TULLYVOGHEEN HISTORIC LANDFILL

TULLYVOGHEEN,

CLIFDEN, CO. GALWAY

APPLICATION TO EPA

FOR

CERTIFICATE OF AUTHORISATION

VOLUME II. SECTION D - PART A

TIER 2 SITE INVESTIGATION & TIER 3 GQRA ASSESSMENT OF TULLYVOGHEEN LANDFILL REPORT

29TH JUNE, 2020

TIER 2 SITE INVESTIGATION &

TIER 3 GENERIC QUANTITATIVE RISK ASSESSMENT

OF

FORMER TULLYVOGHEEN LANDFILL

VOLUME I - REPORT

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AUTHOR	David Gilfedder	David Gilfedder	12/06/14
PROJECT MANAGER	Padraic Mulroy	Padraic Mulroy	09/07/14
CLIENT	Tom Dunworth, Galway C.C.		

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1 INTRODUCTION

1.1 Project Background

Following a meeting on the 18th March, 2013 with Tony McInerney, Senior Engineer and Tom Dunworth, Senior Executive Technician Galway County Council, Mulroy Environmental were instructed to prepare a fee proposal for a Tier 2 Site Investigation and follow up Tier 3 Generic Quantitative Risk Assessment (GQRA) and if necessary a Detailed Quantitative Risk Assessment (DQRA) Assessment of Tullyvogheen Landfill, Clifden, County Galway (see Plate 1 below). This report and the field works carried out in connection with the report (together the "Services") were compiled and carried out for Galway County Council (the "client") in accordance with the terms of a contract, Proposal PRP213.05.04.2013, between Mulroy Environmental and the "client" dated 5th April 2013.

1.2 General Setting

The site is approximately 2 km east of the town centre of Clifden and is located on a narrow country road that leads uphill approximately 660m from the Clifden to Galway Secondary Road (the N59) which runs west to east (see Figures 1 and 2). At a distance of approximately 600m from the N59 the country road turns eastwards. Where the site is located, this country road has been constructed at the edge of a valley between a small mountain to the south and a large hill to the north. The valley is orientated in an approximate west to east direction. The landfill to the south of the country road consists of a substantial infill operation where the valley was raised approximately 3.5m on the eastern side of the site and approximately 7-8m on the western side of the site.

The landfill is located between a small mountain, Cooravoughil Mountain to the south and a number of large hills to the north in an area where the valley widens out into upland bog. A mountain lake, Lough Nambrackeagh, is located 350m to the northwest of the site. Clifden derives its water supply primarily from Lough Nambrackeagh. A small stream discharges from this lake and joins a larger stream which flows in a north to south direction along the country road leading to the landfill. This stream appears to originate from a small lake, Lough Cashleen located approximately 650m to the east of the site. This stream which runs in an east to west direction through the valley is culverted through the landfill before continuing in a south-westerly direction alongside the country road for a distance, then heading south-westwards and eventually joining the Owenglen River 735m to the south of the site (see Plate 1 following).

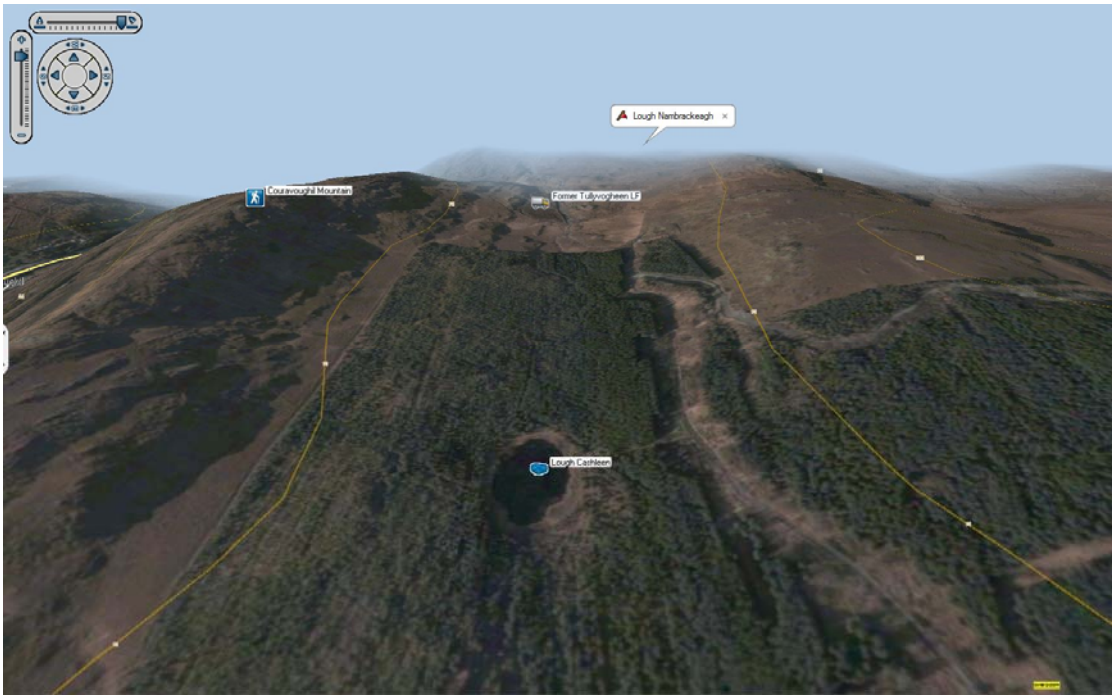


Plate 1. View of valley facing westwards showing Lough Cashleen in foreground in coniferous forest, Couravoughil Mountain to south of former landfill with Lough Nambrackeagh to northwest of site

The site is located in a rural and remote area and as a result there are very few properties located within its immediate vicinity (see Figure 3). No residential or commercial properties are located on the landfill site boundaries. The nearest inhabited residence is located 415m 'as the crow flies' southwest of the site along the country road that leads to the N59 (i.e. the main Clifden to Galway Road) which is located approximately 630m south of the site. Four residences exist along the northern side of the N59 road to the southwest, a distance of 620m from the site. *Cuirt Cregg*, a medium sized housing estate, is located further to the west along the N59 road, with the nearest property in the estate located 630m 'as the crow flies' from the site, as shown on Figure 3. Figure 3 also shows a Galway County Council compound containing a pumping station and an ESB substation located adjacent to the N69 at the bottom of the access road, 610m from the site.

According to Galway C.C., the former municipal landfill at Tullyvogheen, Clifden, County Galway, was in operation between the years of 1984 and 1999. During this period it is estimated by Galway County Council that approximately 23,000 tonnes of mixed waste including domestic, commercial and construction & demolition (i.e. C & D) waste per annum was deposited annually (see Plate 2 below). The site area is 1.27 hectares (ha) and the total waste body is estimated at 114,000m^3 or 205,000 tonnes.

Plate 2. View of former Tullyvogheen Landfill from west of site entrance facing southeast

The site is currently used as a road depot by Galway County Council roads department with a 10,000l aboveground storage tank (AST) used for the storage of road bitumen (see Figure 4). It is understood that the bitumen, prior to use and transfer into the road maintenance vehicle, is heated by an in-built heater powered by gas provided by an on-site LPG tank (see Plate 3 following).

Plate 3. View of 10,000l aboveground storage tank used for the storage of road bitumen

The site is also used by Galway Fire Brigade for fire drills. A hardcore-covered area to the southeast of the entrance has been dedicated for this purpose. This area is bordered by 1.5 metre high earthen berms to the north and east which separate it from the landfill (see Figures 4 and 5). Two 40-foot and a 20-foot truck container are used in the *'Fire Drill Area'* for the ongoing training of Galway Fire Brigade staff (see Plate 3). Another 20-foot container located in the north-western corner of the Fire Drill Area is used for the storage of fire-fighting equipment.

Plate 4. View of Galway Fire Brigade *'Fire Dill Area'* to east of road depot area facing south

1.3 Guidance Background & Preliminary Risk Assessment

Mulroy Environmental have reviewed the following Tier 1 report (see Appendix 1):

- Tier 1 Study/Tier 2 Indicative Work Programme and Costing, Comhairle Chontae na Gaillimhe, Tullyvogheen Landfill, Clifden, County Galway, 16th June, 2010.

The above Tier 1 Risk Assessment/Tier 2 Indicative Work Programme and Costing, as defined by Chapter 4 of the *EPA Code of Practice, Environmental Risk Assessment for Unregulated Waste Disposal Sites, 2007*, was carried out by Galway County Council on the site. It should also be noted that an 'in-house' Tier 1 Risk Assessment was also carried out by Mulroy Environmental. The results of this are summarised in Table A1.1 which summarises the results of *'S-P-R Linkage Prioritisation'* on the former landfill. The detailed rationale behind the in-house risk assessment is also given in Appendix 1.

As can be seen from Table A1.1 in Appendix 1, the highest individual linkage proved to be for *'Leachate to SW*' at 70%. It should be noted that if the score is *'Greater than or equal to 70% for any individual SPR linkage'*, the Highest Risk (Class A) applies. It should also be noted that when each Local Authority carries out a Tier 1 Risk Assessment during their inventory of historic waste sites within their boundaries, typically a Highest Risk (Class A) is regarded as requiring a medium density Tier 2 Environmental Risk Assessment (i.e. Phase II Intrusive Site Investigation) with Generic Quantitative Risk Assessment.

Chapter 5 of EPA Code of Practice, Environmental Risk Assessment for Unregulated Waste Disposal Sites, 2007 deals with the Tier 2 Site Investigation and Testing process and reporting requirements. The scope of works was drawn up following a review of all pollutant linkages identified within the Tier 1

report. In this case, particular attention was given to the '*Leachate to SW*' linkage which was 70% of the maximum score.

Chapter 6 of EPA Code of Practice, Environmental Risk Assessment for Unregulated Waste Disposal Sites, 2007 deals with the Tier 3 process. There are two basic types of quantitative risk assessments: Generic Quantitative Risk Assessment, which uses relevant generic assessment criteria (GAC) (i.e. values which are generally applicable to an entire class or group e.g. based on proposed future land use) or guidelines, and Detailed Quantitative Risk Assessment which uses site-specific assessment criteria using RA tools and models. The decision on which type of QRA should be used is site specific and is dependent on the sensitivity of the site and also on confidence in the available data. In any case the quantitative risk assessment should be detailed enough to allow remedial measures to be proposed with certainty of a successful outcome. The assumptions made should always be clearly defined.

Prior to applying either a generic QRA or a detailed QRA, the site-specific information, on the leachate concentrations, surface water and groundwater quality, as well as information on the levels of landfill gas being produced, must be known. The following site investigation works have been drawn up to provide that information.

1.4 Site History

It is understood from the Tier 1 report that according to Galway C.C., the former municipal landfill at Tullyvogheen, Clifden, County Galway, was in operation between the years of 1984 and 1999. As stated previously, during this period it is estimated by Galway County Council that approximately 23,000 tonnes of mixed waste including domestic, commercial and construction & demolition (i.e. C & D) waste per annum was deposited annually. The site area is 1.27 hectares (ha) and the total waste body is estimated at 114,000m^3 or 205,000 tonnes.

2 OBJECTIVE

The objectives of the risk assessment are as follows:

- To evaluate potential liabilities associated with historic and/or current uses of the site, and their impact on soil and groundwater quality;
- To evaluate potential liabilities associated with historic and/or current uses of the site, and their impact on surface water quality (i.e. Owenglen River which is also a Special Area of Conservation);
- To evaluate potential liabilities associated with historic and/or current uses of the site on off-site residences and their residents; and
- If required, to make recommendations on the remediation of the site or mitigation measures to remove the afore-mentioned risks.

3 SCOPE OF WORKS

Field and laboratory results of geological, hydrogeological and environmental information were collated and interpreted with a view to evaluating potential environmental liabilities associated with soil/groundwater quality.

Risk Assessment

A risk assessment was undertaken to provide a basis for decision making, to ensure there would be no impact on the residence to the southwest of the site and to ensure that there will be no adverse impact to the environment particularly the Owenglen River, which is also a Special Area of Conservation, to the east of the site. A risk assessment is defined as a process of establishing, to the extent possible, the existence, nature and significance of risk. Risk is defined as the probability of the occurrence of, and magnitude of the consequences of, and unwanted adverse effect to a receptor.

There are 4(no.) stages involved in a risk assessment:

1. *Hazard Identification* – This will involve identifying contaminants of concern and will be achieved through the intrusive site investigation programme and the soil and groundwater sampling regime.

2. *Hazard Assessment Stage* - This stage involves the development of a Conceptual Site Model. Conceptual Models are described below.

3. *Risk Estimation Stage* – A Quantitative Risk Assessment is undertaken as part of this stage to determine risks to human health and the surface water and groundwater environments. The proposed Quantitative Risk Assessment for this contract is described in more detail below.

4. *Risk Evaluation Stage* – This stage involves recommendation of remedial works.

Conceptual Model

The risk to the surrounding environment will be assessed based on the geological and hydrogeological information gathered through the site investigation programme. This information can be used to develop a conceptual model of the underlying environment, in terms of identifying potential contaminants, pathways and sensitive receptors.

A conceptual model is defined as a textual and/or schematic hypothesis of the nature and sources of contamination, potential migration pathways (including description of the ground and groundwater) and potential receptors, developed on the basis of the information from the preliminary investigation and refined during subsequent phases of investigation. The development of a conceptual model is an essential basic component of the risk assessment process. The development of a conceptual model is an iterative process, which is progressively refined based on additional focused investigations.

The results of site investigations and the development of a conceptual model should define all known aspects of the site that could impinge upon or affect the overall environment. The conceptual model will be based on the hazard – pathway – receptor concept, where:

- A hazard represents the inherently dangerous quality of a substance, procedure or event;
- A pathway is a mechanism or route by which a contaminant comes in contact with, or otherwise affects, a receptor; and
- A receptor is a human being, living organism, ecological system, controlled water, atmosphere, structures and utilities that could be adversely affected by the hazard. Surface water channels and springs are also considered to be sensitive receptors as the groundwater environment may provide baseflow to these features.

Generic Quantitative Risk Assessment (GQRA) of Soils

As stated previously, a Generic Quantitative Risk Assessment uses relevant generic assessment criteria (GAC) (i.e. values which are generally applicable to an entire class or group e.g. based on proposed future land use) or guidelines. For this purpose Mulroy Environmental propose to use the following GAC for soils:

- UK Department of Environment, Food and Rural Affairs (DEFRA) - Contaminated Land Exposure Assessment (CLEA) Model – Soil Guideline Values, 2009 - Residential with plant, Allotment and Industrial/Commercial for sandy loam soil and 6% soil organic matter (SOM) (i.e. 12 SGVs published); [1]

[1] The Contaminated Land Exposure Assessment (CLEA) Model is used to quantify the risk to the environment. CLEA is a risk-based computer model developed by the UK Department of Environment, Food and Rural Affairs (DEFRA) to aid in the determination the suitability of contaminated land sites for redevelopment/remediation. Instead of applying a set limit or standard to any one parameter, which may deem a site contaminated or unsuitable, the CLEA model takes contaminant and environmental factors into account to determine a site-specific risk. The risk of human health being affected by living or working on a site with contaminated soil would be dramatically lower in an urban setting such as an apartment surrounded by hard standing versus a house with a back garden, where children play and interact with the soil. The CLEA model takes such a risked based approach by modelling the possible effects of a number of key contaminants. Guideline values produced by the model indicate a level below which the site is considered safe. Above the guideline value, further investigation is required. Thus the CLEA guidelines provide an objective basis for decision-making, based on an assessment of risk to human health. A number of Soil Guideline Values (SGVs) have been calculated by DEFRA and have been published in an 'SGV series' of documents

- LQM/CIEH Generic Assessment Criteria for Human Health Risk Assessment, 2nd Edition, 2011 – Residential Land-use, Allotment Land-use and Commercial Land-Use at 6% Soil Organic Matter (i.e. 82 SGVs published); [2]
- National Institute of Public Health and the Environment of The Netherlands - The Soil Protection Guidelines (Dutch Criteria) – Intervention and Target Values; [3] and
- Waste Acceptance Criteria at Murphy Environmental Waste Facility (WA 129-02|) in Hollywood, Co. Dublin – Hazardous Waste Limit.[4]

Generic Quantitative Risk Assessment (GQRA) of Groundwater and Leachate

The results of the groundwater analysis were compared to the Maximum Allowable Concentration (MAC) values of Statutory Instrument No. 81 (Quality of Water Intended for Human Consumption) of 1998 and the Parametric Values of Statutory Instrument No. 439 (Drinking Water Regulations) of 2000. The results of the groundwater analysis were also compared to the EPA Interim Guideline Values (IGVs) from *Towards Setting Guideline Values for The Protection of Groundwater In Ireland – Interim Report* and the Threshold Values from Statutory Instrument No. 9, European Communities Environmental Objectives (Groundwater) Regulations, 2010.

Generic Quantitative Risk Assessment (GQRA) of Surface Water

The results of the surface water analysis were compared to:

- S.I. No. 294,European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989;
- S.I. No. 278, European Communities Environmental Objectives (Drinking Water) (No. 2) Regulations, 2007; and
- S.I. No. 272, European Communities Environmental Objectives (Surface Water) Regulations, 2009.

[2] A joint workshop was held by the Land Quality Management Ltd. and the Chartered Institute of Environmental Health in 2009. This workshop used CLEA Model 1.04 to derive SGVs for 82 organic and inorganic common contaminants.

[3] When dealing with the Due Diligence Site Assessment of brownfield sites in Ireland a set of guidelines called the Soil Protection Guidelines, produced by National Institute of Public Health and the Environment of The Netherlands is generally used. The treatment of polluted soil and groundwater depends on the nature and the concentrations of the polluted substances present in it. The Soil Protection Guidelines used in The Netherlands is built on two values. These values, consisting of different ascending levels of concentration TV and IV are differentiated according to the nature of the pollution:

- Level TV is the target value. Pollutants above the TV level should be investigated more thoroughly. The question asked is: to what extent is the nature, location, and concentration of the pollutants of such a nature that it is possible to speak of a risk of exposure to man or the environment? ; and
- Level IV is the intervention value above which the pollutants should generally be treated. In order to assess the risk of any contaminants contained in the overburden on site as a result of historical practices, the results of the soils analysis are compared to the above levels with particular regard paid to Level IV.

[4] The results of the soils analysis are compared to the values taken from Section A4 'Limit values for pollutant content for inert waste landfills' of Schedule A from the Waste Licence, WA 129-1 for the Murphy Environmental Inert Landfill at Gormanstown, County Dublin (see Appendix 3). These include the 'Total Pollutant Content' limits and the 'L/S = 10 l/kg Limits'. The purpose of comparison with these limits is to determine if an inert landfill such as thee landfill operated by Murphy Environmental would be capable of accepting contaminated soil from the site.

4 ENVIRONMENTAL SETTING

4.1 Introduction

This section describes the site's environmental setting including the site's background (Section 4.2), topography and hydrology (Section 4.3), soil (Section 4.4), geology (Section 4.5) and hydrogeology (Section 4.6) of the area.

4.2 Site Background

As stated in the introduction, the site is located in a remote area. The site is approximately 2 km east of the town centre of Clifden. The site is located on a narrow country road that leads uphill approximately 660m from the Clifden to Galway Secondary Road (the N59) (see Figures 1 and 2). At a distance of approximately 600m from the N59 the country road turns eastwards (see Plate 5 below).

Plate 5. View of country road facing northeast showing nearest residence in foreground, Couravoghil Mountain to south of former landfill with Lough Nambrackeagh to northwest of site

Where the site is located, this country road has been constructed at the edge of a valley between a small mountain, Couravoughil Mountain to the south and a number of hills to the north. The valley is orientated in an approximate west to east direction. The landfill to the south of the country road consists of a substantial infill operation where the valley was raised approximately 3.5m on the eastern side of the site and approximately 7-8m on the western side of the site.

The site area is 1.27 hectares (ha) and the total waste body is estimated by Galway C.C. at 114,000m^3 or 205,000 tonnes.

The site is currently used as a road depot by Galway County Council Roads Department with a 10,000l aboveground storage tank (AST) used for the storage of road bitumen. It is understood that the bitumen, prior to use and transfer into the road maintenance vehicle, is heated by an in-built heater powered by gas provided by an on-site LPG tank (see Plate 2 previous).

The site is also used by Galway Fire Brigade for fire drills. Two 40-foot and a 20-foot truck container are used on site for the ongoing training of Galway Fire Brigade staff (see Plate 3 previous). Another 20-foot container is used for firefighting equipment storage.

4.3 Topography

The existing site and its surrounding property is illustrated in Figures 2 and 3. The existing site layout with topographical data is illustrated in 2 figures, Figures 4 and 5. Figure 4 shows the topography of the western half of the site and Figure 5 shows the eastern half of the site.

The terrain in which the site is located is best described as 'Mountain heath' or highland blanket bog. The landfill is located in a glacial valley between Cooravoughil Mountain to the south and some large hills and an un-named mountain to the northeast. Both of these mountain are approximately 100m to 110m in elevation. The Shanakeever Mountains are located to the west and northwest of the site. The site is located where the valley widens out into upland bog.

The valley contains a stream flowing in an approximate east to west direction which rises from Lough Cashleen which is located approximately 690m to the east of the site in a Coillte Coniferous Forest Plantation (see Figures 3). This stream, which runs in an east to west direction through the valley, is culverted through the landfill before continuing in a south-westerly direction alongside the country road for a distance, then heading south-westwards, following the valley and eventually joining the Owenglen River 735m to the south of the site (see Figures 3 and 10).

A lowland lake, Lough Nambrackeagh, is located 350m to the northwest and hydraulically upgradient of the site (see Figures 2). Clifden derives its water supply primarily from Lough Nambrackeagh. A small stream discharges from this lake and joins the afore-mentioned stream approximately 95m to the west of the landfill.

Where the site is located, the country road has been constructed at the edge of a valley between Couravoughil Mountain to the south and an un-named mountain to the north. The valley is orientated in an approximate west to east direction. The landfill to the south of the country road consists of a substantial infill operation where the valley was raised approximately 3.5m on the eastern side of the site and approximately 7-8m on the western side of the site.

Towards the eastern end of the site, the site slopes towards the north-eastern corner of the site where surface water was found to pond at approximately 50.4mAOD. This side of the site appears to be approximately 3m above natural ground level to the east of the site.

The highest area within the site would appear to be near the northern boundary to the east of the site entrance at approximately 51.87mAOD.

