Limerick County Council

Churchtown Landfill Environmental Risk Assessment Tier 3

Refinement of Conceptual Site Model & Quantitative Risk Assessment

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APPENDICES

1 INTRODUCTION

The Tier 1 Environmental Risk Assessment (i.e. Conceptual Site Model, Risk Screening and Prioritisation) was completed by Limerick County Council in 2007.

The Tier 2 Environmental Risk Assessment (i.e. Site Investigations & Testing) was undertaken by Limerick County Council and TOBIN in accordance with the EPA Code of Practice Environmental Risk Assessment for Unregulated Waste Disposal Sites in 2007. During December 2012, further site investigation works and environmental monitoring were undertaken to provide additional data on the waste disposal site and to inform the Environmental Risk Assessment. The Conceptual Model was well defined in the original site investigation works (Tier 1 & Tier 2 Environmental Site Assessment) using trial pitting, shallow borehole locations and deep borehole investigations. The site had previously been used as waste disposal site for predominantly domestic and commercial waste. The Landfill area covers approximately 1.76 Hectares and waste material deposited at the site is between 1m to 15m deep. The investigation found that 200,000 cubic metres of mixed waste and soils had been deposited at the site. The waste was deposited between the 1930s and 1980s. The waste body was found to be partially saturated with perched Leachate. Landfill gasses were being generated within the waste body.

Overlying the domestic, commercial and industrial wastes, soil and stones were used to cover the waste. The surface cover is not an engineered cap material and therefore volatilisation and venting of landfill gases and VOCs contaminants are likely to occur. The nearest receptors are located less than 50m from the landfill area.

The landfill area is not lined on the base or side and therefore groundwater and surface water pathways exist. The site is underlain by limestones bedrock aquifer. There is a potential for landfill leachate to migrate offsite in the groundwater body. Additionally there is a potential for migration of Leachate towards the nearby stream. No groundwater boreholes were identified downgradient of the landfill. The main receptors in the vicinity of the site are the groundwater aquifer and the nearby stream.

The landfill is comprised predominately of industrial, domestic, commercial and minor quantities of construction and demolition wastes.

This report deals with the Tier 3 Environmental Risk Assessment (i.e. Refinement of Conceptual Site Model and a Detailed Quantitative Risk Assessment). A proposed site restoration plan is proposed outlining potential measures for remediation and risk attenuation. This identifies the potential risks to nearby residents, groundwater and nearby surface water receptors.

Walkover Survey

The site is located to the west of Newcastlewest in the townland of Churchtown, Newcastlewest, Co. Limerick. The site is a rectangular shape and bordered to the east by housing along the R521 and by the old mill road to the south. Agricultural land is located to the east and north of the landfillThe site is located to the north of a tributary stream of the River Dooally (Leonard's stream). The National Grid

Reference for the centre of the site is E 127450 N 134600. The elevation of the site is approximately 68 to 77 metres AOD. The waste body is predominantly soft covered with no permanent structures above the waste body.

The nearest residential dwellings to the landfilled area is Evergreen Close immediately south of the landfill area and housing along Churchtown road (R521). There are 17 No. houses located within 50m of the site. The site and surrounding area is comprised of moderate relief with gently rolling hills. The site and surrounding area vary from 55mOD to 80mOD.

The surface of the landfill area is dry in general, possible due to the use of broken shale to partially cover the landfill area and a steep gradient to the west of the site. A small area of surface water ponding on the landfill area was noted to the western edge of the waste material.

2 SITE SETTING

2.1 SOIL AND SUBSOIL

The soils in the surrounding area are comprised of Basic Deep Well Drained soils (BMinDW) with some areas mapped as Basic Deep Poorly Drained soils (BMinDP). According to EPA subsoil data the predominant subsoil within the study area consist of till derived from limestone (TLs). Further to the north is an area of limestone gravel (GLs). Depths for overburden surrounding the site range from 2 to 22 metres. Visual assessment of the subsoils onsite confirms the EPA classification. Soils assessed within the catchment indicated that slightly sandy gravely clay (limestone till) is present. The native subsoils have a high clay content and low permeability. The subsoils are generally described as "*clayey*" in texture and groundwater gleys dominate. The natural drainage density is high, and estimated to be 1.3 km/km^2, suggestive of low permeability subsoil. The artificial drainage density is high. There are deep drains on slopes, along roads and in fields.

