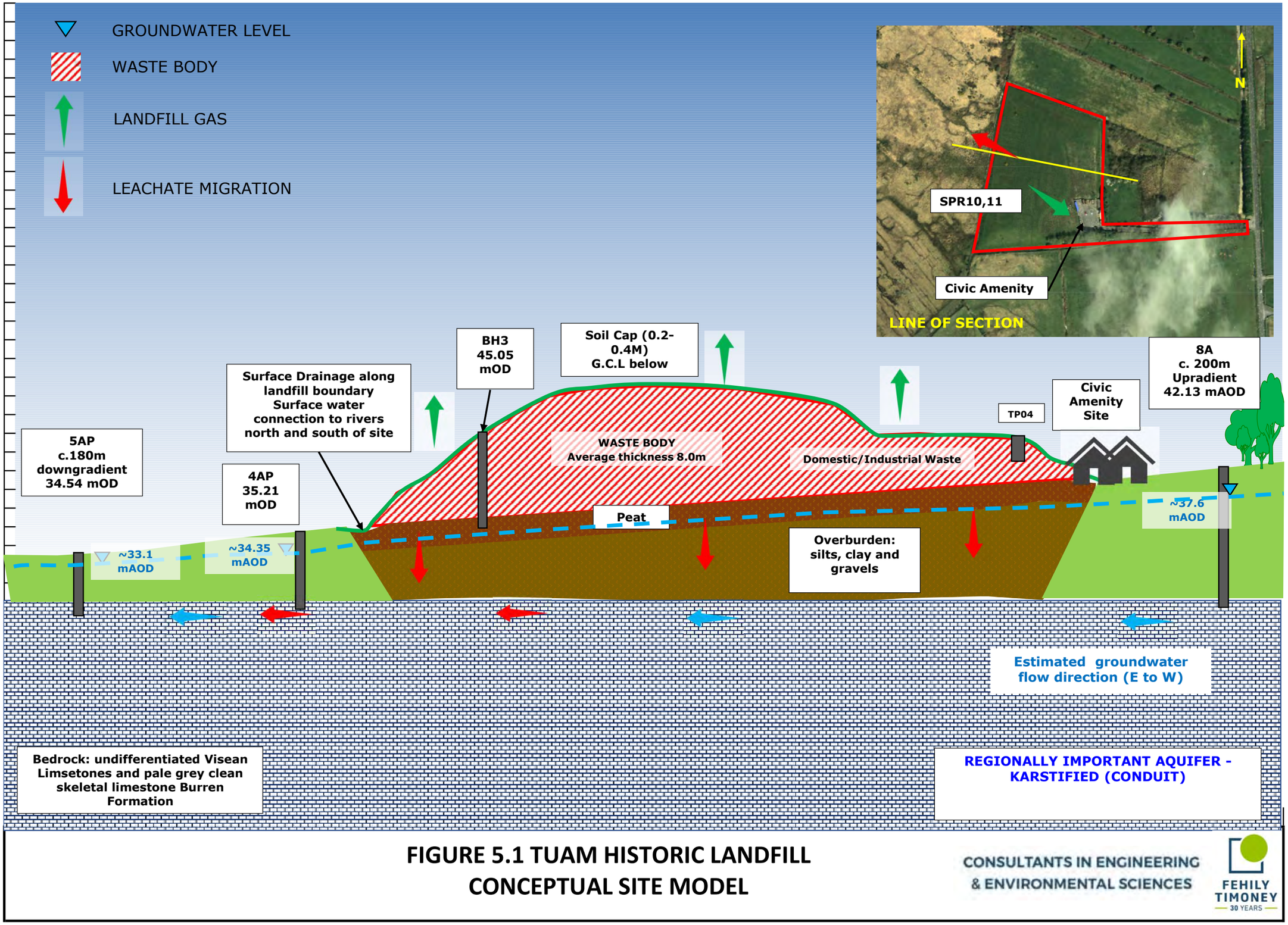

FIGURE 5.1 TUAM HISTORIC LANDFILL CONCEPTUAL SITE MODEL

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5.4 Risk Prioritisation

Risk prioritisation enables resources to be prioritised on the highest risk facilities and on the highest source – pathway – receptor linkage potential.