Towards the western end of the site, the site slopes from the north-eastern corner of the site to the west and southwest. This side of the site appears to be approximately 6-7m above natural ground level to the west of the site which is at approximately 43mAOD.

4.4 Stormwater and Drainage Infrastructure

It is understood that a number of years after the infilling of waste at Tullyvogheen Landfill commenced, the stream which runs through the site was culverted. The stream is culverted 27m from the eastern boundary of the site (see Figure 10).

Plate 6. To east of site at country road facing southwards showing stream/storm access manhole and landfill to west (i.e. left)

In addition to receiving a 475mm ID concrete pipe from the stream to the west, it also received a 475mm ID concrete pipe from a culverted stream to the north of the site, a 300mm ID concrete pipe from a stream/land drain to the south and a 150mm ID concrete pipe from a land drain located just to the east of the landfill. A 900mm ID concrete pipe exits this manhole in a westerly direction. This pipe or appears to run the full length of the landfill (i.e. 260m) and exits to the west of the landfill (see Plate 7 following).

A land drain was observed on the south-eastern boundary of the site. This serves to remove ponded water from this area which results from run-off from Couravoughil Mountain to the south of the site. This land drain follows the southern and eastern boundaries where it discharges to the east feeding into the culverted stream manhole (see Figures 4 and 10).

Another land drain was observed on the south-western boundary of the site (see Figure 4). This also serves to remove ponded water from this area which results from run-off from Couravoughil Mountain to the south of the site. This land drain appears to discharge into the stream at a point immediately adjacent and to the south of the culvert discharge point (see Plate 7 below).

Plate 7. To west of site facing northeast showing culvert discharge point to west of landfill.

4.5 Soil

4.5.1 Soil (Top Horizon)

The formation of topsoil is known as the 'pedogenic' process. Reference to the General Soil Map of Ireland, published by An Foras Talúntais (1980) indicates that the predominant or principal soil type in the Tullyvogheen area is Soil Association No. 24, *Blanket Peat (Low Level)*.

A National Soil Mapping Project carried out jointly by the EPA and Teagasc have identified the footprint of the site as soil type *BktPt, Blanket Peat* for approximately 70% of the eastern side of the site and *AMinSRPT, Podzols Peat* the remainder of the site to the west.

The parent material for these soils are most likely the underlying granite and sandstone and shallow glacial till (i.e. quartzite in places) (see Appendix 3).

Based on Mulroy Environmental's site-specific observations during the trialpitting exercise, the general classification for the area is considered appropriate for the site.

4.5.2 Subsoil (Quaternary) Geology

The origin of the subsoil material in this region is associated with the movement and deposition from glaciers during the last Ice Age. The ice sheets ground down the underlying bedrock, breaking the rock and grinding it to small sizes ranging from clays to boulders. The powerful erosive force of these ice sheets are considered to have moulded/sculpted the landscape in the area, with glacial features evident in the area. Glacial deposits in the area consist of tills, which were deposited at the base of moving glaciers, and to a lesser extent fluvio-glacial sand and gravels, which were deposited by glacial meltwaters.

The National Soil Mapping Project carried out jointly by the EPA and Teagasc have identified the footprint of the site as subsoil type *Rck – Bedrock at surface* to the west of the site and *BktPt, Blanket Peat* on the eastern end of the site (see Appendix 3). This is based on the most up to date mapping set. The soil classifications nearest to the site are Till derived chiefly from Metamorphic Rock (TMp) approximately 400m to the southeast of the site.

Based on Mulroy Environmental's site-specific observations during the trialpitting exercise, the general classification for the area is considered appropriate for the site.

4.6 Geology

4.6.1 Regional Geology

General information concerning the bedrock geology of the region is contained in the Geological Survey of Ireland (GSI) 1:100,000 scale Sheet No. 10 "Geology of Connemara and South Mayo" (see Appendix 4). The Clifden area is composed primarily of Precambrian Quartzites, Gneisses & Schists, Ordovician Metasediments and Silurian Metasediments and Volcanics. Precambrian Marbles cross cut the southern half of the Clifden area in two areas, at Clifden and Letterfrack. The bedrock map indicates that the Streamstown Schist Formation (ST) underlies the site. This formation consists of Pre-cambrian quartzite, gneisses and schists. Approximately 50m to the south of the site the Bennabeola Quartzite Formation (BX) is located. Approximately 200m to the south of the site, the Barnanoraun Schist Formation (BZ) is located. This formation consists of aluminous schists and hornblendic rocks. It contains a pale grey dolomite-bearing marble at the top of the sequence and faserkiesel schists.

A review of GSI geological records within 2km of the site revealed only 1 borehole record. This record which contains a map location is presented in Appendix 4. This borehole is a bored well approximately 1.65km to the west of the site. A total depth of 35m is given with bedrock ground level. A poor yield class (i.e. 21.8m^3) was given. This yield would be expected for a poor aquifer such as that with the Streamstown Schist Formation.

A review of 6-inch mapping and Galway C.C. planning files indicates the presence of a well to the north of a residence 400m southwest of the site. No information is available on this site. It is doubtful whether this well is used as potable water as the planning files indicate that the residence is on public water mains. However, this well may be used for the use of livestock by the residents who are sheep farmers in the area.

4.6.2 Site Geology

4.6.2.1 Subsoil/Made Ground

Twenty two trial pits were dug by Mulroy Environmental from 15th to 16th January, 2014.

Varying depths of a topsoil layer or landfill cap of soft dark brown gravelly sandy silty PEAT was found on all 22 trialpits.

Trial pit depths varied between 1.25m and 4.9m below the ground level (i.e. depending on bedrock and maximum reach of the excavator) (see trialpit logs, TP1 to TP22 in Appendix 7). All trialpits were dug in areas where waste was deposited or where the ground was disturbed previously.

No waste was found in trialpits, TP4 and TP8 which are located on the south-eastern boundary of the site. MADE GROUND consisting of boulders and/or gravel was found in this area to sit directly on top of weathered bedrock which was 1.25m to 1.5m below ground level. This material was most likely deposited in this area as part of the capping works.

A horizon of clayey PEAT was observed beneath the waste in trialpits, TP12 and TP01 at 1.25m to 1.5m and 3.45m to 3.5m below ground level. This was observed to sit directly over weathered bedrock and field evidence indicated that it was undisturbed and indigenous.

A horizon of coarse light green/grey sandy clayey GRAVEL was observed from 1.0 to 1.25m bgl in TP08 and from 1.95 to 2.1m bgl in TP17. This was also observed to sit directly over weathered bedrock and field evidence indicated that it was undisturbed and indigenous.

Bedrock was also encountered in TP11, TP17, TP19 and T22 at 3.04m, 2.1m, 2.15m and 3.2m below ground level. Bedrock was either not encountered in the other 16 trialpits or, the excavation had to be abandoned due to collapsing sides and/or inundation with water.

A mixture of domestic, commercial and construction and demolition WASTE was found in 20 of the 22 trialpits. This waste was found to be dominated by typical domestic black plastic bin bag waste (i.e. approx. 80%) with lesser amounts of construction and demolition (C & D) WASTE (i.e. approx. 10% skip waste consisting of typical residential renovation waste e.g. electric cables, timber shards, etc) and commercial waste (i.e. approx. 10%).

It should be noted that only low to moderate 'domestic waste-type odours' were observed at each of the 20 trialpits. The waste, although exhibiting sulphur staining and slight sulphide odours, gave no evidence of putrescible materials (i.e. a carbon source) still remaining within the waste. As such, it was concluded that the methanogenesis phase within the waste body had either had concluded completely or had decreased to a point where it was no longer a risk to the site. This is consistent with the age of the waste i.e. 15-30 years old.

4.6.2.2 On-site Bedrock

Three groundwater monitoring 50mm diameter boreholes, BH01, BH02 and BH03 and 2 leachate wells, LW01 and LW02 were drilled on site by track-mounted air rotary ODEX technique by J.S. Drilling Ltd. under the supervision of Mulroy Environmental personnel in January, 2014 (see Figure 7). Borehole logs to BS5930 standard, were drawn up for each location (i.e. BH1 to BH3 and LC1 and LC2) and are located in Appendix 8.

It should be noted that the 'air rotary ODEX' technique destroys the spoil as drill cuttings and as such, it cannot be relied on to give an assessment of the absence/presence of waste. However, given the close proximity of the trialpits excavated during the previous week, it is reasonable to infer the depth of waste from on-site observations and where rock was definitively encountered.

Each of the 3 groundwater monitoring boreholes were drilled into bedrock in order to access the underlying bedrock aquifer and to provide adequate levels of groundwater during the driest months of the year i.e. July and August. The drilling for both leachate wells, LC1 and LC2 was halted on encountering bedrock as landfill leachate typically 'ponds' on the top of waste/soil/weathered bedrock interface.

Bedrock was observed in BH1, BH2 and BH3 at 6.4m, 3.0m and 8.6m bgl respectively. The drill cuttings indicated that the bedrock was consistent with regional geological mapping for the area i.e. Streamstown Schist Formation.

Bedrock was observed in LC1 and LC2 at 6.1m and 9.0m bgl respectively.

Two cross-sections, A-A' and B-B' of the site were prepared using the findings of the trialpitting and borehole drilling exercise and these are represented on Figures 8 and 9 respectively. The locations of the Sections A-A' and B-B' are indicated on Figure 7. Figure 7 also illustrates the location of each of the 3 boreholes and 2 leachate monitoring wells.

Section A-A' does not indicate that bedrock slopes in an east to west direction. Section B-B'

4.7 Hydrogeology

4.7.1 General Hydrogeological Classification

As stated in Section 4.6, the bedrock map indicates that Streamstown Schist Formation (ST) underlies the site. This formation consists of Pre-cambrian quartzite, gneisses and schists. This is classed as a *'Pl - Poor Aquifer - Bedrock which is generally unproductive except for local zones.'*

As stated previously, a review of GSI geological records within 2 km of the site revealed only 1 borehole record. This record, which contains a map location, is presented in Appendix 4. This borehole is a bored well approximately 1.65km to the west of the site. A total depth of 35m is given with bedrock at the surface. A poor yield class (i.e. 21.8m^3) was given. This yield would be expected for a poor aquifer such as that with the Streamstown Schist Formation.

The site is located with the Clifden-Castlebar Groundwater Body (see Appendix 5). This GWB is composed primarily of Precambrian Quartzites, Gneisses & Schists, Ordovician Metasediments and Silurian Metasediments and Volcanics. Most groundwater flux will be in the uppermost part of the aquifer; comprising a broken and weathered zone typically less than 3m thick; a zone of interconnected fissuring 10-15 m thick; and a zone of isolated poorly connected fissuring typically less than 150m, in which strikes are noted between 40-50 m and 50-56 m below ground level in two boreholes near Louisburgh, but yields are from these isolated depths are low.

Well data are sparse in the GWB. Three boreholes located in the schists north of Clifden, at Glenbricken and Coolacloy, have reported yields of 33, 26 and 15 m^3/d with specific capacities of 15, 1.3 and 0.6 $m^3/d/m$ respectively. The data indicate low transmissivities – in the range of 0.7-20 m^2/d. Two wells near Louisburgh also have similar yields and implied transmissivities. In the vicinity of faults, transmissivity may be higher. Storativity is expected to be low (<0.5%). The data are inadequate to calculate groundwater gradients, however, these are expected to be greater than 0.01.

Subsoil thickness data are also sparse. Available data indicate the thickness of the subsoils is generally less than 3m over the GWB. Subsoils are thicker in the low lying flatter areas of the GWB. The thickness of the blanket peat ranges from 0-6 m, depending on topography.

Diffuse recharge occurs via rainfall percolating through the subsoil and rock outcrops. Due to the low permeability of much of the subsoil (blanket peat) and the aquifers, a high proportion of the available recharge will discharge to the streams. In addition, the steep slopes in the mountainous areas promote surface runoff. The stream density is approximately 1.5 km/km^2, indicating the high proportion of surface runoff.

The GSI have defined a Groundwater Protection Scheme for County Galway which makes recommendations for restrictions to land use within Source Protection Zones based on the vulnerability of the groundwater aquifers to contamination.

4.7.2 Groundwater Flow

Groundwater flow is most likely through the underlying overburden which consists of metamorphic tills and gravels and to a lesser extent through the underlying schist or marble bedrock. Groundwater follows the topography of the site and land to the south towards Clifden Bay. Probable groundwater flow direction is indicated on Figure 11. Groundwater flow is expected to be concentrated in fractured and weathered zones and in the vicinity of fault zones.

Shallow groundwater is likely to discharge to streams and lakes, but the limited bedrock transmissivity means that the baseflow component of the total streamflow will be low. Small springs and seeps are likely to issue at the stream heads and along their course. Seepages will develop on the coastal cliff faces.

Groundwater flow is expected to be concentrated in fractured and weathered zones and in the vicinity of fault zones. Generally, water levels are 0-8 m below ground level. Flow paths are likely to be short (30-300m) with groundwater discharging rapidly to nearby streams and small springs. There are observed deep water strikes, indicating that there is a component of deep groundwater flow, however shallow groundwater flow is dominant. Groundwater flow directions are expected to follow topography – overall in a westerly direction.

Groundwater will discharge locally to streams and rivers crossing the aquifer and also to small springs and seeps. Owing to the poor productivity of the aquifers in this body it is unlikely that any major groundwater - surface water interactions occur. Baseflow to rivers and streams is likely to be relatively low. Lakes comprise approximately 3% of the GWB.

4.7.3 Groundwater Vulnerability

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.

The DoE-LG, EPA and GSI have produced guidelines on groundwater vulnerability mapping that aim to represent the intrinsic geological and hydrogeological characteristics that determine how easily groundwater may be contaminated by human activities. Vulnerability depends on the quantity of contaminants that can reach the groundwater, the time taken by water to infiltrate to the water table and the attenuating capacity of the geological deposits through which the water travels. These factors are controlled by the types of subsoils that overlie the groundwater, the way in which the contaminants recharge the geological deposits (whether point or diffuse) and the unsaturated thickness of geological deposits from the point of contaminant discharge.

For vulnerability assessments with regard to bedrock aquifers the relevant geological layer is the subsoil between the release point of contaminants and the top of the bedrock. Any unsaturated bedrock layer is not considered as it is assumed that bedrock has little or no attenuation capacity due to its fissure flow characteristics. Groundwater encountered in low permeability glacial tills, or other non-aquifer subsoils, is not considered to be a target. Therefore, where low permeability subsoils overlie the bedrock it is the thickness of subsoil between the release point of contaminants and bedrock that is considered when assessing vulnerability of bedrock aquifers, regardless of whether the low permeability materials are saturated or not.

The DoE-LG, EPA and GSI vulnerability mapping guidelines allow for the assignment of vulnerability ratings from "extreme" to "low", depending upon the subsoil type and thickness. With regard to sites where both low and high permeability subsoils are present, the following thicknesses of unsaturated zone are specified:

Table 1. Groundwater Vulnerability Mapping Guidelines

VULNERABILITY RATING	HIGH PERMEABILITY (SAND/GRAVEL)	MODERATE PERMEABILITY (SANDY TILL, SUBSOIL)	LOW PERMEABILITY (CLAYEY SUBSOIL, CLAY, PEAT)
Extreme	0 – 3.0m	0-3.0 m	0 – 3.0m
High	>3.0m	3.0-10.0m	3.0 – 5.0m
Moderate	N/A	>10m	5.0 – 10.0m
Low	N/A	N/A	>10.0m

Groundwater Source Protection

The DoE-LG, EPA and GSI guidelines for Groundwater Protection Schemes allow for the combination of aquifer classification and vulnerability rating giving classifications of groundwater protection zones. The purpose of these zones is to place a control on the activities practised within a zone and thus provide protection to any underlying groundwater resources. Using DoE-LG, EPA and GSI criteria and the aquifer classification and vulnerability categories defined for the site, a Pl/X (*'X- Rock near surface')* or Pl/E (*'Extreme'*) could be assigned for the site. However, given the relative footprint of each areas, a Poor Aquifer with Extreme vulnerability classification is more likely to be assigned to the entire subject site. It should be noted that the *'X- Rock near surface'* or *'Extreme'* vulnerability classification given by the GSI is based on the perceived lack of overburden and the presence of blanket peat on site (see Appendix 5).

It should also be noted that the a study carried out by the Western River Basin Management Body under the Water Framework Directive in 2008 has classed the 'Clifden-Castlebar' Groundwater Body, in which the site is located as *'2a – Probably Not at Risk'.*

The full water framework directive hydrogeological risk assessment report for the 'Clifden-Castlebar' Surface Groundwater Body is located in Appendix 5.

4.8 Hydrology

The site is located in the periphery of Owenglen-Dauros-Culin-Traheen-Coastal Catchment and is part of Hydrometric Area 32/Erriff Clew Bay of the Western River Basin District. Its Water Management Unit is West Galway.

It is understood that a number of years after the infilling of waste at Tullyvogheen Landfill commenced, the stream which runs through the site was culverted. The stream is culverted approximately 27m to the east of the site. This stream appears to originate from a small lake, Lough Cashleen located approximately 650m to the east of the site. This stream appears to run the full length of the landfill (i.e. 260m) and exits to the west of the landfill before continuing in a south-westerly direction alongside the country road for a distance, then heading south-westwards and eventually joining the Owenglen River 735m to the south of the site.

A mountain lake, Lough Nambrackeagh, is located 350m to the northwest of the site. Clifden derives its water supply primarily from Lough Nambrackeagh. A small stream discharges from this lake and joins the above-mentioned larger stream which flows in a north to south direction along the country road.

A review of flooding archives indicates that no flood events have occurred in the vicinity of the site.

In addition it should be noted that areas prone to flooding are typically noted in historical mapping. A review of all major editions of ordnance survey mapping for the Tullyvogheen area indicates that no evidence of flooding exists.

A study carried out by the Western River Basin Management Body under the Water Framework Directive in 2008 has classed the *'Owenglen-Dauros-Culin-Traheen-Coastal Catchment'* Surface Water Body, in which the site is located as *'1a – At Risk'* (see Appendix 6).

The EPA have carried out biological monitoring upgradient and downgradient of the junction at which the above-mentioned stream joins the Owenglen River. A biological quality value (Q-Rating) of 5 or 'High' status has been given by the EPA for the upgradient point and a biological quality value (Q-Rating) of 4 or 'Good' status has been given for the downgradient location which is adjacent to the bridge in Clifden town (see Appendix 6 for EPA monitoring point locations). No detailed historical data on the Q-status of the river at the point was obtainable from the EPA website

5 ENVIRONMENTAL SOILS RESULTS

Four soil samples were collected at 4 of the 22 trial pitting locations: TP03, TP12, TP17 and TP19. Each of these soil samples were taken from PEAT or GRAVEL indigenous horizons identified during the site investigation as lying under domestic waste and as undisturbed. The purpose behind analysing these 4 samples was to identify the extent of vertical migration (i.e. penetration) of leachate contaminants where soil was found beneath the waste.

The samples were taken from the waste body directly from the excavator bucket to avoid cross-contamination with the overlying domestic waste. The laboratory schedule for the soil samples was based on Schedule A of Waste Licence, WA 129-1 for the Murphy Environmental Inert Landfill at Gormanstown, County Dublin. This laboratory suite is consistent with the European Waste Directive Waste Acceptance Criteria specified by Council Directive 2003/33/EC. However, it was decided to analyse for Total Pollutant content first prior to analysing for leachate. If significant contaminants were identified within the soil samples, then CEN 2 Leachate testing would be carried out to assess the binding or cation exchange capacity of the soils underlying the waste on site.

This laboratory suite for soils was as follows:

- Total Petroleum Hydrocarbons – Core Working Group (CWG)[5];
- Polyaromatic Hydrocarbons (PAHs) (17 speciated) to include Coronene;
- Total Phenols;
- Polychlorinated Biphenyls (PCBs) - 7 congeners;
- Heavy Metals - As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se and Zn;
- Total Organic Carbon; and
- pH.

It should be noted that the above laboratory suite covers the Waste Acceptance Criteria which is in place within the Murphy Environmental waste facility (WA 129-02|) in Hollywood Great, The Nag's Head, The Naul, Co. Dublin.

The following table, Table 2 represents the results of the soils analyses. These results are compared against the following Generic Assessment Criteria:

- *UK Department of Environment, Food and Rural Affairs (DEFRA) - Contaminated Land Exposure Assessment (CLEA) Model* – Soil Guideline Values, 2009 - Residential with plant, Allotment and Industrial/Commercial for sandy loam soil and 6% soil organic matter (SOM);
- *LQM/CIEH Generic Assessment Criteria for Human Health Risk Assessment, 2nd Edition, 2011* – Residential Land-use, Allotment Land-use and Commercial Land-Use at 6% Soil Organic Matter*;*
- *EIC/AGS/CL:AIRE Soil Generic Assessment Criteria for Human Health, 2010;*

[5] *The TPHCWG approach defines petroleum hydrocarbon transport fractions by equivalent carbon number grouped into 13 fractions. The "analytical fractions" are then set to match these transport fractions, using specific n-alkanes to mark the analytical results for aliphatics and selected aromatics to delineate hydrocarbons containing benzene rings.*

- *UK Department of Environment, Food and Rural Affairs (DEFRA) - Contaminated Land Exposure Assessment (CLEA) Model* –Soil Guideline Values, Pre-2008 - Residential with plant and Industrial/Commercial for sandy loam soil and 6% soil organic matter (SOM);
- *National Institute of Public Health and the Environment of The Netherlands - The Soil Protection Guidelines (Dutch Criteria)* – Intervention and Target Values; and
- Waste Acceptance Criteria at Murphy Environmental Waste Facility (WA 129-02|) in Hollywood, Co. Dublin.

It should be noted that where exceedances were found of the above Dutch Criteria 'Target Values' the values are underlined. Where exceedances were found for all other criteria the values are highlighted in yellow and in bold. The data in the attached tables is assessed in the following 2 sections by chemical subgrouping.

Given that significant levels of contaminants were not found within the soil samples it was decided not to submit samples for leachate preparation and subsequent analysis.

5.1 Total Petroleum Hydrocarbons – Core Working Group (CWG)

As can be seen from Table 2, no petroleum hydrocarbons were found in the 4 soil samples taken (i.e. levels were below the Method Detection Limit). These results correspond with observations in the field while sampling.