2.2 AQUIFER CLASSIFICATION

Geological Service of Ireland (GSI) records indicate that the main aquifer beneath the site is the Carboniferous bedrock of the Waulsortian Formation. The bedrock beneath the site is classified in the Limerick Groundwater Protection Scheme (Limerick County Council & GSI, 1999) as a '*Regionally important diffuse karst aquifer with good development potential (Rkd)'*. Based on the Newcastlewest Groundwater body description, the pure unbedded limestones (Waulsortian limestones) are a maximum 1200 m in thickness. However, the effective flowing thickness is likely to be about 30 m, although much deeper inflows can occur if associated with faults or dolomitisation.

2.3 GROUNDWATER USAGE ON-SITE AND OFF-SITE

There are no existing groundwater abstraction points at the subject site, nor are there any proposed. There are no groundwater abstraction points between the site and Leonard's stream.

2.4 GROUNDWATER VULNERABILITY

The DoEHLG, 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 DoEHLG, 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 extreme and high permeability subsoils are present, the following thicknesses of unsaturated zone are specified:

Table 2.1 Groundwater Vulnerability Mapping Guidelines

Vulnerability rating	High permeability (sand/gravel)	Moderate permeability(sandy till)	Low permeability (clayey subsoil)
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

On the basis of these DoEHLG, EPA and GSI recommendations, and the site investigation data, which are discussed earlier*, an ‘Extreme to Low’* vulnerability rating is conservatively assigned to the surrounding area based on borehole data.

2.5 NATIONAL HERITAGE AREAS

There are no protected area is located within 4km of the site and there are no protected areas in hydraulic connection within 15 km of the site.

2.6 TIER 2 - SITE INVESTIGATION 2007

Site investigation works were conducted in July 2007 as follows.

- 10 no. Trial pits (TP1-TP10) were excavated in the presence of Limerick County Council in 2007, with sampling of Leachate and soils in the excavated trial trenches was conducted as well as surface water sampling.
- 7 No. monitoring boreholes were installed in July 2007 to facilitate the monitoring of groundwater and Leachate within the waste body; and gas generation, including the possible migration of landfill gas towards an occupied residence on the site.
- Monitoring sampling points were also established for the surface water bodies on two sides of the landfill.
- Gas sampling of leachate wells and surrounding areas was completed.

2.7 TIER 2 - SITE INVESTIGATION 2012

The 2012 site investigation aimed to identify any gaps in the information, test the aquifer properties and refine the conceptual model for the site.

2.7.1 Well Drilling

A total of two groundwater and three gas boreholes were drilled as part of the 2012 site investigation works. Both boreholes were drilled into the bedrock between 29th November and the 4th December 2012 by Irish Drilling Ltd. using a rotary core rig, supervised by TOBIN. The locations of these boreholes/wells are shown in Figure 1, Appendix 1. The locations of the existing boreholes at the site are shown in Figure 1, Appendix 1.

During drilling, the geology was logged from drilling returns, the drilling progress and core returns. The terminology used in British Standard 5930, Code of Practice for Site Investigations (BSI, 1999) logging descriptions were used. Water strikes and casing depths were recorded during drilling. Borehole logs are included in Appendix 1. In general, light grey fractured limestone with poor yields was encountered in the two boreholes drilled on site. A summary of the information recorded while drilling the boreholes is provided in Table 3.2 below.

Table 2.2 Summary Information from Trial Wells Drilled on Site

Well No.	Lithologies	Depth to Bedrock	Total Well depth (mbgl)	Water Strikes during drilling
MW9	Weathered bedrock 13 to 17.50 m bgl. Highly weathered from 14.50 to	13	30	Minor strikes at 17.5 mbgl at top of limestone.

	17.5 mbgl. Strong massive marbled light grey limestone with fractured zones. Fractures mainly clay filled.			
MW10	Strong massive light grey limestone with fractured zones 13.2 to 20 mbgl. Weakly Dolotomized, vuggy. Weathered limestone with orange brown clay filled fractures.	13.2	20	Minor strikes at 18.5 mbgl at top of limestone.