The risk prioritisation process assigns a score to each linkage and the overall score is the maximum of the individual linkages for the site. The higher the score a site/linkage receives the higher the risk.

To classify the risk, scores will be applied to the information obtained during the site investigation of Tuam Historic Landfill. Where there is insufficient information available (i.e. where there is a high degree of uncertainty) the highest score is assumed.

In accordance with the EPA CoP (2007) the scoring matrices are as follows:

- Leachate: Source/hazard scoring matrix, based on waste footprint;
- Landfill gas: Source/hazard scoring matrix based on waste footprint;
- Leachate migration: Pathway (Vertical);
- Leachate migration: Pathway (Horizontal);
- Leachate migration: Pathway (Surface water drainage);
- Landfill gas: Pathway (Lateral migration potential);
- Landfill gas: Pathway (Upwards migration potential);
- Leachate migration: Receptor (Surface water drainage);
- Leachate migration: Receptor (Human presence);
- Leachate migration: Receptor (Protected areas – SWDTE or GWDTE) (Surface water/groundwater dependent terrestrial ecosystems);
- Leachate migration: Receptor (Aquifer category – Resource potential);
- Leachate migration: Receptor (Public water supplies – other than private wells);
- Leachate migration: Receptor (Surface water bodies);
- Landfill gas: Receptor (Human presence).

Table 5.1 calculates the points awarded to each of the headings listed above:

Table 5.1: Risk Classification Calculation – Tuam Landfill

EPA Ref	Risk	Points	Rationale
1a	Leachate; source/hazard scoring matrix, based on waste footprint.	7	Based on a waste footprint of 2.7 ha and the presence of municipal waste the score of 7 is being maintained.
1b	Landfill gas; source/hazard scoring matrix, based on waste footprint.	7	Based on a waste footprint of 2.7 ha and the presence of municipal waste the score of 7 is being maintained.

EPA Ref	Risk	Points	Rationale
2a	Leachate migration: Pathway (Vertical)	2	GSI describes the groundwater vulnerability as High. Geophysical survey suggests that there is 5-10m of overburden underlying the waste material and atop competent limestone bedrock.
2b	Leachate migration: Pathway (Horizontal)	5	The underlying bedrock groundwater aquifer is classified by the GSI as a Regionally Important Aquifer - Karstified - conduit (Rkd).
2c	Leachate migration: Pathway (Surface water drainage)	2	Surface water drains have been constructed immediately to the boundary of the landfill flowing into the River Killeelaun and Clare River.
2d	Landfill gas: Pathway (Lateral migration potential)	3	Nearest receptor is the adjacent civic amenity site which is constructed on made ground. Made ground presents a preferential pathway for landfill gas migration.
2e	Landfill gas: Pathway (Upwards migration potential)	5	The Civic Amenity (CA) Site is located adjacent to capped landfill. Results of the 2022 SI indicate waste is likely not present beneath the civic amenity site, however the complete absence of waste under the civil amenity cannot be discarded.
3a	Leachate migration: Receptor (Human presence)	1	The Civic Amenity (CA) Site is located adjacent to capped landfill however no groundwater drinking water supply is present. Other closest receptor (agricultural buildings) is greater than 250m from the site.
3b	Leachate migration: Receptor (Protected areas – SWDTE or GWDTE) (Surface water/ groundwater dependent terrestrial ecosystems)	0	The River Clare is part of the Lough Corrib SAC (Site Code: 000297) and is located approximately 2km south-west of the site.
3c	Leachate migration: Receptor (Aquifer category – Resource potential)	5	Regionally Important Aquifer - Karstified - conduit (Rkd).
3d	Leachate migration: Receptor (Public water supplies – other than private wells)	3	The Claretuam Belclare Group Water Scheme is located c.4.6km west of the site.
3e	Leachate migration: Receptor (Surface water bodies)	2	Clare River is located c.90m of the site boundary.
3f	Landfill Gas: Receptor (Human presence)	5	The Civic Amenity Site is located adjacent to the site.