5.2 Polyaromatic Hydrocarbons (17 speciated including Coronene)

As can be seen from Table 2, of the 17 PAH compounds analysed, none were found in the 4 soil samples taken (i.e. levels were below the Method Detection Limit). These results correspond with observations in the field while sampling.

5.3 Polychlorinated Biphenyls (PCBs - 7 congeners)

Two of the 4 samples, TP12 and TP19 were analysed for Polychlorinated Biphenyls. No Polychlorinated Biphenyls were detected within the soil samples submitted (see Table 2).

5.4 Phenols

As can be seen from Table 2, no phenol compounds were found in the 4 soil samples taken (i.e. levels were below the Method Detection Limit). These results correspond with observations in the field while sampling.

5.5 Heavy Metals - As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se and Zn

As can be seen from Table 2, of the 11 heavy metals analysed in the 4 soil samples, all were found to be below their corresponding Generic Assessment Criteria with the exception of:

- Mercury which was found to exceed the Dutch Target Value Level of 0.3mg/kg in the sample taken from TP17; and
- Mercury which was found to equal the *CLEA 2009 Soil Guideline Value for Residential with Plant Uptake* of 1mg/kg in the sample taken from TP19.

Table 2. Results of TPH-CWG, Polyaromatic Hydrocarbon, PCB, Total Phenol Heavy Metal, Organic Matter and pH Laboratory Analysis on Soil Samples taken from former landfill at Tullyvogheen, Clifden, County Galway

CHEMICAL SUBGROUPING				Aliphatics									Aromatics								
GENERIC ASSESSMENT CRITERIA		Parameter		EC C5-C6	EC>C6-C8	EC>C8-C10	EC>C10-C12	EC>C12-C16	EC>C16-C35	EC>C21-C35	EC>C35-C44	Total Aliphatics	EC C5-C7	EC>C7-C8	EC>C8-C10	EC>C10-C12	EC>C12-C16	EC>C16-C21	EC>C21-C35	EC>C35-C44	Total Aromatics
		Units		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
DUTCH CRITERIA CRITERIA		Dutch Intervention Levels (IV)		-	-	-	-	-	-	-	-	5000	-	-	-	-	-	-	-	-	-
		Dutch Target Level (TV)		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LQM/CIEH GENERIC ASSESSMENT CRITERIA		Residential		110	370	110	540 (283)^{vap}	3000 (142)^{sol}	76000	-	76000	-	280	611	151	346	593	770	1230	1230	-
		Allotment		3900	13000	1700	7300	13000	270000	-	270000	-	57	120	51	74	130	260	1600	1600	-
		Commercial		13000 (1150)^{sol}	42000 (736)^{sol}	12000 (451)^{vap}	49000 (283)^{vap}	91000 (142)^{sol}	1800000	-	1800000	-	90000 (4710)^{sol}	190000 (4360)^{vap}	18000 (3580)^{vap}	34500 (2150)^{sol}	37800	28000	28000	28000	-
CLEA SOIL GUIDELINE VALUES		2009 Published SGV [1]	Residential with plant	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			Allotment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			Industrial/ Commercial	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MURPHY ENVIRONMENTAL WASTE LICENCE WA 129-02		WAC Values		-	-	-	-	-	-	-	-	500	-	-	-	-	-	-	-	-	-
		SAMPLE ID	SAMPLING DEPTH (metres BGL)																		
		SO-TP03-01	2.8-3.0	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5
		SO-TP12-01	1.25-1.50	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5
		SO-TP17-01	1.95-2.1	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5
		SO-TP19-01	2.0-2.25	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5	< 0.1	< 0.1	< 0.1	< 1	< 1	< 1	< 1	< 1	<5

Notes:

553	Values are underlined wherever Dutch-TV is exceeded
553	Values are shaded yellow and in **RED bold** wherever Dutch-IV, LIEH/LQM GAC, CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value is exceeded
~	'~' signifies laboratory analysis not carried out.
-	'-' signifies no Dutch Criteria or CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value available.

1. Based on a sandy loam soil as defined in Environment Agency (2009b) and 6% soil organic matter (SOM).

^{sol} GAC presented exceeds the solubility saturation limit, which is presented in brackets
^{vap} GAC presented exceed the vapour saturation limit, which is presented in brackets

Table 2. Results of TPH-CWG, Polyaromatic Hydrocarbon, PCB, Total Phenol Heavy Metal, Organic Matter and pH Laboratory Analysis on Soil Samples taken from former landfill at Tullyvogheen, Clifden, County Galway

CHEMICAL SUBGROUPING				Total Petroleum Hydrocarbons				Polyaromatic Hydrocarbons (PAHS)																	
GENERIC ASSESSMENT CRITERIA	Parameter			TPH (DRO/EPH C8-C40)	Total Aliphatics	Total Aromatics	% Aliphatics	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(bb)fluoranthene	Benzo(k)pyrene	Indeno(123cd)pyrene	Dibenzo(ah)anthracene	Benzo(ghi)perylene	Coronene	Total 10 EPA PAHs	Total 16 EPA PAHs	Total 17 EPA PAHs
	Units			mg/kg	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
DUTCH CRITERIA CRITERIA	Dutch Intervention Levels (IV)			-	5000	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	40	-	-
	Dutch Target Level (TV)			-	50	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	1	-	-
LQM/CIEH GENERIC ASSESSMENT CRITERIA	Residential			-	-	-	-	8.7	850	1000	780	380	9200	670	1600	5.9	9.3	7	1	4.2	0.9	47	-	-	-	-
	Allotment			-	-	-	-	23	160	200	160	90	2200	290	620	10	12	13	2.1	7.1	2.3	160	-	-	-	-
	Commercial			-	-	-	-	1100 (432)[sol]	100000	100000	71000	23000	540000	23000	54000	97	140	100	14	62	13	660	-	-	-	-
CLEA SOIL GUIDELINE VALUES	2009 Published SGV [1]	Residential with plant		-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
		Allotment		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Industrial/ Commercial		-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-
MURPHY ENVIRONMENTAL WASTE LICENCE WA 129-02	WAC Values			-	500	-	-	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	100
	SAMPLE ID	SAMPLING DEPTH (metres BGL)																								
	SO-TP03-01	2.8-3.0		< 10	<5	<5	-	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<2.0	<2.0	<2.0
	SO-TP12-01	1.25-1.50		< 10	<5	<5	-	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<2.0	<2.0	<2.0
	SO-TP17-01	1.95-2.1		< 10	<5	<5	-	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<2.0	<2.0	<2.0
	SO-TP19-01	2.0-2.25		< 10	<5	<5	-	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<2.0	<2.0	<2.0

Notes:

553	Values are underlined wherever Dutch-TV is exceeded
553	Values are shaded yellow and in **RED bold** wherever Dutch-IV or CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value is exceeded
~	'~' signifies laboratory analysis not carried out.
-	'-' signifies no Dutch Criteria or CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value available.

1. Based on a sandy loam soil as defined in Environment Agency (2009b) and 6% soil organic matter (SOM).

[sol] GAC presented exceeds the solubility saturation limit, which is presented in brackets

[vap] GAC presented exceed the vapour saturation limit, which is presented in brackets

Table 2. Results of TPH-CWG, Polyaromatic Hydrocarbon, PCB, Total Phenol Heavy Metal, Organic Matter and pH Laboratory Analysis on Soil Samples taken from former landfill at Tullyvogheen, Clifden, County Galway

CHEMICAL SUBGROUPING				Polychlorinated Biphenyls									Phenols
GENERIC ASSESSMENT CRITERIA	Parameter			PCB Congener 28	PCB Congener 52	PCB Congener 101	PCB Congener 118	PCB Congener 153	PCB Congener 138	PCB Congener 180	PCB Total of 6 Congeners	PCB Total of 7 Congeners	Total Phenols
	Units			µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	µg/kg	mg/kg
DUTCH CRITERIA CRITERIA	Dutch Intervention Levels (IV)			-	-	-	-	-	-	-	1	-	40
	Dutch Target Level (TV)			-	-	-	-	-	-	-	0.02	-	0.05
LQM/CIEH GENERIC ASSESSMENT CRITERIA	Residential			-	-	-	-	-	-	-	-	-	780
	Allotment			-	-	-	-	-	-	-	-	-	120
	Commercial			-	-	-	-	-	-	-	-	-	1200000
CLEA SOIL GUIDELINE VALUES	2009 Published SGV [1]	Residential with plant		-	-	-	-	-	-	-	-	-	-
		Allotment		-	-	-	-	-	-	-	-	-	-
		Industrial/ Commercial		-	-	-	-	-	-	-	-	-	-
MURPHY ENVIRONMENTAL WASTE LICENCE WA 129-02	WAC Values			-	-	-	-	-	-	-	-	1	1
	SAMPLE ID	SAMPLING DEPTH (metres BGL)											
	SO-TP03-01	2.8-3.0		~	~	~	~	~	~	~	~	~	<0.3
	SO-TP12-01	1.25-1.50		< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	<0.05	<0.05	<0.3
	SO-TP17-01	1.95-2.1		~	~	~	~	~	~	~	~	~	<0.3
	SO-TP19-01	2.0-2.25		< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	<0.05	<0.05	<0.3

Notes:

553	Values are underlined wherever Dutch-TV is exceeded
553	Values are shaded yellow and in **RED bold** wherever Dutch-IV or CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value is exceeded
~	'~' signifies laboratory analysis not carried out.
-	'-' signifies no Dutch Criteria or CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value available.

1. Based on a sandy loam soil as defined in Environment Agency (2009b) and 6% soil organic matter (SOM).

[sol] GAC presented exceeds the solubility saturation limit, which is presented in brackets

[vap] GAC presented exceed the vapour saturation limit, which is presented in brackets

Table 2. Results of TPH-CWG, Polyaromatic Hydrocarbon, PCB, Total Phenol Heavy Metal, Organic Matter and pH Laboratory Analysis on Soil Samples taken from former landfill at Tullyvogheen, Clifden, County Galway

CHEMICAL SUBGROUPING				Heavy Metals											Physico-Chemical	
GENERIC ASSESSMENT CRITERIA	Parameter			Arsenic Low Level	Barium Low Level	Cadmium Low Level	Chromium Low Level	Copper Low Level	Lead Low Level	Nickel Low Level	Molybdenum Low Level	Mercury Low Level	Selenium Low Level	Zinc Low Level	Total Organic Carbon (%)	pH
	Units			mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	%	pH Units
DUTCH CRITERIA CRITERIA	Dutch Intervention Levels (IV)			55	-	12	380	190	530	210	-	10	-	720	-	-
	Dutch Target Level (TV)			29	-	0.8	100	36	85	35	-	0.3	-	140	-	-
LQM/CIEH GENERIC ASSESSMENT CRITERIA	Residential			-	-	3	-	2330	-	-	-	-	-	3750	-	-
	Allotment			-	-	0.53	-	524	-	-	-	-	-	618	-	-
	Commercial			-	-	348	-	71700	-	-	-	-	-	665000	-	-
CLEA SOIL GUIDELINE VALUES	2009 Published SGV [1]		Residential with plant	32	-	10	-	-	-	130	-	1	350	-	-	-
			Allotment	43	-	1.8	-	-	-	230	-	26 [2]	120	-	-	-
			Industrial/ Commercial	640	-	230	-	-	-	1800	-	26 [2]	13000	-	-	-
MURPHY ENVIRONMENTAL WASTE LICENCE WA 129-02	WAC Values			-	-	-	-	-	-	-	-	-	-	-	3	-
	SAMPLE ID	SAMPLING DEPTH (metres BGL)														
	SO-TP03-01	2.8-3.0		<2.0	<10	<0.10	<5.0	<5.0	<5.0	<5.0	<2.0	<0.10	<0.20	<10	~	~
	SO-TP12-01	1.25-1.50		<2.0	12	<0.10	<5.0	<5.0	<5.0	<5.0	<2.0	<0.10	<0.20	<10	**16**	7.6
	SO-TP17-01	1.95-2.1		2.3	20	<0.10	16	6.3	12	14	<2.0	0.78	<0.20	41	~	~
	SO-TP19-01	2.0-2.25		<2.0	22	0.2	12	11	12	11	<2.0	**1**	<0.20	27	0.98	7.7

Notes:

553	Values are underlined wherever Dutch-TV is exceeded
553	Values are shaded yellow and in **RED bold** wherever Dutch-IV or CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value is exceeded
~	'~' signifies laboratory analysis not carried out.
-	'-' signifies no Dutch Criteria or CLEA Soil Guideline Value or Murphy Environmental Waste Licence WAC Value available.

1. Based on a sandy loam soil as defined in Environment Agency (2009b) and 6% soil organic matter (SOM).

[sol] GAC presented exceeds the solubility saturation limit, which is presented in brackets

[vap] GAC presented exceed the vapour saturation limit, which is presented in brackets

It should be noted that the *CLEA 2009 Soil Guideline Values for Residential with Plant Uptake* should be regarded as the most conservative Generic Assessment Criteria for the risk assessment of soils and as such, they should regarded as more appropriate for a high risk environment (e.g. occupied semi-detached Residences with front and back gardens with a potential for a vegetable patch) and not for the assessment of soils within a former domestic landfill.

5.6 Total Organic Carbon

Total Organic Carbon (TOC) analysis was carried out on 2 soil samples, one from TP12 and one from TP19. The sample taken from TP12 was described as a silty sandy gravelly PEAT and as such it would be expected to have a high percentage TOC (i.e. 16%) and to exceed the Murphy Environmental Waste Licence WA129-02 Waste Acceptance Criteria for Inert Waste. The sample taken from TP19 was described as a sandy GRAVEL and as such it would be expected to have a low percentage TOC (i.e. 0.98%) and to be less than the Waste Acceptance Criteria for Inert Waste (i.e. 3%).

5.7 pH

pH analysis was carried out on 2 soil samples, that from TP12 and TP19. Both soil samples were found to be slightly alkaline.

6 GEOTECHNICAL SOILS RESULTS

Three representative samples of the clayey peat top soil underlying used as landfill cap were taken from trialpits, TP6, TP11 and TP19 at 0 to 0.3m below ground level (bgl) and submitted for geotechnical testing through Chemtest Ltd. to Soil Property Testing Ltd. in the UK (see Figure 6 and following table, Table 3).

Each soil sample was analysed for particle size distribution (PSD) and Liquid and Plastic Limit and Plasticity Index by Atterburg Test. The purpose of this test is to assess whether the topsoil or landfill cap is preventing precipitation from percolating through to the underlying waste body.

For landfilling purposes soils the permeability of a re-moulded clay used as a landfill cap is influenced by a number of factors, the key ones being plasticity, density, moisture content during compaction and method of compaction. Although the detailed requirements for compacted clay liners (CCLs) vary, the following parameters usually apply:

- Coefficient of permeability (hydraulic conductivity) of 1 x 10^{-9}m/s or less;
- Minimum layer thickness of 1m;
- Minimum clay content of 10%;
- Minimum Fines (clay & silt) content > 30%;
- Plasticity index >10% and <65%;
- Liquid limit < 90%; and
- Maximum particle size of 75mm.

As can be seen from Table 3, all 3 soil samples were described as *'Dark brown gravelly sandy silty PEAT with fibrous roots'*. All 3 soil samples conformed to the above criteria for Plasticity Index and Liquid Limit. However, each of the soil samples was found to be under the recommended minimum % Fines Content of 30% (i.e. silt and clay). This is consistent with field observations.

Table 3. Results of Particle Size Distribution and Atterburg Tests on Landfill Cap Samples taken from former landfill at Tullyvogheen, Clifden, County Galway

Soil Sample	SPT Ltd. Sample No.	Soil Sampling Depth (m bgl)	Soil Description	Plasticity Index	Liquid Limit (%)	Plastic Limit (%)	Fines % (clay & silt)
			ACCEPTABLE RANGE	*>10% and <65%*	*< 90%*	-	*> 30%*
SO-TP6-01	80845	0-0.30	Dark brown gravelly sandy silty PEAT with fibrous roots	28	72	44	**24**
SO-TP11-01	80844	0-0.30	Dark brown gravelly sandy silty PEAT with fibrous roots	28	83	55	**17**
SO-TP19-02	80843	0-0.30	Dark brown gravelly sandy silty PEAT with fibrous roots	18	60	42	**9**

7 ENVIRONMENTAL GROUNDWATER RESULTS

Three groundwater samples and two leachate samples were collected from within the site at locations BH101, BH102, BH103, LC1 and LC2 and submitted for laboratory analysis. The laboratory suite was as follows:

Physico-chemical Parameters

- pH;
- Electrical Conductivity;
- Dissolved oxygen (DO); and
- Redox potential.

Inorganic Analysis

- Heavy Metals - As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se and Zn;
- Total suspended solids;
- Total alkalinity (as $CaCO_3$); [6]
- Ammoniacal Nitrogen (as N);
- Total Oxidised Nitrogen (TON) as N;
- Chloride (Cl^-);
- Fluoride (F^-);
- Sulphate (SO_4^{2-})
- Ortho-Phosphate (PO_4);
- MR-Phosphate as P; and
- Total Cyanide.

Major Cations and Anions

- Potassium (K);
- Sodium (N);
- Calcium (Ca); and
- Magnesium (Mg).

Oxygen Demand/Organic Carbon

- Chemical Oxygen Demand; and
- Dissolved Organic Carbon.

Trace Organic Analysis

- Volatile Organic Compound;
- Semi-volatile Organic Compound;
- Benzene, Toluene, Ethylbenzene, Xylenes and MTBE;
- Polyaromatic Hydrocarbons (PAHs) (17 speciated) to include Coronene;
- Organo-phosphorous pesticides; and
- Organo-chlorine pesticides & Acid Herbicides.

[6] *The leachate samples were not analysed for Total Alkalinity.*

The following table, Table 4 represent the results of the inorganic and BOD analyses on the groundwater and leachate samples. The results of the Volatile Organic Compound (VOC), Semi-volatile Organic Compound (sVOC), BTEX, Polyaromatic Hydrocarbon (PAH), Organo-phosphorus and Organo-chlorine/Acid Herbicide analyses are located in tables in Appendix 10. These results are compared against the following Generic Assessment Criteria, statutory limits, Interim Guideline Values and Threshold Values. A detailed description of each of the following Generic Assessment Criteria is given in Section 3:

- *National Institute of Public Health and the Environment of The Netherlands - The Soil Protection Guidelines (Dutch Criteria)* – Intervention and Target Values;
- The maximum allowable concentration (MAC) values of Statutory Instrument No. 81 (Quality of Water Intended for Human Consumption) of 1988;
- The parametric values of Statutory Instrument No. 106 (Drinking Water Regulations) of 2007;
- The Interim Guideline Values from *Towards Setting Guideline Values For The Protection Of Groundwater In Ireland – Interim Report;* and
- The Threshold Values from EC Environmental Objectives (Groundwater Regulations) Statutory Instrument No. 9, 2010.

7.1 Physicochemical Analysis

pH values vary across the site with the lowest being 7.2 in LC2 and the highest, 8.1 in BH102. The pH of the groundwater although slightly alkaline is within normal ranges for groundwater and leachate samples.

Electrical conductivity values were as expect lowest in the groundwater samples with conductivity varying from 550µS/cm at BH102 to 490µS/cm at BH103. However, the conductivity in the upgradient well, BH101 was 1,000µS/cm which also exceeded the EC Statutory Instrument No. 9, 2010 Threshold Value of 800µS/cm.

Electrical conductivity values were as expected, high in the leachate samples with conductivity varying from to 1,300µS/cm at LC1 to 1,500µS/cm at LC2.

Dissolved oxygen concentrations were as expected, lowest in the leachate samples from LC1 and LC2. These values also correlate with Redox Potential readings which ranged from 22mV in LC1 to -43mV in LC2. This is consistent with the anaerobic nature of the samples taken in the field i.e. grey/black discoloration of sample and sulphide/sulphur odour (see monitoring well sampling logs in Appendix 8).

7.2 Total Dissolved Solids

The results obtained for Total Dissolved Solids was highest in the upgradient groundwater sample taken from BH101 at 630mg/l. As expected, the TDS was highest in the 2 leachate samples at 770mg/l and 890mg/l for LC1 and LC2 respectively. It should be noted however that the EPA Interim Guideline Value (IGV) was not exceeded.

7.3 Total Hardness & Total Alkalinity

The levels of Hardness found in all 5 samples exceeded the EPA Interim Guideline Value (IGV) of 200mg/l.

Total Alkalinity ranged from 210mg/l in BH103 to 710mg/l in LC02.

7.4 Ammoniacal Nitrogen & Total Oxidised Nitrogen (TON)

The results obtained within the groundwater samples for Ammoniacal Nitrogen ranged from 8.6mg/l in BH101 (i.e. the upgradient borehole) to 0.4mg/l in BH103 (i.e. a downgradient borehole).

The results obtained within the leachate samples for Ammoniacal Nitrogen were as expected, noticeably higher at 72mg/l in LC1 to 47mg/l in LC2. These levels would be expected and are typical of leachate from domestic waste.

Generally it would be expected that ammonia levels in BH101 would be lower than those values obtained in the downgradient boreholes, BH102 and BH103. It is possible that the levels of ammonia detected in BH01 are attributable to agricultural practices or forestry practices upgradient of the site.

No nitrates or nitrates were detected in the 3 groundwater samples. Low levels of nitrates were found in LC1.

7.5 Anions (Chloride (Cl^-), Fluoride (F^-), Sulphate (SO_4^{2-}) and Sulphides (S^{2-}))

The results obtained within the groundwater samples for chloride ranged from 54mg/l in BH101 (i.e. the upgradient borehole) to 110mg/l in BH102 and 43mg/l in BH103 (i.e. the downgradient boreholes). These levels which exceed the S.I. No. 9, 2010 Threshold Value, would be expected given the proximity of waste and the direction of groundwater flow towards the west.

The results obtained within the leachate samples for chloride ranged from 74mg/l in LC2 to 82mg/l in LC1. These levels would be expected and are typical of leachate from domestic waste.

Fluoride was detected at low levels within the groundwater and leachate samples taken on site. There was negligible difference between the levels found in groundwater and the levels found in leachate.

The results obtained within the groundwater samples for sulphate ranged from 59mg/l in BH101 (i.e. the upgradient borehole) to 5.8mg/l in BH103 (i.e. the downgradient borehole). These results were significantly less than the S.I. No. 9, 2010 Threshold Value of 187.5mg/l.

The results obtained within the leachate samples for sulphate ranged from 54mg/l in LC1 to 25mg/l in LC2. These results were significantly less than the S.I. No. 9, 2010 Threshold Value of 187.5mg/l.

No sulphides were detected in the groundwater or leachate samples.

7.6 MR-Phosphate (as P) and Total Cyanide.

The results obtained within the groundwater samples for phosphates ranged from 0.074mg/l in BH101 (i.e. the upgradient borehole) to 0.073mg/l in BH01 (i.e. the downgradient borehole). These levels would be regarded as low.

The results obtained within the leachate samples for phosphates ranged from 0.073mg/l in LC1 to 0.074mg/l in LC2. These levels would be regarded as low.

No cyanides were detected within the groundwater or leachate samples taken on site.

7.7 Major Cations

The results obtained within the groundwater samples for potassium ranged from 9.4mg/l in BH101 (i.e. the upgradient borehole) to 3mg/l in BH103 (i.e. the downgradient borehole). The values obtained for the sample from BH101 and BH102 exceeded the EPA Interim Guideline Value (IGV). The level of potassium found in BH102 was also reflected in the Potassium/Sodium ratio which was 0.46. A ratio greater than 0.4 generally would indicate an impact by domestic leachate.

The results obtained within the leachate samples for potassium ranged from 19mg/l in LC1 to 20mg/l in LC2. Both of these values grossly exceeded the EPA Interim Guideline Value (IGV) of 5mg/l. These levels were also reflected in the Potassium/Sodium ratios of 0.51 and 0.38. A ratio greater than 0.4 generally would indicate an impact by domestic leachate.

The results obtained for sodium, calcium and magnesium were all less than their respective MAC Values quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988, Parametric Values quoted in the Drinking Water Regulations of 2007, their corresponding EPA Interim Guideline Values (IGVs) and their corresponding Threshold Values quoted in the E.C. Environmental Objectives (Groundwater Regulations), 2010.

7.8 Oxygen Demand/Organic Carbon

Chemical Oxygen Demand (COD) and Dissolved Organic Carbon (DOC) were carried out on the groundwater and leachate samples.

Chemical Oxygen Demand (COD)

A value of 27mg/l was obtained for the sample taken from BH101. A value of 100mg/l was obtained for both LC1 and LC2 respectively. These values exceed the corresponding EPA IGV of 20mg/l.

Dissolved Organic Carbon (DOC)

The results obtained within the groundwater samples for DOC ranged from 28mg/l in BH101 (i.e. the upgradient borehole) to 6.7mg/l in BH103 (i.e. the downgradient borehole).

The results obtained within the leachate samples for DOC ranged from 19mg/l in LC1 to 20mg/l in LC2.

7.9 Heavy Metals

Of the 12 heavy metals analysed, the reported concentrations for all parameters are within their corresponding Dutch Criteria Intervention and Target Levels, World Health Organisation Guideline Values 2008, MAC Values quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988, Parametric Values quoted in the Drinking Water Regulations of 2007, their corresponding EPA Interim Guideline Values (IGVs) and their corresponding Threshold Values quoted in the E.C. Environmental Objectives (Groundwater Regulations) 2010 with the exception of:

- *Arsenic*

A value of 28µg/l was obtained in BH103. This value exceeded the corresponding EPA IGV and Threshold Value.

- *Boron*

Values of 810µg/l and 810µg/l were obtained in LC1 and LC2 respectively. These exceed the corresponding Threshold Value

- *Iron*

Values of 260µg/l and 2,900µg/l were obtained in LC1 and LC2 respectively. These values exceed the corresponding Drinking Water MACs and Parametric Values which are 200µg/l. These values would be expected as iron, which is sensitive to oxygen levels, is typically reduced to its more mobile Fe^{2+} species and released or leached from soil and bedrock into groundwater during anaerobic (i.e. reducing) conditions.

- *Manganese*

Values of 1,800µg/l, 1,100µg/l and 970µg/l were obtained in BH101, BH102 and BH103 respectively. Values of 880µg/l and 1,300µg/l were obtained in LC1 and LC2 respectively. These values exceed the corresponding Drinking Water MACs and Parametric Values which are 50µg/l. Like iron, these values would be expected as manganese is typically reduced to its more mobile Mn^{2+} species and released or leached from soil and bedrock into groundwater during anaerobic (i.e. reducing) conditions which occur in domestic waste landfills.

- *Nickel*

A value of 16µg/l was obtained in LC2. This value exceeded the corresponding Threshold Value which is 15µg/l.

7.10 Volatile Organic Compounds/Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) & MTBE

The results of the Volatile Organic Compounds analysis for groundwater and perched water samples are located on Table A10.1. The BTEX and MTBE results are recorded in both Table A10.1 and Table A10.3 located in Appendix 10. As can be seen from Table A10.1,[7] all of the VOCs analysed were below their respective Method Detection Limits with the exception of:

[7] *Where VOCs are detected they are highlighted in yellow. Where values are underlined, this indicates and exceedance of the corresponding Dutch Target Value. Where values are highlighted in Red bold, this indicates an exceeded of Dutch Intervention Value or of the 1988 Regulations, MAC values.*

- *Benzene*

Benzene was detected in leachate sample taken from LC2 at 0.0014mg/l. This value exceeded the corresponding EPA IGV and Threshold Value.

- *Toluene*

Toluene was detected in groundwater samples taken from BH101 and BH102 at 0.0023mg/l and 0.0011mg/l respectively.

Toluene was detected in leachate samples taken from LC1 and LC2 at 0.014mg/l and 0.011mg/l respectively. These values exceeded their corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *Chlorobenzene*

Chlorobenzene was detected in leachate sample taken from LC2 at 0.0044mg/l. This value exceeded the corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *Ethylbenzene*

Ethylbenzene was detected in leachate sample taken from LC1 at 0.0012mg/l. This value exceeded the corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *p/m-Xylenes*

p/m-Xylenes were detected in groundwater samples taken from BH101 at 0.0032mg/l.

P/m-Xylenes were detected in leachate samples taken from LC1 and LC2 at 0.0083mg/l and 0.0079mg/l respectively. These values exceeded their corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *o-Xylene*

o-Xylene was detected in groundwater samples taken from BH101 at 0.0015mg/l.

O-Xylene was detected in leachate samples taken from LC1 and LC2 at 0.0023mg/l and 0.0022mg/l respectively. These values exceeded their corresponding Dutch Target Value.

- *1,2,4-Trimethylbenzene*

1,2,4-Trimethylbenzene was detected in leachate samples taken from LC1 and LC2 at 0.0065mg/l and 0.0045mg/l respectively. No Generic Assessment Criteria are available for this compound.

7.11 Semi-Volatile Organic Compounds (sVOC)

The results of the Semi-Volatile Organic Compounds analysis for groundwater and perched water samples are located on Table A10.2 located in Appendix 10. As can be seen from Table A10.2, all of the sVOCs analysed were below their respective Method Detection Limits.

Table 4. Results of Laboratory Analyses on Groundwater and Leachate Samples taken at Former Landfill at Tullyvogheen, Clifden, County Galway

Parameter	Units	Standards		Guidelines		Analytical Results				
		SI No. 81 of 1988 - EC Regs (Quality of water intended for human consumption).	*SI No. 439 of 2000 - EC Drinking Water Regs.*	*EPA Guideline Values - From Interim Report on 'Towards Setting Guideline Values for the Protection of Groundwater in Ireland'.*	*S.I. No. 9, European Communities Environmental Objectives (Groundwater) Regulations, 2010*	SOURCE				
						GROUNDWATER MONITORING WELLS			LEACHATE WELLS	
		MACs	*Parametric Values*	*Interim Guideline Values*	*Threshold Values*	WA-BH101-01 (UPGRADIENT)	WA-BH102-01 (DOWN-GRADIENT)	WA-BH103-01 (DOWN-GRADIENT)	WA-LC1-01	WA-LC2-01
Physico-Chemical Parameters										
pH	-	*6.0<pH<9.0*	*6.5<pH<9.5*	*6.5<pH<9.6*	*6.5<pH<9.6*	7.6	8.10	7.70	7.30	7.2
Electrical cond. (EC)	µS/cm	*1500*	*2500*	*1000*	*800-1875*	**1100**	550	490	**1300**	**1500**
Dissolved oxygen (DO)	mg/l	-	-	-	-	7.5	7.5	8.1	5.5	5.1
Redox potential	mV	-	-	-	-	170	210	200	22	-43
Standard Chemistry										
Total Dissolved Solids	mg/l	-	-	*1000*	-	630	330	300	770	890
Total hardness (as $CaCO_3$)	mg/l	*60 MRC (**)*	-	*200*	-	**500**	**240**	**220**	**210**	**420**
Total alkalinity (as $CaCO_3$)	mg/l	*30 MRC (**)*	-	-	-	590	360	210	660	710
Ammon. Nitrogen (as N)	mg/l	*0.23*	-	*0.12*	*0.065-0.175*	**8.6**	**0.86**	**0.4**	**72**	**47**
Total Oxidised Nitrogen (TON) as N	mg/l	-	-	-	-	<0.20	<0.20	<0.20	<0.20	<0.20
Nitrate NO3	mg/l	*50*	*50*	*25*	*37.5*	<0.50	<0.50	<0.50	0.56	<0.50
Nitrite NO2	mg/l	*0.1*	*0.5*	*0.1*	*0.375*	<0.020	<0.020	<0.020	<0.020	<0.020
Chloride Cl^-	mg/l	*250*	*250*	*30*	*24-187.5*	**54**	**110**	**43**	**82**	**74**
Fluoride F^-	mg/l	-	-	-	-	0.13	0.18	0.13	0.12	0.12
Sulphate SO_4	mg/l	*250*	*250*	*200*	*187.5*	59	14	5.8	54	25
Sulphide S^{2-}	mg/l	-	-	-	-	<0.050	<0.050	<0.050	<0.050	<0.050
MR-Phosphate as P	mg/l	-	-	-	0.035	0.074	0.073	0.08	0.073	0.074
Total Cyanide	mg/l	*0*	-	*0*	-	<0.050	<0.050	<0.050	<0.050	<0.050
Major Cations										
Potassium K	mg/l	*12*	-	*5*	-	**9.4**	**12**	3	**19**	**20**
Sodium Na	mg/l	*150*	*200*	*150*	*150*	47	26	25	37	53
Potassium K/Sodium Na Ratio	-	-	-	-	-	0.20	0.46	0.12	0.51	0.38
Calcium Ca	mg/l	*200*	-	*200*	-	170	81	62	57	140
Magnesium Mg	mg/l	*50*	-	*50*	-	17	8.1	16	16	20
Heavy Metals										
Antimony	µg/l	-	-	-	-	<1.0	1.2	2.2	9.8	<1.0
Arsenic	µg/l	50	10	10	7.5	3	6.2	**28**	3	1.5
Boron	µg/l	*2000*	*1000*	*1000*	*750*	520	500	600	**810**	**810**
Cadmium Cd	µg/l	*5*	*5*	*5*	*3.75*	<0.080	<0.080	0.35	<0.080	<0.080
Chromium Cr	µg/l	*50*	*50*	*30*	*37.5*	<1.0	<1.0	<1.0	<1.0	2
Copper	µg/l	*500*	-	*30*	*1500*	1.1	<1.0	<1.0	<1.0	<1.0
Iron Fe	µg/l	*200*	*200*	*200*	-	<20	30	<20	**260**	**2900**
Lead Pb	µg/l	*50*	*10*	*10*	*18.75*	<1.0	<1.0	1.3	1.7	<1.0
Nickel Ni	µg/l	*50*	-	*20*	*15*	4.2	4.4	<1.0	8.2	**16**
Manganese Mn	µg/l	*50*	*50*	*50*	-	**1800**	**1100**	**970**	**880**	**1300**
Mercury Hg	µg/l	*1*	*1*	*1*	*0.75*	<0.50	<0.50	<0.50	<0.50	<0.50
Zinc Zn	µg/l	*1000*	-	*100*	-	10	3	2.5	7.1	9.3
Oxygen Demand/Organic Carbon										
COD	mg/l	-	-	20	-	**27**	12	10	**100**	**100**
DOC	mg/l	-	-	-	-	28	11	6.7	19	20

Note:

450 Values are shaded yellow and in RED boldwhere SI No. 81 of 1988 MACs, SI No. 439 of 2000 Parametric Values, EPA Guideline Values or S.I. No. 9 Groundwater Reg. Threshold Levels have been exceeded

** M.R.C = Minimum Required Concentration specified in the Drinking Water Regulations (S.I. No. 81 of 1988)

< = Less than

'-' signifies analysis not carried out on sample or no SI No. 81 of 1988 MACs, SI No. 439 of 2000 Parametric Values, EPA Guideline Values or S.I. No. 9 Groundwater Reg. Threshold Levels are available.

7.12 Polyaromatic Hydrocarbons (PAHs)

The results of the Polyaromatic Hydrocarbons (PAHs) analysis on groundwater and perched water samples are located on Table A10.3 located in Appendix 10. As can be seen from Table A10.3, all of the PAHs analysed were below their respective Method Detection Limits.

7.13 Organophosphorus Pesticides

The results of the Organophosphorus pesticide analysis on groundwater and perched water samples are located on Table A10.5 located in Appendix 10. As can be seen from Table A10.5, all of the organophosphorus pesticides analysed were below their respective Method Detection Limits.

7.14 Organochlorine Pesticides & Acid Herbicides

The results of the Organochlorine pesticide and Acid Herbicide analysis on groundwater and perched water samples are located on Table A10.6 located in Appendix 10. As can be seen from Table A10.5, all of the organochlorine pesticides and acid herbicides analysed were below their respective Method Detection Limits.

7.15 Major Cation and Anion Ion Balance & Summary of Groundwater Quality

An ion balance was carried out on the results of the inorganic anion and cation analysis of the groundwater and leachate samples. As can be seen from Table A10.7 (see Appendix 10), the largest ion balance was obtained for BH102 i.e. 24%. For groundwater, an ion balance error of up to 15 per cent is generally acceptable. Only the leachate sample taken from LC2 was less than this level. The potassium/sodium ratio, the levels of trace organics and ammonia and the distribution of heavy metals within the groundwater in the upgradient and downgradient boreholes and leachate wells on site indicate that the groundwater has been moderately impacted by leachate emanating from the domestic waste deposited on site.

8 ENVIRONMENTAL SURFACE WATER RESULTS

It is understood that the EPA carried out sampling at 3 locations, SW1, SW2 and SW3 on 3 occasions during 2012. SW1 is located to the east of the waste body and upgradient of the site. SW2 is located immediately downgradient of the waste body and SW3 is located further downgradient of the site (see Figure 10). The same surface water monitoring points were used in the January, 2014 survey carried out by Mulroy Environmental. The laboratory suite was as follows:

Physico-chemical Parameters

- pH;
- Electrical Conductivity;
- Dissolved oxygen (DO); and
- Redox potential.

Inorganic Analysis

- Heavy Metals - As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se and Zn;
- Total suspended solids;
- Total alkalinity (as $CaCO_3$);
- Ammoniacal Nitrogen (as N);
- Total Oxidised Nitrogen (TON) as N;
- Chloride (Cl^-);
- Fluoride (F^-);
- Sulphate (SO_4^{2-})
- MR-Phosphate as P; and
- Total Cyanide.

Major Cations and Anions

- Potassium (K);
- Sodium (N);
- Calcium (Ca); and
- Magnesium (Mg).

Oxygen Demand/Organic Carbon

- Biological Oxygen Demand; and
- Chemical Oxygen Demand.

Microbiological

- Total Coliform; and
- Faecal Coliform.

Trace Organic Analysis

- Volatile Organic Compound;
- Semi-volatile Organic Compound;

- Benzene, Toluene, Ethylbenzene, Xylenes and MTBE;
- Polyaromatic Hydrocarbons (PAHs) (17 speciated) to include Coronene;
- Organo-phosphorous pesticides; and
- Organo-chlorine pesticides & Acid Herbicides.

The following table, Table 5 represent the results of the inorganic, oxygen demand and microbiological analyses on the surface water samples. The results of the Volatile Organic Compound (VOC), Semi-volatile Organic Compound (sVOC), BTEX, Polyaromatic Hydrocarbon (PAH), Organo-phosphorus and Organo-chlorine/Acid Herbicide analyses are located in tables in Appendix 10. These results are compared against the following Generic Assessment Criteria/statutory limits. A detailed description of each of the following Generic Assessment Criteria is given in Section 3:

- S.I. No. 294, European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989;
- S.I. No. 278, European Communities Environmental Objectives (Drinking Water) (No. 2) Regulations, 2007; and
- S.I. No. 272, European Communities Environmental Objectives (Surface Water) Regulations, 2009.

8.1 Physicochemical Analysis

The pH of the surface water samples although slightly alkaline are within normal ranges (see Table 5). The electrical conductivity of the surface water samples also appears to be within normal ranges for groundwater. The dissolved oxygen of the surface water samples was at normal levels. The Redox Potential of the surface water samples was also at normal levels.

8.2 Total Suspended Solids

The results obtained for Total Suspended Solids was highest in the upgradient surface water sample, SW1 at 17mg/l with the lowest at SW2 at 1mg/l. This is consistent with the discoloration found (i.e. brown taint) in the upgradient sample (see surface water monitoring field logs in Appendix 8). No discoloration was observed in the SW3 sample.

8.3 Total Hardness & Total Alkalinity

The levels of Hardness found in all 3 samples was significantly less than the EPA Interim Guideline Value (IGV) of 200mg/l. This is consistent with the type of bedrock in the area (i.e. schist) which has low levels of calcium carbonate.

Total Alkalinity ranged from 40mg/l in SW1 to 57mg/l in SW2.

8.4 Ammoniacal Nitrogen, Nitrates & Nitrites

The results obtained for the upgradient surface water sample, SW1 for Ammoniacal Nitrogen was 0.09mg/l which equalled the S.I. No. 272 Surface Water Threshold Value (see Table 5). The results for the downgradient samples was 2.3mg/l and 1.5mg/l for SW2 and SW3 respectively which exceeded the S.I. No. 272 Surface Water Threshold Value. It is possible that the low level of ammonia detected

within the upgradient surface water sample is attributable to agricultural practices upgradient of the site. However, it should be noted that the ammonia results for the downgradient samples indicate that the landfill is having a low to moderate impact on the surface water body.

The results of nitrate analyses on the surface water samples show relatively low levels in each sample. No nitrites were detected in the 3 surface water samples.

These results are consistent with the results of the testing carried out by the EPA in 2012(see Appendix10).

8.5 Anions (Chloride (Cl^-), Sulphate (SO_4^{2-}) and Sulphide (S^{2-})

The results obtained for the surface water samples for chloride and Sulphate (SO_4^{2-}) were all lower than their respective Parametric Values (see Table 5).

The results obtained for the surface water samples Sulphide (S^{2-}) were all lower than their respective Method Detection Limit.

8.6 MR-Phosphate (as P) and Total Cyanide.

The results obtained for the surface water samples for Molybdate Reactive-phosphate were 0.084mg/l, 0.077mg/l and 0.077mg/l for SW1, SW2 and SW3 respectively. These results exceeded the S.I. No. 272 Surface Water Threshold Value (see Table 5). It is possible that the low level of phosphates detected in the surface water are attributable to agricultural practices upgradient of the site.

No cyanides were detected within the surface water sample taken on site.

8.7 Major Cations

The results obtained within the surface water samples for potassium ranged from below the Method Detection Limit to 2.5mg/l in SW2. These low levels are reflected in the Potassium/Sodium ratio which range from 0.07 to 0.06. A ratio greater than 0.4 generally would indicate an impact by domestic leachate (see Table 5).There was negligible difference in the sodium, calcium and magnesium levels in the upgradient and downgradient samples.

8.8 Heavy Metals

Of the 13 heavy metals analysed, the reported concentrations for all parameters are within their respective MAC Values quoted in S.I. No. 294, Parametric Values quoted in the S.I. No. 278 Drinking Water Regulations of 2007 and S.I. No. 272, European Communities Environmental Objectives (Surface Water) Regulations 2009 Threshold Values (see Table 5) with the exception of:

- *Iron*

For iron, values of 300mg/l, 810mg/l and 460mg/l were obtained in SW1, SW2 and SW3 respectively. These values were above the S.I. No. 278 Drinking Water Regulations 2007 Parametric Value (i.e. 200mg/l) (see Table 5).

- *Manganese*

For manganese, values of 65mg/l, 94mg/l and 52mg/l were obtained in SW1, SW2 and SW3 respectively. These values were above the S.I. No. 278 Drinking Water Regulations 2007 Parametric Value (i.e. 200mg/l) (see Table 5).

Like iron, these values would be expected as manganese is typically reduced to its more mobile Mn^{2+} species and released or leached from soil and bedrock into groundwater during anaerobic (i.e. reducing) conditions.

8.9 Oxygen Demand

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) analyses were carried out on the surface water samples. For Biological Oxygen Demand (BOD) analysis, a value below the detection limit was obtained in all 3 samples. For Chemical Oxygen Demand (COD) analysis, values of 30mg/l, 20mg/l and 15mg/l were obtained in SW1, SW2 and SW3 respectively. These values were below the Threshold Value (see Table 5).

8.10 Microbiology

Total Coliform and Faecal Coliform (i.e. Thermo-tolerant *E. coli*) analyses were carried out on the surface water samples. For Total Coliform analysis, values of 57CFUs/100ml, 41CFUs/100ml, and 34CFUs/100ml, were obtained in SW1, SW2 and SW3 respectively. For Faecal Coliform analysis, values of 5CFUs/100ml, 3CFUs/100ml, and 9CFUs/100ml, were obtained in SW1, SW2 and SW3 respectively. These values exceeded the S.I. No. 278 Drinking Water Regulations 2007 Parametric Value (i.e. 0CFUs/100ml). It is possible that the low level of faecal coliforms detected in the surface water samples is attributable to agricultural practices upgradient of the site.

8.11 Volatile Organic Compounds/Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) & MTBE

The results of the Volatile Organic Compounds analysis for the surface water samples are located on Table A10.1. The BTEX and MTBE results are recorded in both Table A10.1 and Table A10.4 located in Appendix 10. As can be seen from Table A10.1,[8] all of the VOCs analysed were below their respective Method Detection Limits.

8.12 Semi-Volatile Organic Compounds (sVOC)

The results of the Semi-Volatile Organic Compounds analysis for the surface water samples are located on Table A10.2 located in Appendix 10. As can be seen from Table A10.2, all of the sVOCs analysed were below their respective Method Detection Limits.