Table 5.2: Normalised Score of S-P-R Linkage

Calculator		S-P-R Values	Maximum Score	Linkage	Normalised Score
Leachate migration through combined groundwater and surface water pathways					
SPR1	1a x (2a + 2b + 2c) x 3e	**126**	300	Leachate => surface water	**42%**
SPR2	1a x (2a + 2b + 2c) x 3b	**0**	300	Leachate => SWDTE	0%
Leachate migration through groundwater pathway					
SPR3	1a x (2a + 2b) x 3a	**49**	240	Leachate => human presence	20%
SPR4	1a x (2a + 2b) x 3b	**0**	240	Leachate => GWDTE	0%
SPR5	1a x (2a + 2b) x 3c	**245**	400	Leachate => Aquifer	**61%**
SPR6	1a x (2a + 2b) x 3d	**147**	560	Leachate => Public Supply (well)	26%
SPR7	1a x (2a + 2b) x 3e	**98**	240	Leachate => Surface water body	**41%**
Leachate migration through surface water pathway					
SPR8	1a x 2c x 3e	**28**	60	Leachate => Surface Water	**47%**
SPR9	1a x 2c x 3b	**0**	60	Leachate => SWDTE	0%
Landfill gas migration pathway (lateral & vertical)					
SPR10	1b x 2d x 3f	**105**	150	Landfill Gas => Human Presence	**70%**
SPR11	1b x 2e x 3f	**175**	250	Landfill Gas => Human Presence	**70%**
Site maximum S-P-R Score					**70%**
Risk Classification					**Class A**

Table 5.2 shows the maximum S-P-R scoring for the site is **70%**.

The following are the risk classifications applied:

- Highest Risk (Class A) Greater than 70 for any individual SPR linkage;
- Moderate Risk (Class B) 41-69 for any individual SPR linkage;
- Lowest Risk (Class C) Less than 40 for any individual SPR linkage.

Based on this, the site can be classified as a **High Risk Classification (Class B)**. The principal risk identified on the site is the risk posed to the human presence from landfill gas migration. The site also poses a moderate risk to surface water and the underlying aquifer. Underlying aquifer from leachate migration and to human receptors from landfill gas migration.

6. CONCLUSION

A Tier 2 study was conducted by FT in accordance with the EPA CoP for Tuam Historic Landfill. The study consisted of a desktop study, geophysical survey and intrusive site investigation works. These works informed the development of the CSM and risk screening model.

The findings of the site investigation work and geophysical surveying suggest the waste material is deposited in a single infill area with the extent of the landfill is estimated at 23,300 m^2.

An estimated waste volume of 145,407.7 m^3 based on a combination of the topographical and geophysical surveys and borehole logs for installed in waste boreholes (BH1 - BH3) was determined.

Trial pitting and site walkovers have confirmed the waste material is near the surface with a minimal topsoil and clay cover present across the site atop an installed geocomposite clay liner. Some wate also encountered at TP04 located adjacent to the civic amenity site. No GCL liner was present at this location.

Analysis of groundwater samples recovered from 8 No. monitoring wells have reported ammoniacal nitrogen concentrations which exceed threshold values for all 3 rounds of monitoring in 2020 and 2022. Ammoniacal nitrogen concentration at upgradient boreholes could be considered representative of background levels possibly due to agricultural activities, or the presence of peat in the area. However, considering the slightly higher ammonia concentration recorded downgradient, the historic landfill could be impacting water quality. Recent and historical groundwater monitoring does indicate that leachate migration is impacting groundwater quality immediately downgradient of the site however this impact has not been observed further from the site at monitoring locations further downgradient. The impact on groundwater quality is therefore likely to be localised.

Landfill gas monitoring in 2020 from 11 No. perimeter boreholes and in 2022 from the civic amenity (CA) monitoring well indicate gas concentrations detected are generally below threshold levels set by the EPA CoP. Despite low gas concentrations measured at the wells, due to the proximity of the CA site to the landfill and the potential for the CA site to be underlain by waste material high risk scores of 70% have been calculated for SPR10 and SPR11. The pathway between the waste body and the on and offsite building receptors will require further investigation to verify the risk, if any, to these receptors.