8.13 Polyaromatic Hydrocarbons (PAHs)

The results of the Polyaromatic Hydrocarbons (PAHs) analysis on the surface water samples are located on Table A10.4 located in Appendix 10. As can be seen from Table A10.4, all of the PAHs analysed were below their respective Method Detection Limits.

[8] *Where VOCs are detected they are highlighted in yellow. Where values are underlined, this indicates and exceedance of the corresponding Dutch Target Value. Where values are highlighted in Red bold, this indicates an exceeded of Dutch Intervention Value or of the 1988 Regulations, MAC values.*

8.14 Organophosphorus Pesticides

The results of the Organophosphorus pesticide analysis on groundwater and the surface water samples are located on Table A10.5 located in Appendix 10. As can be seen from Table A10.5, all of the organophosphorus pesticides analysed were below their respective Method Detection Limits.

8.15 Organochlorine Pesticides & Acid Herbicides

The results of the Organochlorine pesticide and Acid Herbicide analysis on the surface water samples are located on Table A10.6 located in Appendix 10. As can be seen from Table A10.6, all of the organochlorine pesticides and acid herbicides analysed were below their respective Method Detection Limits.

8.16 Major Cation and Anion Ion Balance & Summary of Groundwater Quality

An ion balance was carried out on the results of the inorganic anion and cation analysis of the surface water samples. As can be seen from Table A10.7 (see Appendix 10), the largest ion balance was obtained for SW1 i.e. 15.82%. For surface water, an ion balance error of up to 10 per cent is generally acceptable. The levels of ammonia, phosphates, iron and manganese within the surface water in the stream suggest that the stream may have been impacted prior to entering the site. However, the data obtained also suggests that the landfill is impacting on the quality of the surface water i.e. landfill leachate is entering the culvert and mixing with surface water.

Table 5. Results of Laboratory Analyses on Surface Water Samples (SW1, SW2 SW3) taken at Tullyvogheen, Clifden, County Galway

Parameter	Units	Statutory Limits			WA-SW1-01 (UPGRADIENT)	WA-SW2-01 (DOWNGRADIENT)	WA-SW3-01 (DOWNGRADIENT)
		S.I. No. 294, European Communities (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989 MACs	*S.I. No. 278, European Communities Environmental Objectives (Drinking Water) (No. 2) Regulations, 2007* Parametric Values	*S.I. No. 272, European Communities Environmental Objectives (Surface Water) Regulations, 2009* Threshold Values			
Physico-Chemical Parameters							
pH	-	-	-	*6..0<pH<9..0*	8.6	8.3	8.3
Electrical cond. (EC)	µS/cm	-	*2500*	-	270	280	250
Dissolved oxygen (DO)	%	-	-	*80*	11.2	11	11.1
Redox potential	mV			-	150	150	160
Standard Chemistry							
Total suspended solids	mg/l	*50*	-	-	17	8	1
Total hardness (as $CaCO_3$)	mg/l	-	*200*	-	55	50	38
Total alkalinity (as $CaCO_3$)	mg/l	-	-	-	40	57	45
Ammon. Nitrogen (as N)	mg/l	-	-	*0.09*	**0.09**	**2.3**	**1.5**
Ammonium	mg/l	-	*0.3*	-	0.11	**2.90**	**1.90**
Nitrate NO_3	mg/l	-	-	-	0.78	0.96	0.5
Nitrite NO_2	mg/l	-	-	-	<0.020	<0.020	<0.020
Chloride Cl^-	mg/l	-	*250*	-	66	63	60
Sulphate SO_4	mg/l	-	*250*	-	15	12	10
Sulphide S^{2-}	mg/l	-	-	-	<0.050	<0.050	<0.050
MR-Phosphate as P	mg/l	-	-	*0.025*	**0.084**	**0.077**	**0.077**
Total Cyanide	mg/l	-	-	*10*	<0.050	<0.050	<0.050
Major Cations							
Potassium K	mg/l	-	-	-	<0.50	2.5	1.9
Sodium Na	mg/l	-	-	-	39	37	32
Potassium K/Sodium Na Ratio		-	-	-	0.00	0.07	0.06
Calcium Ca	mg/l	-	-	-	9.6	12	9.3
Magnesium Mg	mg/l	-	-	-	4.2	5.4	4.5
Heavy Metals							
Antimony	µg/l	-	-	-	<1.0	<1.0	<1.0
Arsenic	µg/l	-	-	*25*	<1.0	<1.0	<1.0
Boron	µg/l	-	*1000*	-	580	530	440
Cadmium Cd	µg/l	-	*5*	-	<0.080	<0.080	<0.080
Chromium Cr	µg/l	-	-	-	<1.0	<1.0	<1.0
Copper	µg/l	-	-	*30*	1.1	1.1	<1.0
Iron Fe	µg/l	-	*200*	-	**300**	**810**	**460**
Lead Pb	µg/l	-	-	*7.2*	1.6	<1.0	<1.0
Nickel Ni	µg/l	-	-	*20*	<1.0	<1.0	<1.0
Manganese Mn	µg/l	-	*50*	-	**65**	**94**	**52**
Mercury Hg	µg/l	-	-	-	<0.50	<0.50	<0.50
Selenium	µg/l	*10*	-	-	<1.0	<1.0	<1.0
Zinc Zn	µg/l	-	-	-	9.4	6.7	6.6
Oxygen Demand/Organic Carbon							
BOD	mg/l	-	-	*1.3*	<1	<1	<1
COD	mg/l	-	-	*40*	30	20	15
Microbiology							
Total coliforms (i.e. Confirmed)	CFU/100ml	*0*	*0*	-	**57**	**41**	**34**
Faecal coliforms (E. coli)	CFU/100ml	*0*	*0*	-	**5**	**3**	**9**

Note:

450 Values are shaded yellow and in RED bold where SI No. 294 of 1989 MACs, SI No. 278 of 2007 Parametric Values, or S.I. No. 272 Surface Water Reg. Threshold Levels, Wastewater Discharge Licence Reg. No. D0513-01 Interim Emission Limit Values/2016 Emission Lim

< = Less than

'-' signifies analysis not carried out on sample or no SI No. 294 of 1989 MACs, SI No. 278 of 2007 Parametric Values, or

9 GENERIC QUANTITATIVE RISK ASSESSMENT

In line with the scope of works provided by Galway County Council, the soil, groundwater leachate and surface water results have been compared to Generic Acceptance Criteria (GAC) in Sections 5, 7 and 8. In assessing what poses the most risk to potential receptors only exceedances of soil and groundwater GACs are used. However, it should be noted that the surface water body, which was sampled and analysed should also be regarded as a receptor.

For soils, although the assessment of contaminants in CEN 10:1 leachate is useful, as an indicator of potential long-term leachability, 'Total Pollutant' content provides the most relevant data for risk assessment to potential receptors.

For groundwater risk assessment, although the assessment of contaminants in leachate is useful, actual groundwater contaminant concentrations provide the most relevant data for risk assessment to potential receptors.

The exceedances of the above-mentioned GACs can be summarised as follows:

9.1 Soil

- Mercury which was found to exceed the Dutch Target Value Level of 0.3mg/kg in the sample taken from TP17; and
- Mercury which was found to equal the *CLEA 2009 Soil Guideline Value for Residential with Plant Uptake* of 1mg/kg in the sample taken from TP19.

9.2 Groundwater

The results obtained within the groundwater samples for Ammoniacal Nitrogen ranged from 8.6mg/l in BH101 (i.e. the upgradient borehole) to 0.4mg/l in BH103 (i.e. a downgradient borehole).

The results obtained within the leachate samples for Ammoniacal Nitrogen were as expected, noticeably higher at 72mg/l in LC1 to 47mg/l in LC2. These levels would be expected and are typical of leachate from domestic waste.

The results obtained within the groundwater samples for chloride ranged from 54mg/l in BH101 (i.e. the upgradient borehole) to 110mg/l in BH102 and 43mg/l in BH103 (i.e. the downgradient boreholes). These levels which exceed the S.I. No. 9, 2010 Threshold Value, would be expected given the proximity of waste and the direction of groundwater flow towards the west.

The results obtained within the leachate samples for chloride ranged from 74mg/l in LC2 to 82mg/l in LC1. These levels would be expected and are typical of leachate from domestic waste.

The results obtained within the groundwater samples for potassium ranged from 9.4mg/l in BH101 (i.e. the upgradient borehole) to 3mg/l in BH103 (i.e. the downgradient borehole). The values obtained for the sample from BH101 and BH102 exceeded the EPA Interim Guideline Value (IGV). The level of

potassium found in BH102 was also reflected in the Potassium/Sodium ratio which was 0.46. A ratio greater than 0.4 generally would indicate an impact by domestic leachate.

The results obtained within the leachate samples for potassium ranged from 19mg/l in LC1 to 20mg/l in LC2. Both of these values grossly exceeded the EPA Interim Guideline Value (IGV) of 5mg/l. These levels were also reflected in the Potassium/Sodium ratios of 0.51 and 0.38. A ratio greater than 0.4 generally would indicate an impact by domestic leachate.

Of the heavy metals the following exceedances of GACs were found:

- *Arsenic*

A value of 28µg/l was obtained in BH103. This value exceeded the corresponding EPA IGV and Threshold Value.

- *Boron*

Values of 810µg/l and 810µg/l were obtained in LC1 and LC2 respectively. These exceed the corresponding Threshold Value

- *Iron*

Values of 260µg/l and 2,900µg/l were obtained in LC1 and LC2 respectively. These values exceed the corresponding Drinking Water MACs and Parametric Values which are 200µg/l. These values would be expected as iron, which is sensitive to oxygen levels, is typically reduced to its more mobile Fe^{2+} species and released or leached from soil and bedrock into groundwater during anaerobic (i.e. reducing) conditions.

- *Manganese*

Values of 1,800µg/l, 1,100µg/l and 970µg/l were obtained in BH101, BH102 and BH103 respectively. Values of 880µg/l and 1,300µg/l were obtained in LC1 and LC2 respectively. These values exceed the corresponding Drinking Water MACs and Parametric Values which are 50µg/l. Like iron, these values would be expected as manganese is typically reduced to its more mobile Mn^{2+} species and released or leached from soil and bedrock into groundwater during anaerobic (i.e. reducing) conditions which occur in domestic waste landfills.

- *Nickel*

A value of 16µg/l was obtained in LC2. This value exceed the corresponding Threshold Value which is 15µg/l.

As can be seen from Table A10.1,[9] all of the VOCs analysed were below their respective Method Detection Limits with the exception of:

[9] *Where VOCs are detected they are highlighted in yellow. Where values are underlined, this indicates and exceedance of the corresponding Dutch Target Value. Where values are highlighted in Red bold, this indicates an exceeded of Dutch Intervention Value or of the 1988 Regulations, MAC values.*

- *Benzene*

Benzene was detected in leachate sample taken from LC2 at 0.0014mg/l. This value exceeded the corresponding EPA IGV and Threshold Values.

- *Toluene*

Toluene was detected in groundwater samples taken from BH101 and BH102 at 0.0023mg/l and 0.0011mg/l respectively.

Toluene was detected in leachate samples taken from LC1 and LC2 at 0.014mg/l and 0.011mg/l respectively. These values exceeded their corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *Chlorobenzene*

Chlorobenzene was detected in leachate sample taken from LC2 at 0.0044mg/l. This value exceeded the corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *Ethylbenzene*

Ethylbenzene was detected in leachate sample taken from LC1 at 0.0012mg/l. This value exceeded the corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *p/m-Xylenes*

p/m-Xylenes were detected in groundwater samples taken from BH101 at 0.0032mg/l.

p/m-Xylenes were detected in leachate samples taken from LC1 and LC2 at 0.0083mg/l and 0.0079mg/l respectively. These values exceeded their corresponding MAC Value quoted in the E.C. Regulations (Quality of water intended for human consumption) of 1988.

- *o-Xylene*

O-Xylene was detected in groundwater samples taken from BH101 at 0.0015mg/l.

o-Xylene was detected in leachate samples taken from LC1 and LC2 at 0.0023mg/l and 0.0022mg/l respectively. These values exceeded their corresponding Dutch Target Value.

- *1,2,4-Trimethylbenzene*

1,2,4-Trimethylbenzene was detected in leachate samples taken from LC1 and LC2 at 0.0065mg/l and 0.0045mg/l respectively. No Generic Assessment Criteria are available for this compound.

Most of the afore-mentioned exceedances of, particularly, groundwater GACs would not be classed as gross exceedances.

The levels of ammonia, phosphates, iron and manganese within the surface water in the stream suggest that the stream may have been impacted prior to entering the site. However, the data obtained also suggests that the landfill is impacting slightly on the quality of the surface water i.e. landfill leachate is entering the culvert and mixing with surface water. In effect, the landfill is impacting on the surface water body which enters the Owenglen River approximately 670m to the south and downstream of the site.

Given that there is, in effect, a confirmed pollutant linkage for *'leachate to adjacent surface water body'*, the requirement for a Detailed Quantitative Risk Assessment (DQRA) is redundant. The results of the ammoniacal nitrogen analyses on the surface water suggest that any input of ammonia or other pollutants from the landfill are being diluted by the other streams feeding into the stream downgradient of the site e.g. the stream from Lough Nambrackeagh. As this stream flows southwards, prior to it entering the Owenglen River it is fed with other mountain streams. Given, the hydrology of the Owenglen River, the levels of ammonia, iron and manganese within the stream would be significantly diluted on entering the Owenglen River.

Table 6. Landfill Gas Readings on 21st April, 2014 at Former Landfill at Tullyvogheen, Clifden, County Galway

Gas Well Reference No.	Total Depth of well (m)	O_2 %		CO_2 %		CH_4 %		Peak CH_4 %	H_2S ppm		CO ppm		Barometric Pressure mb	Relative Pressure mb	Weather conditions
		Initial	60 secs	Initial	60 secs	Initial	60 secs		Initial	60 secs	Initial	60 secs			
BH101	12.0	19.6	19.7	0.1	0.1	0.2	0	0.2	0	0	0	0	1020	-0.44	Bright sunny, dry, 12-13°c.
BH102	17.5	20.1	20.1	0.1	0.1	0.1	0	0.1	0	0	3	0	1020	-0.44	Bright sunny, dry, 12-13°c.
BH103	10.0	19.3	19.3	0.2	0	0.2	0	0	0	0	1	0	1020	-0.44	Bright sunny, dry, 12-13°c.
LC1	6.1	18.9	19.1	0.5	0.2	1.1	0.5	0.5	0	0	0	0	1020	-0.44	Bright sunny, dry, 12-13°c.
LC2	9.0	18.7	18.9	0.7	0.2	0.8	0.3	0.8	0	0	0	0	1020	-0.44	Bright sunny, dry, 12-13°c.

Notes:

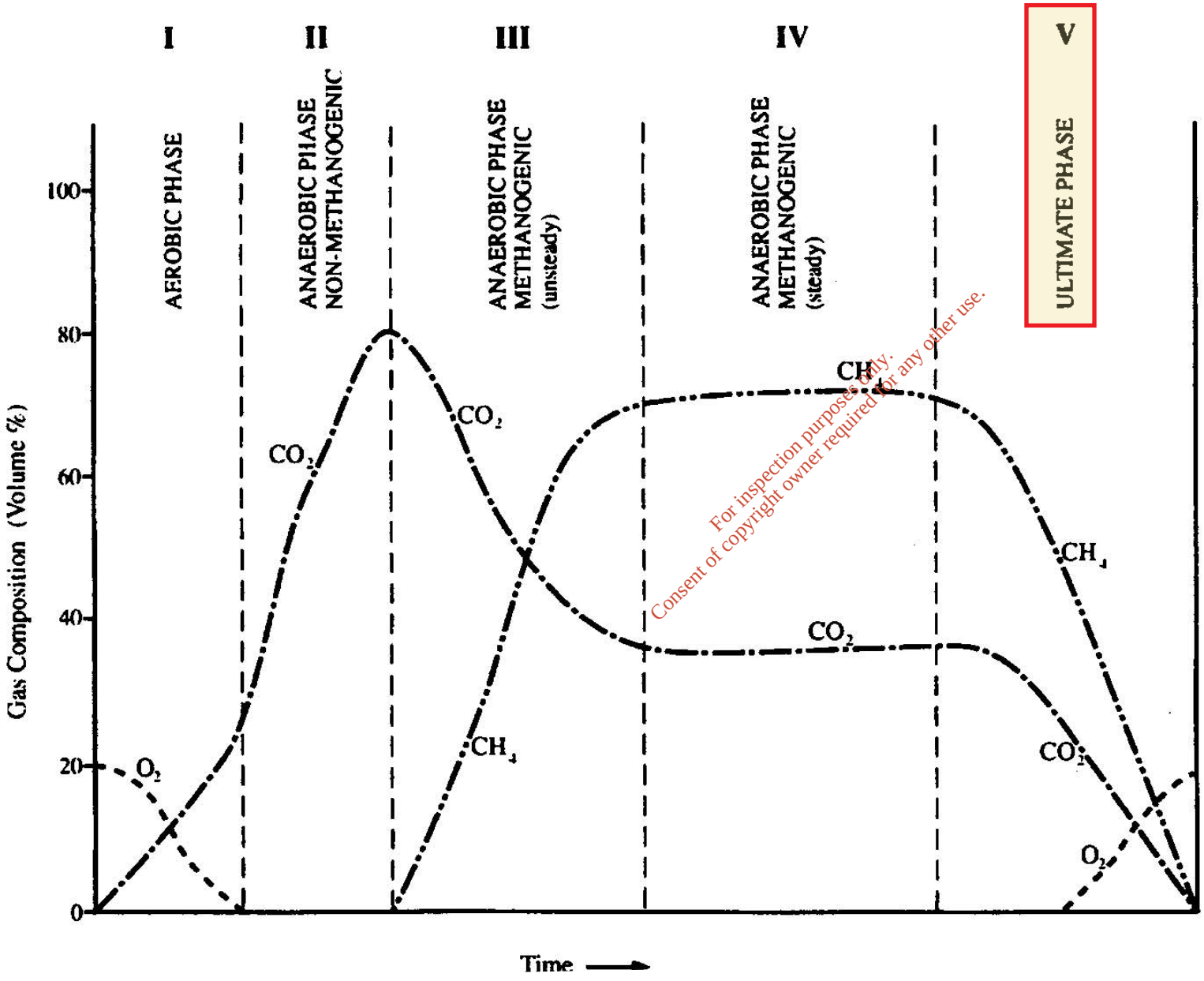
Department of the Environment publication on the '*Protection of New Buildings and Occupants from Landfill Gas*' (1994).

Lower Explosive Limit (LEL) for methane = 5% - Exceendance underlined

Upper Explosive Limit (LEL) for methane = 15% - Exceedance highlighted in yellow and **red bold**

Landfill gas survey using GA 94

Chart 1. Idealised Degradation Phases for Domestic Waste



Client: Galway C.C.		
Project: Tier 2 Site Investigation & Tier 3 GQRA of Former Landfill at Tullyvogheen, Clifden, County Galway		
MULROY environmental	Figure: Degradation Phases for Organic Wastes	
Chart No.: 1	Drawn By: DG	Checked By: PM
Scale: NA	Date: 8th July, 2014	

10 LANDFILL GAS RISK ASSESSMENT

Following the sampling of groundwater and leachate from the 3 groundwater monitoring wells and the 2 leachate wells on the 29th January, 2014, a 2-inch rubber bung fitted with a gas tap was fitted to each well. Potential landfill gas was allowed to equilibrate for 82 days before testing on the 21st April, 2014. Landfill gas concentrations were measured using a GA2000 Landfill Gas analyser. The GA2000 instrument was hired by Mulroy Environmental from Odour Monitoring Ireland who calibrated the instrument to the factory standards prior to its handover.

The results of the landfill gas monitoring are summarised in the following table, Table 6. As can be seen from Table 6, the levels of oxygen (O_2), carbon dioxide (CO_2), methane (CH_4) and nitrogen (N_2) were measured in the initial 10 seconds and then recorded again after 60 seconds (i.e. the steady reading). As can be seen from Table 6, maximum methane levels were found in leachate well, LC1 at 1.1% with this decreasing to 0.5% after 60 seconds. As can be seen from Table 6, the levels found are significantly less than the Lower Explosive Limit (LEL) for methane, which is 5%, and as such, no mitigation measures are required to protect operatives on site.

Methane generation in a typical domestic landfill follows the pattern in the attached chart, Chart 1. Typically, it will take about 2 years to pass through phases I, II and III and reach a steady state of methane production (i.e. Phase IV). This steady state may then continue for a further fifteen to twenty years after which methane production will gradually decline (Phase V). At steady state the typical composition of the landfill gas is in the ranges of 50-70% methane and 30-50% carbon dioxide. As can be seen from Tables 6, methane and carbon dioxide levels on site are significantly less than the afore-mentioned values. Therefore, it is likely that the organic waste observed within the domestic waste has broken down and is in latter stages of Phase 5 *'Ultimate Phase'*. However, it is also possible that the culvert running through the site has provided a horizontal 'pathway of least resistance' expediting the lateral migration of methane out of the site.

11 REFINED CONCEPTUAL SITE MODEL

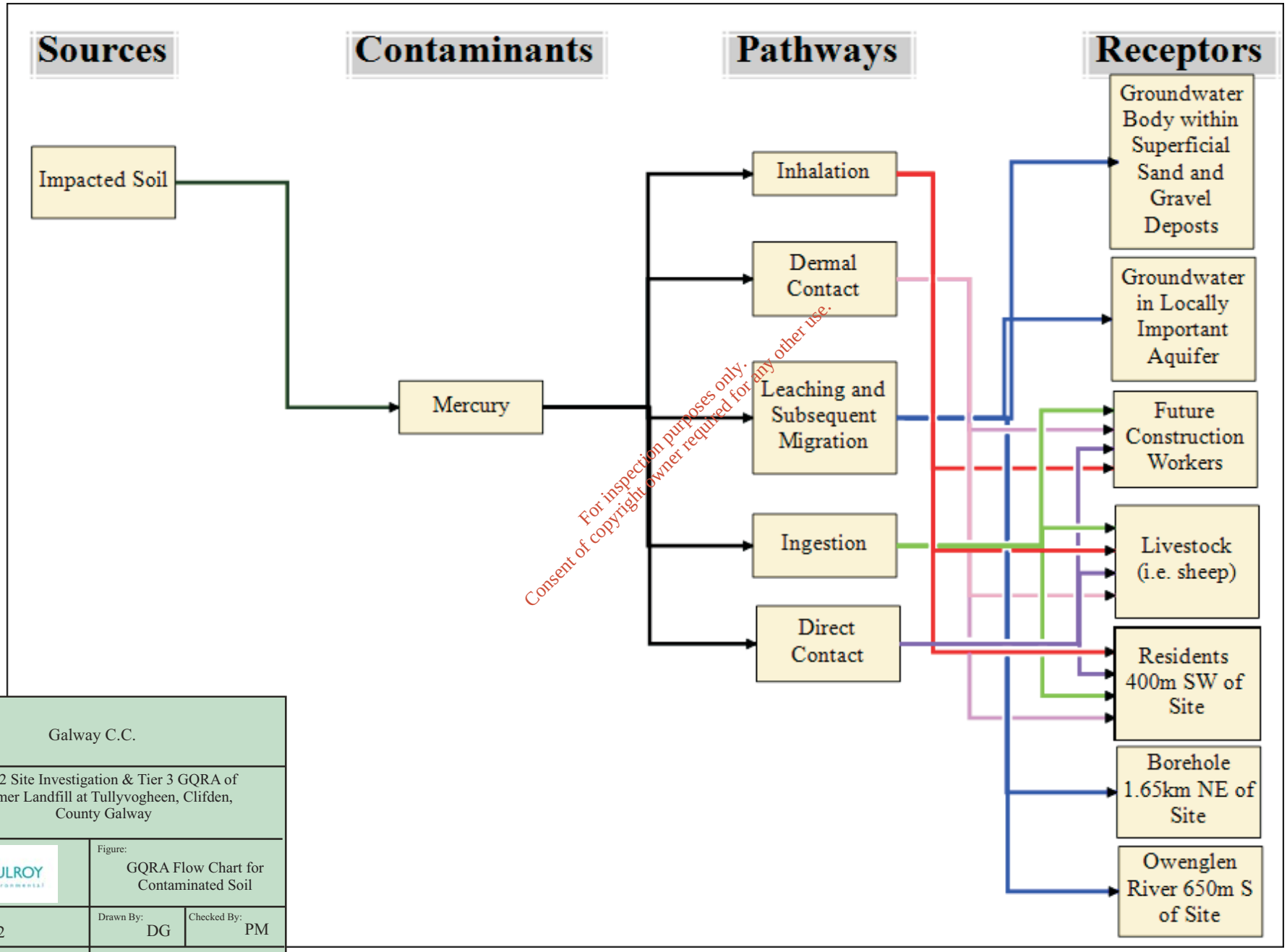
Due to the exceedance of the generic assessment criteria for groundwater and surface water, a refined conceptual model for the site has been collated in line with BS10175 (5) and CLR11 (6). The conceptual site model (CSM) identifies sources of contamination and receptors that could be impacted together with pathways, termed potentially complete pollutant linkages, that connect the two. When a potentially complete pollutant linkage is identified, an estimation of the risk should be made which may involve further investigation or risk assessment. Table 7 records the potential pollutant linkages that have been identified at the site. Justifications for the identification of a potential pollutant linkage together with the likelihood are also discussed in Table 7. Please see Figure 11 for visual representation of the Conceptual Site Model.

Table 7. Identification of Potentially Complete Pollutant Linkages

Source	Pathway	Receptor	Linkage?
Mercury impacted soil (i.e. gravel matrix)	Direct contact; ingestion, dermal contact and inhalation of dust and soils.	Residents of house to southwest of site	**Incomplete.** Site covered in 250mm capping with waste overlying soil - plausible pathway absent. Residents not expected to come into contact with underlying soil during routine activities.
		Livestock (i.e. sheep)	**Incomplete.** Site covered in 250mm capping with waste overlying soil - plausible pathway absent. Livestock not expected to come into contact with underlying soil during routine activities.
		Future construction workers	**Incomplete.** No structure proposed for landfill. However, construction workers for drainage works may come into contact with site soil although unlikely given depth under waste. However the use of suitable PPE and good hygiene measures should mitigate risks posed through this pathway.
	Leaching and subsequent migration	Groundwater in locally important aquifer	**Incomplete:** Pathway exists due to location of gravel soil lying directly on bedrock. However, given hydrophobic nature of Hg it is unlikely to migrate to aquifer. Mercury was not detected in groundwater or surface water.
		Groundwater (shallow) body within superficial sand & gravel deposits	**Incomplete:** Pathway exists due to location of gravel soil lying directly on bedrock. However, given hydrophobic nature of Hg it is unlikely to migrate to aquifer. Mercury not detected in groundwater or surface water.
		Owenglen River 650m to south of site	
		Well at residence 400m south of site & Borehole 1.65km to the northeast of the site	**Incomplete**. Plausible pathway absent due to distance for both boreholes and direction of groundwater flow for borehole to NE of site.

A process flow chart, Chart 2 showing the Source-Contaminant-Pathway-Receptor rationale has been prepared to explain the above table.

Chart 2. GQRA Flow Chart for Contaminated Soil (i.e Mercury)



Client: Galway C.C.		
Project: Tier 2 Site Investigation & Tier 3 GQRA of Former Landfill at Tullyvogheen, Clifden, County Galway		
MULROY environmental	Figure: GQRA Flow Chart for Contaminated Soil	
Chart No.: 2	Drawn By: DG	Checked By: PM
Scale: NA	Date: 8th July, 2014	

Table 7. Identification of Potentially Complete Pollutant Linkages (continued)

Source	Pathway	Receptor	Linkage?
Ammonia, chloride, potassium, arsenic, boron, iron, manganese, nickel, toluene, chlorobenzene, ethylbenzene, xylenes, Trimethylbenz -ene impacted groundwater	Direct contact; ingestion and dermal contact	Residents of house to southwest of site	**Incomplete.** Residence 400m to south of site on water mains. Plausible pathway absent.
		Livestock (i.e. sheep)	**Possibly complete.** Well to north of residence not used for residence but possibly used for livestock.
		Future construction workers	**Incomplete.** Construction workers may come into contact with groundwater (i.e. during pipe laying). However the use of suitable PPE and good hygiene measures should mitigate risks posed through this pathway.
	Migration	Groundwater in poor aquifer	**Complete:** Pathway present due to presence of permeable sands & gravels underlying waste in close proximity to underlying bedrock
		Groundwater (shallow) body within superficial deposits	**Complete:** Pathway due to presence of permeable sands & gravels underlying waste on site. Contamination in site groundwater may migrate vertically and horizontally.
		Stream flowing through site via culvert	**Complete:** Pathway due to presence of permeable sands & gravels underlying waste on site. Stream is culverted through site and is in contact with groundwater. Ammonia, phosphates, iron, manganese, and coliforms found in surface water samples.
		Owenglen River 650m to south of site	**Potentially Complete:** Ammonia, phosphates, iron, manganese, and coliforms found in surface water samples. However, stream is being diluted prior to reaching Owenglen River and is significantly diluted on feeding into Owenglen River.
		Well at residence 400m south of site & Borehole 1.65km to the northwest of the site	**Incomplete**. Plausible pathway absent due to distance for both boreholes and direction of groundwater flow for borehole to NE of site.
Potential vapours associated with toluene, chlorobenzene, ethylbenzene, xylenes, Trimethylbenz -ene impacted groundwater impacted groundwater	Vertical migration and inhalation of vapours	Residents of house to southwest of site	**Incomplete.** Low levels of toluene, chlorobenzene, ethylbenzene, xylenes, 1,2,4-Trimethylbenzene, in groundwater and not identified in surface water.
		Livestock (i.e. sheep)	**Incomplete.** Low levels of toluene, chlorobenzene, ethylbenzene, xylenes, 1,2,4-Trimethylbenzene, in groundwater and not identified in surface water. Livestock are not impacted as none on site.
		Future construction workers	**Incomplete**. Low levels of toluene, chlorobenzene, ethylbenzene, xylenes, 1,2,4-Trimethylbenzene, in groundwater and not identified in surface water. Vapours likely to migrate vertically and then dilute with air at the surface hence plausible pathway considered absent.

A process flow chart, Chart 3 showing the Source-Contaminant-Pathway-Receptor rationale has been prepared to explain the above table.

Table 7. Identification of Potentially Complete Pollutant Linkages (continued)

Source	Pathway	Receptor	Linkage?
Ammonia, phosphate, iron, manganese, and coliforms impacted surface water	Surface water/stream feeding into Owenglen River	Water quality of Owenglen River 650m to south of site	**Incomplete:** Ammonia, phosphates, iron, manganese, and coliforms found in surface water samples. However, stream is being diluted prior to reaching Owenglen River and is significantly diluted on feeding into Owenglen River.
		Ecosystem of SAC No. SAC No. 002031, The Twelve Bens/ Garaun Complex	**Incomplete:** Ammonia, phosphates, iron, manganese, and coliforms found in surface water samples. However, stream is being diluted prior to reaching Owenglen River and is significantly diluted on feeding into Owenglen River.
Landfill gas from domestic waste within landfill body	Lateral migration	Residents of house to southwest of site	**Incomplete:** Maximum methane levels were found in leachate well, LC1 at 1.1% with this decreasing to 0.5% after 60 seconds. Levels not high enough to present a risk to off-site residences nearest of which is 400m south of site.
		On-site buildings & enclosed areas Owenglen River 650m to south of site	**Incomplete:** Truck containers on site are well vented and will not trap landfill gas thus preventing a potential build up. Monitoring indicated that landfill gas is not being produced at a level which would pose a risk to on-site or off-site receptors.

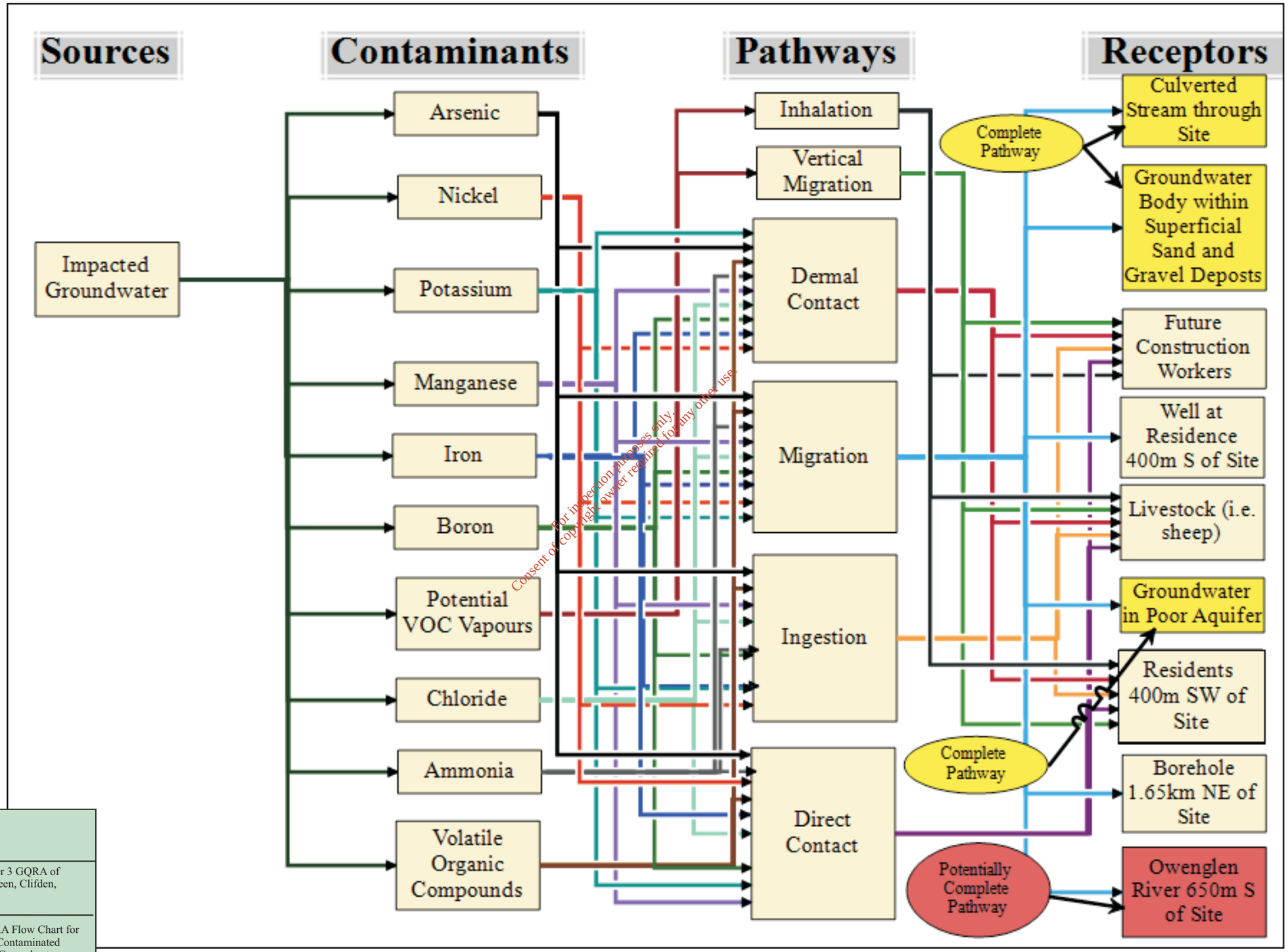
A process flow chart, Chart 4 showing the Source-Contaminant-Pathway-Receptor rationale has been prepared to explain the above table. Please see Figure 11 for visual representation of the Conceptual Site Model.

The scope of the site specific risk assessment included the surface water body which flows through the site. It should be noted that the stream flowing through the site is regarded as both a receptor and a pathway. It is regarded as a pathway or 'conduit' between the landfill and the Owenglen River 650m to the south of the site.

The residence 400m to the south of site is regarded as a potential receptor. Likewise the water abstraction well on this property is regarded as a receptor although it is a considerable distance from the site. It should be noted that the residence is on public water mains. It is not known if the water abstraction well is disused.

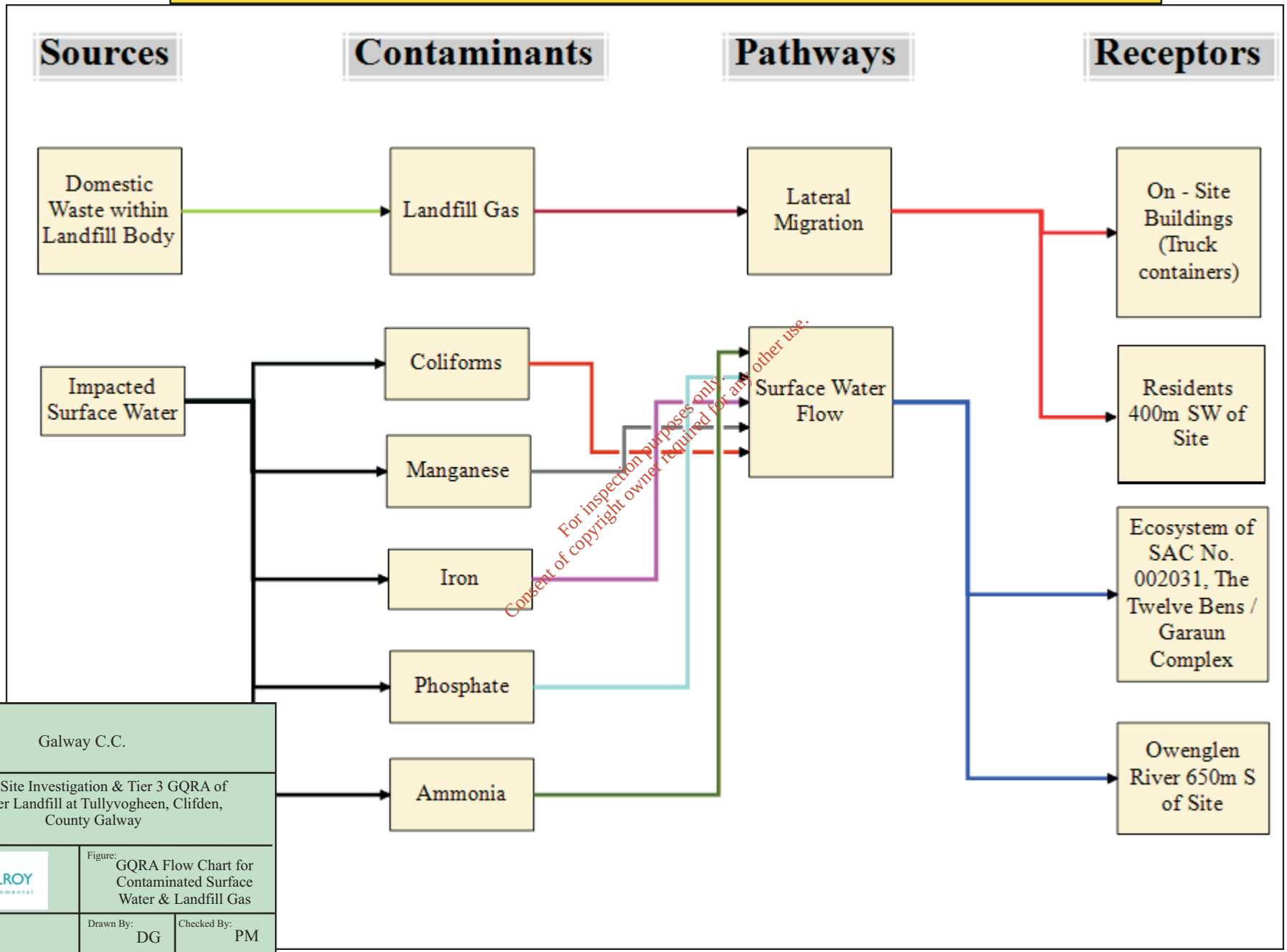
There are no other viable receptors such as water abstraction boreholes identified in the immediate vicinity of the site and more importantly downgradient of the site.

Chart 3. GQRA Flow Chart for Contaminated Groundwater



Client: Galway C.C.		
Project: Tier 2 Site Investigation & Tier 3 GQRA of Former Landfill at Tullyvogheen, Clifden, County Galway		
MULROY environmental	Figure: GQRA Flow Chart for Contaminated Groundwater	
Chart No.: 3	Drawn By: DG	Checked By: PM
Scale: NA	Date: 8th July, 2014	

Chart 4. GQRA Flow Chart for Contaminated Surface Water & Landfill Gas



Client: Galway C.C.	
Project: Tier 2 Site Investigation & Tier 3 GQRA of Former Landfill at Tullyvogheen, Clifden, County Galway	
MULROY environmental	Figure: GQRA Flow Chart for Contaminated Surface Water & Landfill Gas
Chart No.: 4	Drawn By: DG / Checked By: PM
Scale: NA	Date: 8th July, 2014

Complete pollutant linkages have been identified at the site with respect to:

- Migration of groundwater impacted with Ammonia, chloride, potassium, arsenic, boron, iron, manganese, nickel, toluene, chlorobenzene, ethylbenzene, xylenes, 1,2,4-Trimethylbenzene to:
    - Groundwater in poor aquifer;
    - Groundwater (shallow) body within superficial deposits; and
    - Stream flowing through site via culvert.

However, it should be noted that analysis of the surface water at upgradient (SW1) and downgradient points (i.e. SW2 and SW3) did not show elevated levels of chloride, potassium, arsenic, boron, iron, manganese, nickel, toluene, chlorobenzene, ethylbenzene, xylenes, 1,2,4-Trimethylbenzene (see Table 5).

Elevated ammonia, phosphates, iron, manganese, and coliforms were found in surface water samples. However, it should be noted that faecal coliforms were also detected upgradient of the site at SW1.

Potentially complete pollutant linkages have been identified at the site with respect to:

- Migration of groundwater impacted with Ammonia, chloride, potassium, arsenic, boron, iron, manganese, nickel, toluene, chlorobenzene, ethylbenzene, xylenes, 1,2,4-Trimethylbenzene to:
    - Owenglen River 650m to south of site.

Given the contribution of other streams to the surface water flowing through the site culvert (i.e. downgradient of the site) and given the dilution afforded by the Owenglen River, it is likely that the ammonia, phosphates, iron, manganese and faecal coliforms would be significantly diluted on entering the Owenglen River system. This dilution should be significant and should serve to negate any effect on the existing water quality in the Owenglen River and its associated ecosystem.

12 CONCLUSIONS

12.1 Soil & Groundwater Contamination

The results of the laboratory analysis on the soil indicated that the soil (i.e. 2 soils samples out of 4) underlying the waste on site has been impacted by low levels of mercury contamination as a result of waste infilling.

The results of the laboratory analysis on the groundwater and leachate indicate that the groundwater in the vicinity of the site and downgradient has been historically contaminated by the waste infilling. Elevated levels of Ammonia, chloride, potassium, arsenic, boron, iron, manganese, nickel, toluene, chlorobenzene, ethylbenzene, xylenes, 1,2,4-Trimethylbenzene were indentified in the groundwater monitoring wells. These levels were identified at greater levels in the on-site leachate wells as expected. The highest level of contamination was identified in the downgradient boreholes to the west of the site.

The evidence suggests strongly that a contaminant plume exists on site which is emanating in an east to west direction along the valley following the culverted stream. Given the relative permeability of the underlying schist bedrock, it is likely that most of the leachate generated on site is entering the culverted stream. This culvert was constructed along the course of the former stream which would have been located at the lowest point in the valley.

12.2 Impact on Human Receptors

Given the low levels of soil contamination identified on site, leachate generated from the soil is unlikely to impact on the residence 400m to the southwest.

Negligible risk is posed by landfill gas from the site to off-site residences given the age of the waste on site and the distance from the site.

Given the distance from the site, it is unlikely that contaminated groundwater is impacting on the residence to the southwest or on the water abstraction well located to the north of this property. It should be noted that this residence is known to be provided with public water mains.

12.3 Impact on Livestock

Given the low levels of soil contamination identified on site, leachate generated from the soil is unlikely to impact on the livestock in the surrounding areas.

Given the distance from the site, it is unlikely that contaminated groundwater is impacting on the residence to the southwest or on the water abstraction well located to the north of this property. It is not known if this well is currently in use.

12.4 Impact on Culverted Stream

As stated previously, elevated ammonia, phosphates, iron, manganese, and coliforms were found in surface water samples. However, it should be noted that faecal coliforms were also detected upgradient of the site at SW1.