Analysis of surface water samples from the River Killeelaun and River Clare found several exceedances to the MAC and EQS guideline limit values in 2020. The presence of elevated dissolved metal concentrations such as Chromium and Nickel in downstream samples which weren't recorded in upstream samples indicates potential leaching of metals from landfill and migration to the receiving drainage network and stream. The additional round of monitoring undertaken in 2022 show one exceedance downstream of the site for the EQS threshold values for Ammoniacal Nitrogen, which could be an indicative of leachate migration from the landfill to surface water.

Based on this, the site can be classified as a **High-Risk Classification (Class A)**. The principal risk identified on the site is the risk posed to the human presence from landfill gas migration. The site also poses a moderate risk to surface water and the underlying aquifer.

6.1 Recommendations

Based on the results of the initial Tier 2 assessment the site is classified as High-risk. For a high risk site, the CoP indicates that a Tier 3 Environmental risk analysis be undertaken including a Quantitative Risk Assessment (QRA) either as a Detailed Quantitative Risk Assessment (DQRA) or Generic Quantitative Risk Assessment (GQRA). The purpose of the QRA will be to quantitatively assess the primary S-P-R linkage identified i.e. landfill gas migration to nearby human receptors, leachate migration to the underlying aquifer and leachate migration to surface water receptors.

It is therefore recommended by FT that a Tier 3 QRA be undertaken for the site in conjunction with an application for a Certificate of Authorisation for this site.

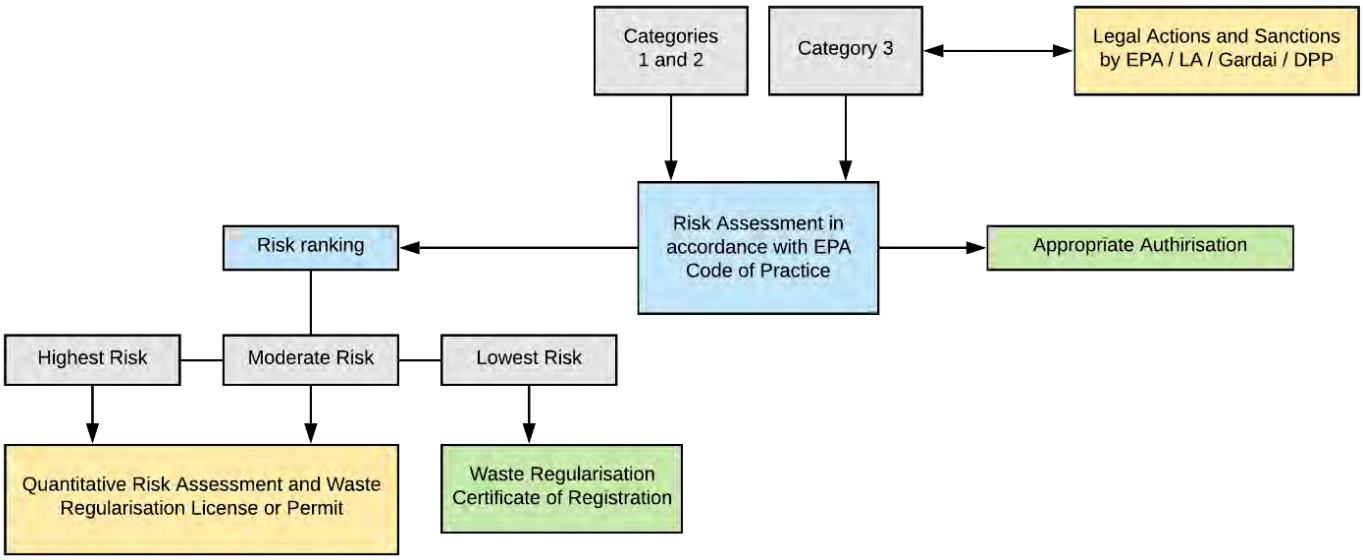

Figure 6-1: Extract from Section 1.3 of the EPA Code of Practice