12.5 Impact on Controlled Waters (i.e. Owenglen River)

As stated previously, given the contribution of other streams to the surface water flowing through the site culvert (i.e. downgradient of the site) and given the dilution afforded by the Owenglen River, it is likely that the ammonia, phosphates, iron, manganese and faecal coliforms would be significantly diluted on entering the Owenglen River system. This dilution should be significant and should serve to negate any effect on the existing water quality in the Owenglen River and its associated ecosystem.

13 RECOMMENDATIONS

1. It is recommended that surface water monitoring is continued by Galway County Council and the EPA at the 3 existing sites. However, it is recommended that another 4 surface water monitoring points are set up to assess the impact on the Owenglen River:

    - SW4 to be located to the west of the residence southwest of the site;
    - SW5 to be located at the stream 5m upgradient of where it feeds into the Owenglen River;
    - SW6 to be located on the Owenglen River upgradient of the confluence of the stream and the Owenglen River; and
    - SW7 to be located on the Owenglen River upgradient of the confluence of the stream and the Owenglen River.

    The purpose of this is to determine if the contaminants identified within the surface water body culverted through the landfill are reaching and discharging to the Owenglen River at levels which would be a risk to downgradient receptors and/or the ecosystem which is a Special Area of Conservation (i.e. SAC No. 002031, The Twelve Bens/ Garaun Complex).

2. It is recommended that a Small Stream Ecological Risk Assessment is carried out on the stream downgradient of the site as per the Western River Basin District Project's *Small Streams Risk Score Method Manual, December 2005.*

3. Even though it is unlikely that the well located at the residence 400m from the site has been impacted by contaminated groundwater emanating from the site, it is recommended that, in the event that this well is used for livestock that it is sampled and analysed for a comprehensive laboratory suite (i.e. identical to the laboratory suite used in this study).

If you have any questions or require clarification with regard to any item of this report, please contact me at 086-8770380.

Padraic Mulroy

BSc., MSc., MIEI, MIPSS, C.Sci., SiLC, GSAS-CGP
Managing Director
Mulroy Environmental

14 REFERENCES

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3 BS10175. Investigation of Potentially Contaminated Sites -Code of Practice. BSi. 2001.

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9 Environment Agency. Review of the Fate and Transport of Selected Contaminants in the Soil Environment. Draft Technical Report P5-079/TR1. September 2003.

10 Hartman, B. 2002. How to collect reliable soil-gas data for risk-based applications. Part 1: Active Soil-Gas Method. LUST Line Bulletin, 42, October 2002.

MULROY ENVIRONMENTAL
SERVICE CONSTRAINTS

1. This report and the Environmental Site Assessment carried out in connection with the report (together the "Services") were compiled and carried out by Mulroy Environmental for Galway County Council (the "client") in accordance with the terms of a contract, PRP212.5.04.2013 between Mulroy Environmental and the "client" dated 5th April 2013. The Services were performed by Mulroy Environmental with the skill and care ordinarily exercised by a reasonable Environmental consultant at the time the Services were performed. Further, and in particular, the Services were performed by Mulroy Environmental taking into account the limits of the scope of works required by the client, the time scale involved and the resources, including financial and manpower resources, agreed between Mulroy Environmental and the client.

2. Other than that expressly contained in paragraph 1 above, Mulroy Environmental provides no other representation or warranty whether express or implied, in relation to the Services.

3. Unless otherwise agreed the Services were performed by Mulroy Environmental exclusively for the purposes of the client. Mulroy Environmental is not aware of any interest of or reliance by any party other than the client in or on the Services. Unless expressly provided in writing, Mulroy Environmental does not authorise, consent or condone any party other than the client relying upon the Services. Should this report or any part of this report, or otherwise details of the Services or any part of the Services be made known to any such party, and such party relies thereon that party does so wholly at its own and sole risk and Mulroy Environmental disclaims any liability to such parties. Any such party would be well advised to seek independent advice from a competent environmental consultant and/or lawyer.

4. It is Mulroy Environmental understanding that this report is to be used for the purpose described in the introduction to the report. That purpose was a significant factor in determining the scope and level of the Services. Should the purpose for which the report is used, or the proposed use of the site change, this report may no longer be valid and any further use of or reliance upon the report in those circumstances by the client without Mulroy Environmental be requested to review the report after the date hereof, Mulroy Environmental shall be entitled to additional payment at the then existing rates or such other terms as agreed between Mulroy Environmental and the client.

5. The passage of time may result in changes in site conditions, regulatory or other legal provisions, technology or economic conditions which could render the report inaccurate or unreliable. The information and conclusions contained in this report should not be relied upon in the future without the written advice of Mulroy Environmental. In the absence of such written advice of Mulroy Environmental, reliance on the report in the future shall be at the client's own and sole risk. Should Mulroy Environmental be requested to review the report in the future, Mulroy Environmental shall be entitled to additional payment at the then existing rate or such other terms as may be agreed between Mulroy Environmental and the client.

6. The observations and conclusions described in this report are based solely upon the Services which were provided pursuant to the agreement between the client and Mulroy Environmental. Mulroy Environmental has not performed any observations, investigations, studies or testing not specifically set out or required by the contract between the client and Mulroy Environmental. Mulroy Environmental is not liable for the existence of any condition, the discovery of which would require performance of services not otherwise contained in the Services. For the avoidance of doubt, unless otherwise expressly referred to in the introduction to this report, Mulroy Environmental did not seek to evaluate the presence on or off the site of asbestos, electromagnetic fields, lead paint, heavy metals, radon gas or other radioactive or hazardous materials.

7. The Services are based upon Mulroy Environmental's observations of existing physical conditions at the Site gained from a walk-over survey of the site together with Mulroy Environmental's interpretation of information including documentation, obtained from third parties and from the client on the history and usage of the site. The Services are also based on information and/or analysis provided by independent testing and information services or laboratories upon which Mulroy Environmental was reasonably entitled to rely. The Services clearly are limited by the accuracy of the information, including documentation, reviewed by Mulroy Environmental and the observations possible at the time of the walk-over survey. Further Mulroy Environmental was not authorised and did not attempt to independently verify the accuracy or completeness of information, documentation or materials received from the client or third parties, including laboratories and information services, during the performance of the Services. Mulroy Environmental is not liable for any inaccurate information or conclusions, the discovery of which inaccuracies required the doing of any act including the gathering of any information which was not reasonably available to Mulroy Environmental and including the doing of any independent investigation of the information provided to Mulroy Environmental save as otherwise provided in the terms of the contract between the client and Mulroy Environmental.

8. The Phase II or intrusive environmental site investigation aspects of the Services is a limited sampling of the site at pre-determined borehole and soil vapour locations based on the operational configuration of the site. The conclusions given in this report are based on information gathered at the specific test locations and can only be extrapolated to an undefined limited area around those locations. The extent of the limited area depends on the soil and groundwater conditions, together with the position of any current structures and underground facilities and natural and other activities on site. In addition chemical analysis was carried out for a limited number of parameters [as stipulated in the contract between the client and Mulroy Environmental] [based on an understanding of the available operational and historical information,] and it should not be inferred that other chemical species are not present.

9. Any site drawing(s) provided in this report is (are) not meant to be an accurate base plan, but is (are) used to present the general relative locations of features on, and surrounding, the site.

LEGEND

- Site Boundary
- Special Area of Conservation (SAC)
- Special Protected Area (SPA)
- Proposed Natural Heritage Area (pNHA)

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING

2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:

Galway County Council

Project:

Tier 2 Site Investigation & Tier 3 GQRA Assessment of Former Tullyvogheen Landfill

Title:

Site Location & Proximity of SACs, pNHAs & SPAs

Scale: 1:20,000@A3

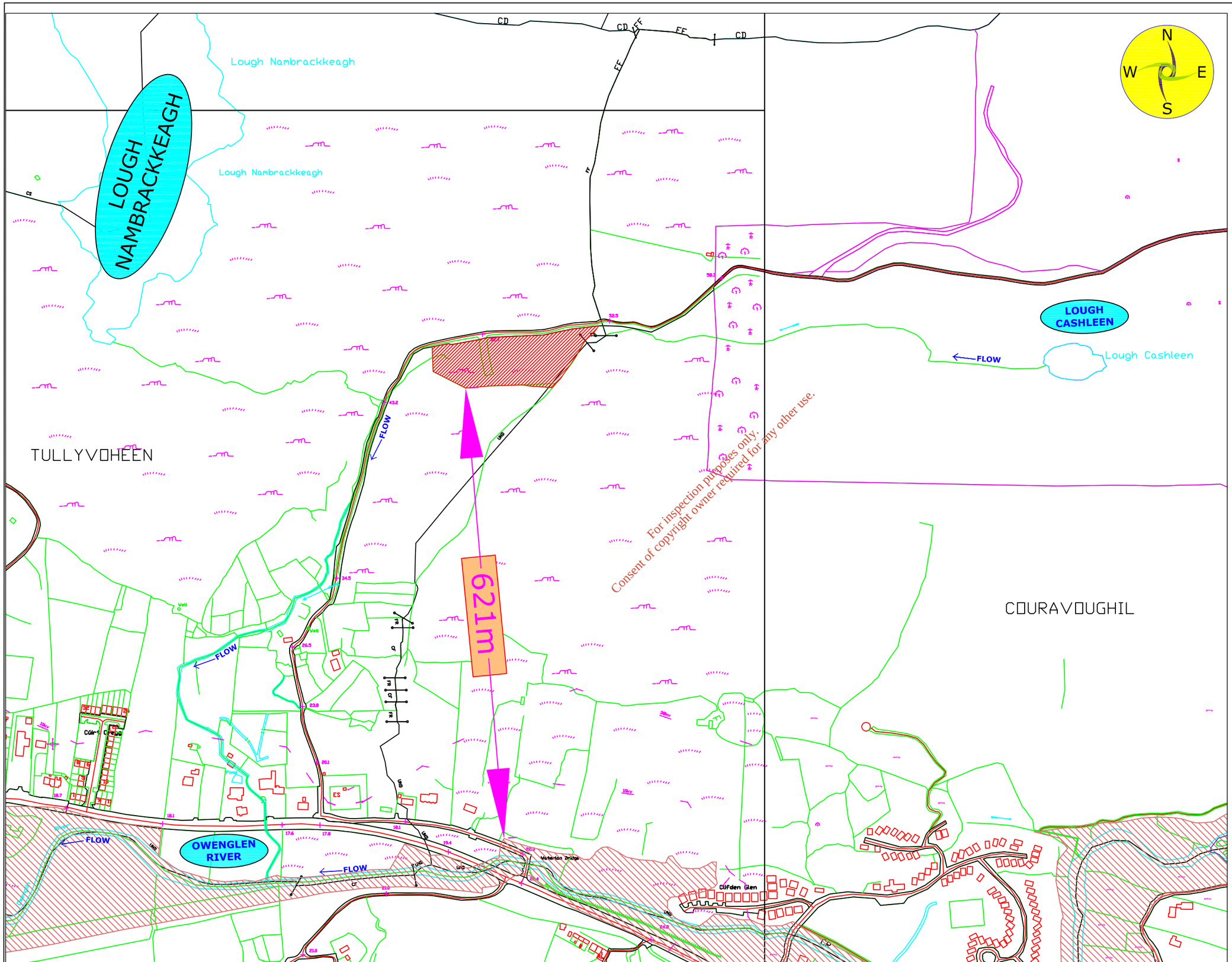
Prepared by:	Checked:	Date:
C.D.	P.M.	08-04-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 1

Issue: 0



LEGEND

Site Boundary

Special Area of Conservation
SAC No. 002031
The Twelve Bens/ Garaun Complex

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING

2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:
Galway County Council

Project:
Tier 2 Site Investigation &
Tier 3 GQRA Assessment
of Former Tullyvogheen Landfill

Title:
Site Location
&
Proximity of SAC No. 002031,
The Twelve Bens/Garaun Complex

Scale:
1:5,000@A3

Prepared by:	Checked:	Date:
C.D.	P.M.	08-04-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 2

Issue: 0

ULLYVOHEEN

SHEEP/CATTLE PASTURELAND

500m BUFFER

Well

FLOW

CUIRT CREGG HOUSING ESTATE

Cúirt Créga

Pond

River

FLOW

OWENGLEN RIVER

GALWAY C.C. PUMPING STATION

ESB SUBSTATION

SHEEP/CATTLE PASTURELAND

SHEEP/CATTLE PASTURELAND

Well

FLOW

UND

FR

CF

38kv

10kv

Waterloo Bridge

52.5

43.2

34.5

26.5

23.8

20.1

18.7

18.1

17.6

17.8

19.4

22.3

N
W
E
S

LEGEND

- Site Boundary
- Residential Property
- Public Property
- 500m Buffer

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING

2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:
Galway County Council

Project:
Tier 2 Site Investigation & Tier 3 GQRA Assessment of Former Tullyvogheen Landfill

Title:
Site Location & Surrounding Property

Scale:
1:3,000@A3

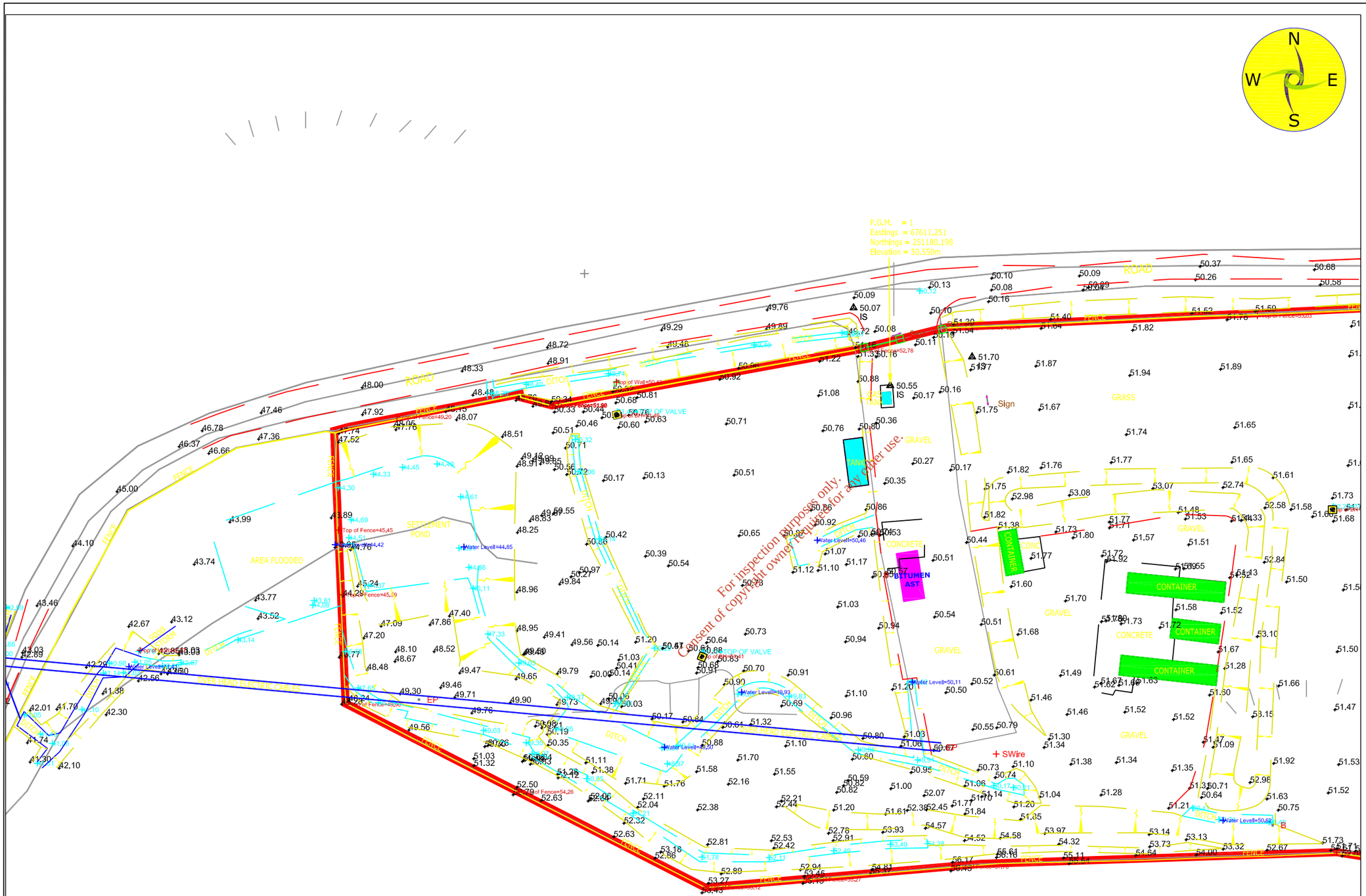
Prepared by:	Checked:	Date:
C.D.	P.M.	08-04-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 3

Issue: 0



LEGEND

Site Boundary

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING

2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:

Galway County Council

Project:

Tier 2 Site Investigation &
Tier 3 GQRA Assessment
of Former Tullyvogheen Landfill

Title:

Site Layout
&
Topographical Survey
(Western Half)

Scale:

1:500@A3

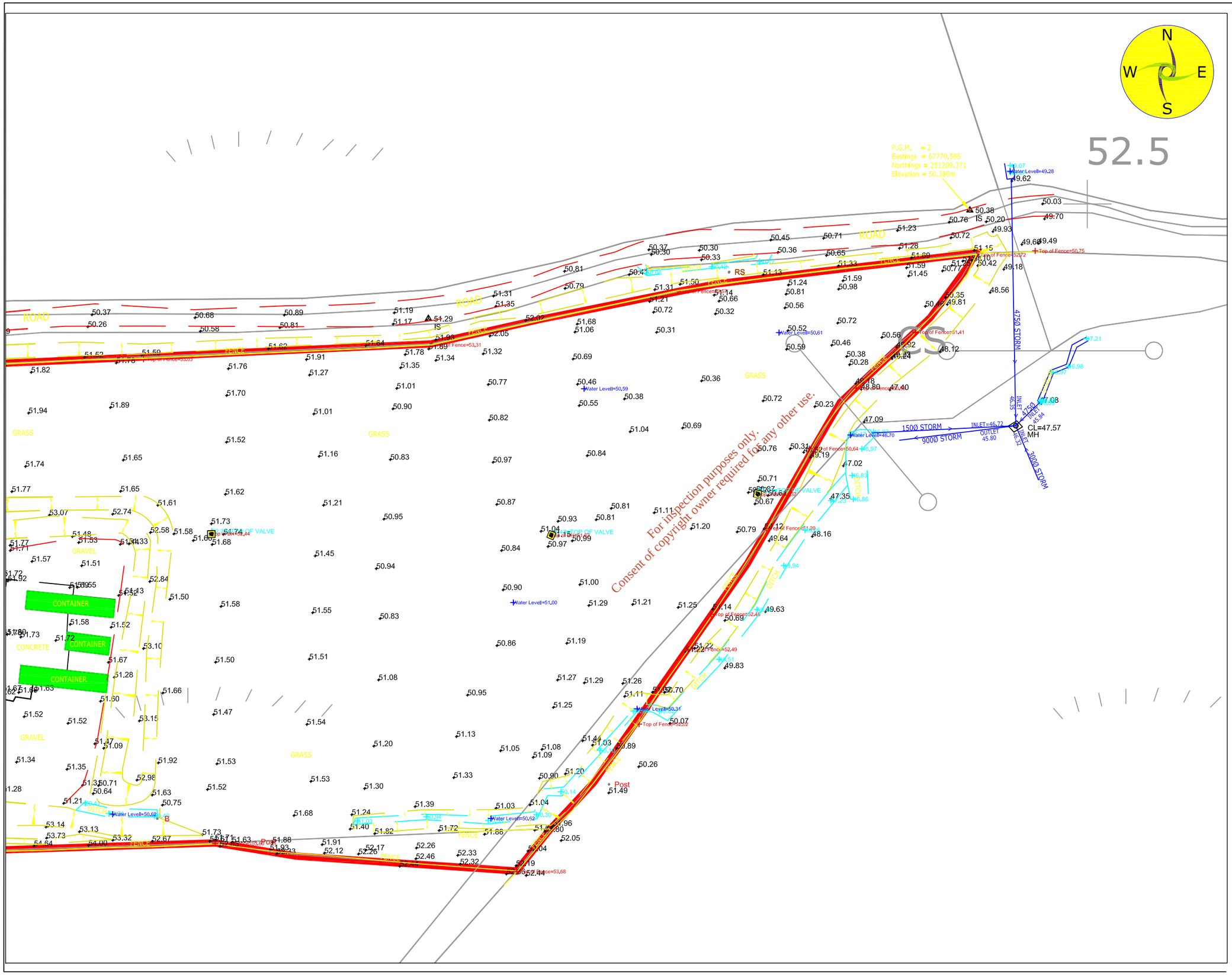
Prepared by:	Checked:	Date:
G.F.	P.M.	08-04-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 4

Issue: 0



LEGEND

Site Boundary

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING

2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:

Galway County Council

Project:

Tier 2 Site Investigation &
Tier 3 GQRA Assessment
of Former Tullyvogheen Landfill

Title:

Site Layout
&
Topographical Survey
(Eastern Half)

Scale:

1:500@A3

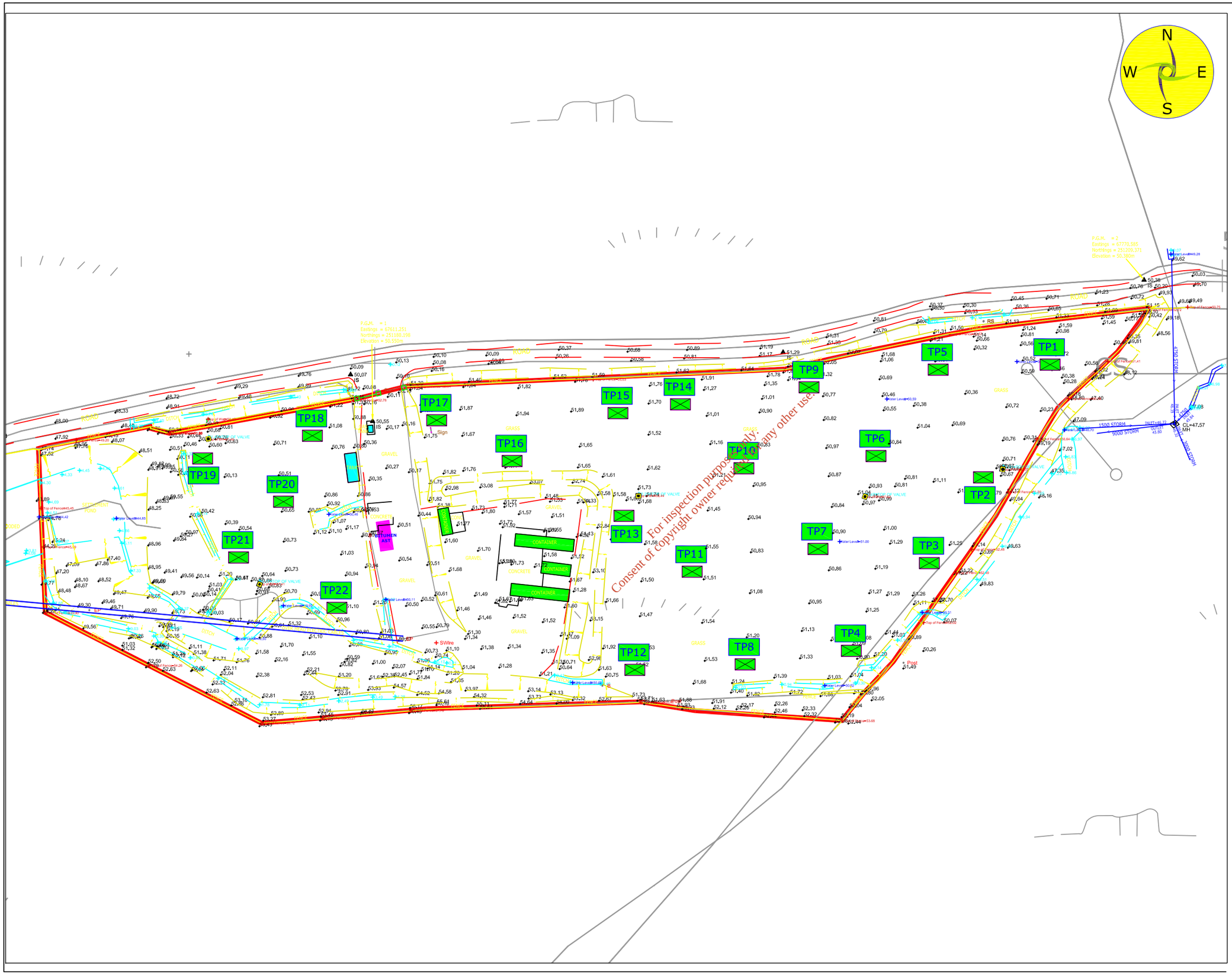
Prepared by:	Checked:	Date:
G.F.	P.M.	08-04-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 5

Issue: 0



LEGEND

Site Boundary

TP1 Trialpit Location

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING

2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client: Galway County Council

Project: Tier 2 Site Investigation & Tier 3 GQRA Assessment of Former Tullyvogheen Landfill

Title: Trialpit Locations

Scale: 1:750@A3

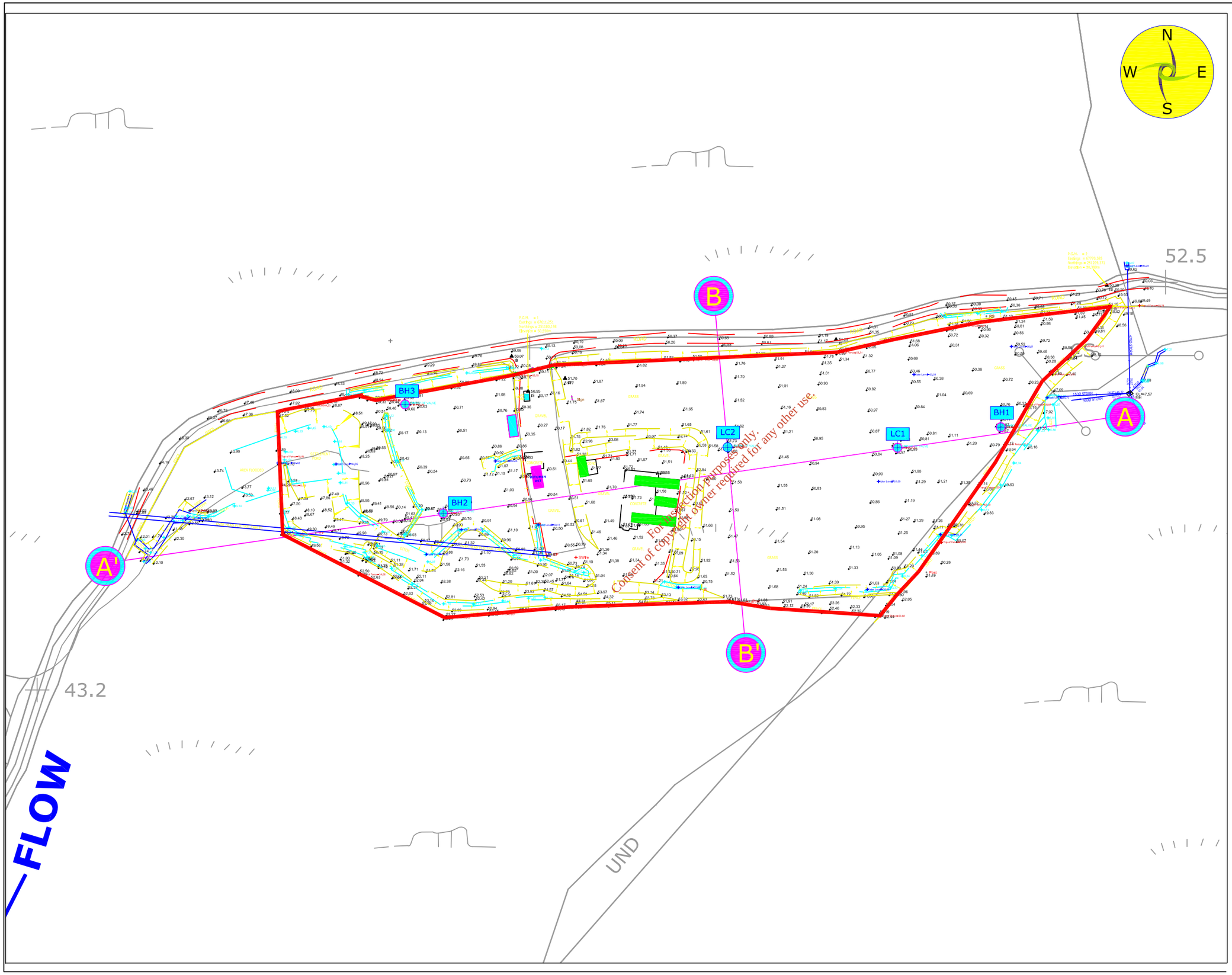
Prepared by:	Checked:	Date:
G.F.	P.M.	29-05-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 6

Issue: 0



LEGEND

- Site Boundary
- BH2 — Groundwater Monitoring Borehole Location
- LC2 — Leachate Monitoring Well Location
- A — Section Line Location

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:
Galway County Council

Project:
Tier 2 Site Investigation & Tier 3 GQRA Assessment of Former Tullyvogheen Landfill

Title:
Groundwater Monitoring Well, Leachate Well Locations & Section Locations

Scale:
1:1,000@A3

Prepared by:	Checked:	Date:
G.F.	P.M.	29-05-14

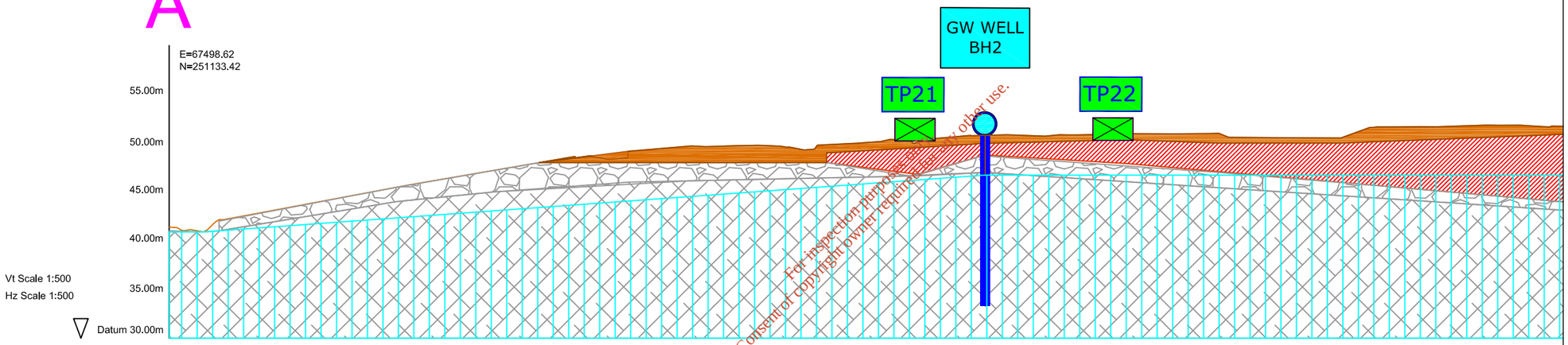
Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 7

Issue: 0

A'



Vt Scale 1:500
Hz Scale 1:500

LEGEND

- Landfill cap (silty PEAT)
- Domestic WASTE
- Underlying GRAVEL/PEAT
- Approximate depth of BEDROCK
- Approximate location of groundwater table
- Trialpit marker
- Borehole marker

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:
Galway County Council

Project:
Tier 2 Site Investigation &
Tier 3 GQRA Assessment
of Former Tullyvogheen Landfill

Title:
Section A-A'
(East to West,
See Figure 7)

Scale:
1:500@A3

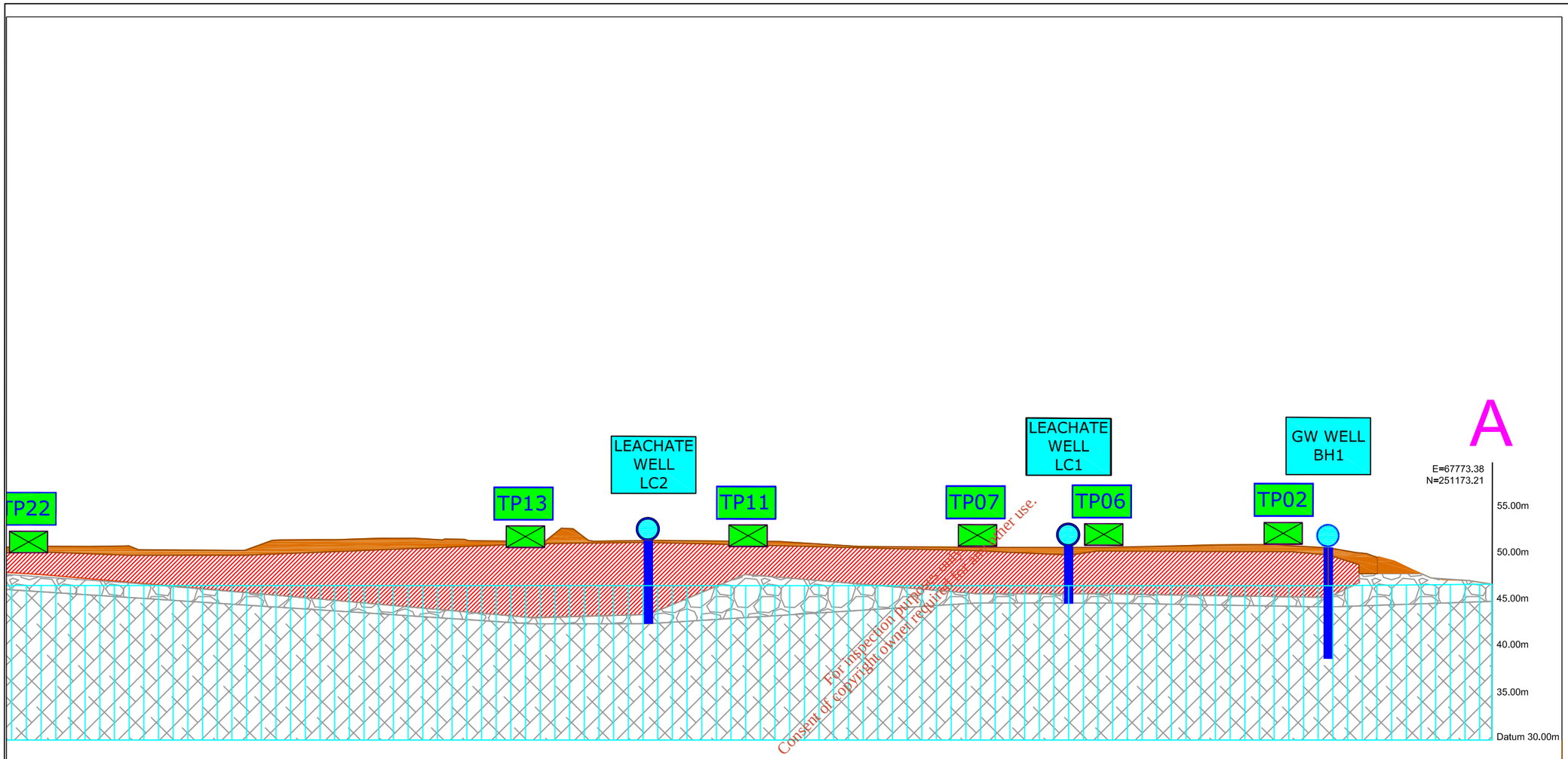
Prepared by:	Checked:	Date:
G.F.	P.M.	28-05-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 8

Issue: 0



LEGEND

- Landfill cap (silty PEAT)
- Domestic WASTE
- Underlying GRAVEL/PEAT
- Approximate depth of BEDROCK
- Approximate location of groundwater table
- Trialpit marker
- Borehole marker

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client:
Galway County Council

Project:
Tier 2 Site Investigation &
Tier 3 GQRA Assessment
of Former Tullyvogheen Landfill

Title:
Section A-A'
(East to West,
See Figure 7)

Scale:
1:500@A3

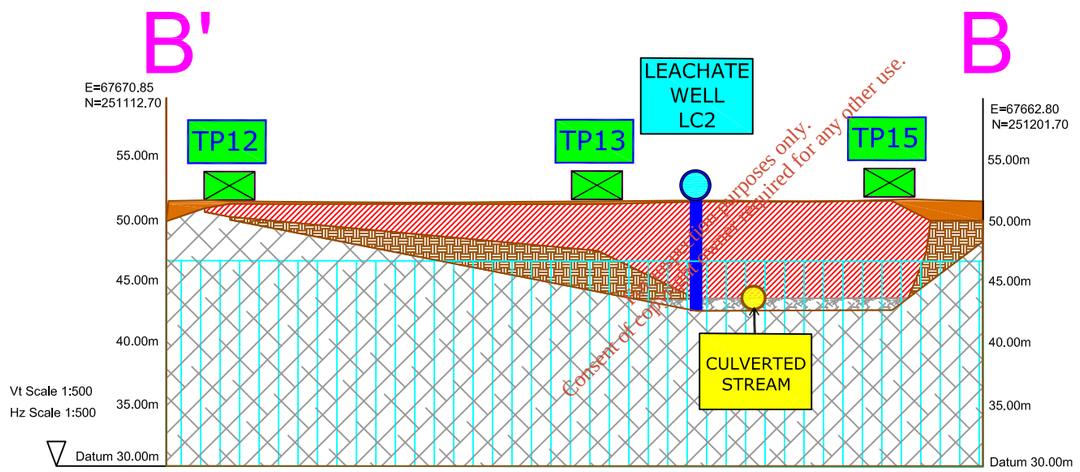
Prepared by:	Checked:	Date:
G.F.	P.M.	28-05-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 8

Issue: 0



LEGEND

- Landfill cap (silty PEAT)
- Domestic WASTE
- Underlying PEAT
- Underlying GRAVEL
- Approximate depth of BEDROCK
- Approximate location of groundwater table
- Trialpit marker
- Borehole marker
- Approximate location of culverted stream

Issue	Date	Description	By	Chkd.

Client:
Galway County Council

Project:
Tier 2 Site Investigation &
Tier 3 GQRA Assessment
of Former Tullyvogheen Landfill

Title:
Section B-B'
(See Figure 7)

Scale:
1:500@A3

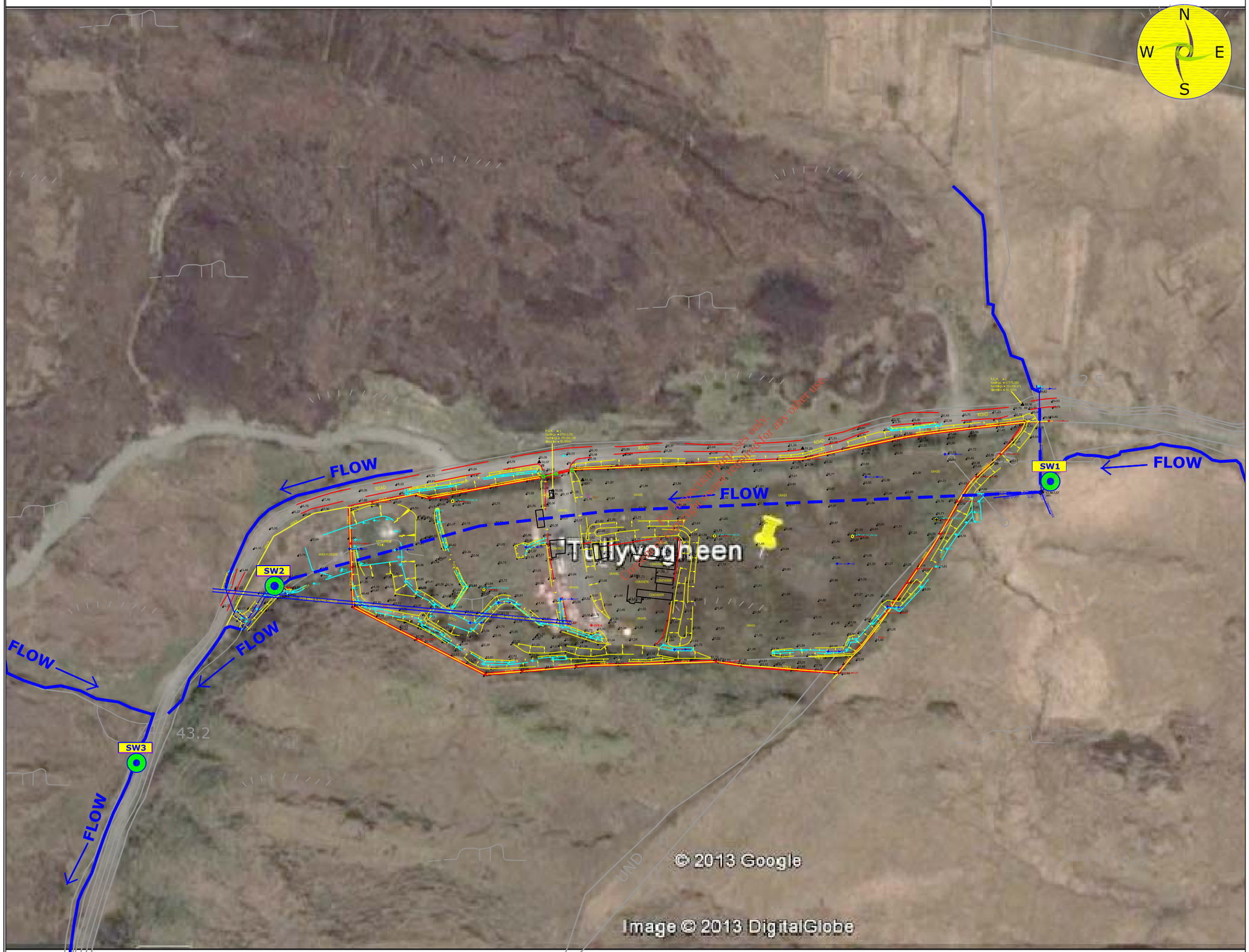
Prepared by:	Checked:	Date:
G.F.	P.M.	9-07-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 9

Issue: 0



LEGEND

- Site Boundary
- Surface Water Monitoring Point Location (SW3)
- Surface Water Body
- Culverted Surface Water Body

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Issue	Date	Description	By	Chkd.

Client: Galway County Council

Project: Tier 2 Site Investigation & Tier 3 GQRA Assessment of Former Tullyvogheen Landfill

Title: Surface Water Monitoring Point Locations

Scale: 1:1,250@A3

Prepared by:	Checked:	Date:
G.F.	P.M.	29-05-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 10

Issue: 0

LANDFILL GAS MIGRATION OFF-SITE TO RESIDENCES

GROUNDWATER BASEFLOW INTO CULVERTED ON-SITE STREAM

GROUNDWATER FLOW DIRECTION

TARGET 1

SOURCE

PATHWAY

GROUNDWATER MIGRATION OFF-SITE TO WIDER GROUNDWATER BODY

PATHWAY

TARGET 5

SHEEP/CATTLE PASTURELAND

TARGET 3

NEAREST RESIDENCE 400m

TARGET 4

CUIRT CREGG HOUSING ESTATE

SHEEP/CATTLE PASTURELAND

ESB SUBSTATION

GALWAY C.C. PUMPING STATION

TARGET 2

OWENGLEN RIVER

Waterloo Bridge

FLOW

UND

FR

CF

Well

Pond

River

Cúirt Creggs

38kv

10kv

52.5

43.2

34.5

26.5

23.8

20.1

18.7

18.1

17.6

17.8

19.4

22.3

LEGEND

- Site Boundary
- Residential Property
- Public Property
- SOURCE — Remaining residual waste contaminants from Domestic Waste on site
- PATHWAY — Migration by groundwater, surface water or landfill gas through overburden
- TARGET 1 — Culverted stream
- TARGET 2 — Owenglen River
- TARGET 3 — Residence Water Abstraction Well
- TARGET 4 — Residence 400m SW of site
- TARGET 5 — Livestock off-site

Issue	Date	Description	By	Chkd.

Client: Galway County Council

Project: Tier 2 Site Investigation & Tier 3 GQRA Assessment of Former Tullyvogheen Landfill

Title: Conceptual Site Model (CSM)

Scale: 1:3,000@A3

Prepared by:	Checked:	Date:
P.MCC.	P.M.	10-07-14

Project Director: P.MULROY

MULROY environmental

Drawing No.: Figure 11

Issue: 0