2.8 HYDROGEOLOGY

This section describes the current understanding of the hydrogeology in the vicinity of the site. Hydrogeological and hydrochemical information was obtained from the following sources:

- Geology of Shannon Estuary. Bedrock Geology 17: 100,000 Map series, Sheet 17, Geological Survey of Ireland (Sleeman, *et al.,* 1999);
- GSI Website and Well Database;
- County Council Staff;
- EPA website and Groundwater Monitoring database;
- Local Authority Drinking Water returns;
- Hydrogeological mapping by TOBIN Consulting Engineers ;
- Deakin et al (1998) *County Limerick Groundwater Protection Scheme;*
- Pumping Test data 2012, (HES/IDL for TOBIN/Limerick Co. Co.).

2.8.1 Groundwater body and status

The Landfill area is located within the Newcastlewest Groundwater Body which has been classified as being of Good Status www.wfdireland.ie/maps.html. The groundwater body descriptions are available from the GSI website: www.gsi.ie and the 'status' is obtained from the Water Framework Directive website: www.wfdireland.ie .

2.8.2 Groundwater levels, flow directions and gradients

It is assumed that shallow and deep groundwater discharge to the River Dooally and its tributaries which are the main surface water features in the area. The smaller streams in the vicinity of the source appear to be groundwater fed (described in the next section) due to field hydrochemistry mapping (high conductivity) and it is assumed that these are primarily fed by shallow groundwater from the subsoil and upper fractured rock. Potentially deep groundwater associated with increased dolomitization at depth could be flowing from a more easterly direction but there is no evidence to support this.

The shallow geology (overburden) across the site is complex, and consists of mixed made ground comprised of reworked natural materials, with pockets of rubble and heterogeneous waste materials. In order to determine the groundwater flow direction and the groundwater gradients within the site, the topographic elevation of all monitoring points was established. Based on the water level monitoring and the topographic elevation it was possible to establish the piezometric head at each monitoring point.

All levels were measured relative to Ordnance Datum (Malin Head). The elevation of all measured points is tabulated on Table 3.3. The piezometric data and inferred groundwater contours for December 2012 are shown on Figure 1, Appendix 1. Static hydraulic gradient across the site is estimated to be a maximum of 2.2 x 10^{-2} and decreases to 1 x 10^{-2} downgradient of the site.

Table 2.3: Location and Elevation of Groundwater Monitoring Points and Piezometric Head

Reference	Easting	Nothing	Static Water Level (m OD) on 10/12/13
MW1	127399.6	134659.8	66.748
MW3	127502.9	134693.6	70.835
MW6	127428.5	134526.3	67.042
MW7	127328.8	134642	66.222
MW8	127508.8	134482.2	66.36
MW9	127350.5	134567.6	63.96
MW10	127422	134630.2	67.019

It is not possible to accurately tell the natural piezometric level of the area prior to the quarry excavations and backfilled landfill area. The shallow subsoil piezometric levels and the deep bedrock piezometric levels are likely to differ across the site. The shallow piezometric levels are considered to be heavily influenced by the presence of waste material in the quarry.

The deep bedrock piezometric levels, which vary from 70m OD (MW3) to 64m OD (MW9) on the 10th December 2012, strongly indicate that the groundwater flow is from a northeast and southwest direction towards Leonards Stream. The highest hydraulic gradient across the site is 0.022 to the south-southwest. This is a conservative assumption. Localised lenses of perched water are present in the made ground in the landfilled area but are not extensive or continuous.

2.8.3 Aquifer characteristics

The GSI bedrock aquifer map of the area classifies the Dinantian Pure Unbedded Limestones (Waulsortian Limestones) as a Regionally *Important diffuse Aquifer (RKd*); Based on the Newcastlewest GWB, The Pure Unbedded Limestones (Waulsortian limestones) are a maximum 1200 m in thickness. However, the effective flowing thickness is likely to be about 30 m, although much deeper inflows can occur if associated with faults or dolomitisation. An epikarst layer at least a couple of metres thick is likely to exist at the top of the bedrock. In the vicinity of Newcastle West, borehole logs indicate three main production zones: a high permeability karstified band in the upper 10–15 m of bedrock; a middle zone from 35–50 m, where north/south trending fractures, spaced at between 500 m and 800 m apart, have been preferentially dolomitized; and a lower fractured zone at a depth of over 100 m (www.gsi.ie).

The piezometric surface/ water table is likely to generally follow the topography. Seasonal water level variations at the two monitoring points in this GWB are less than 1 m. Local groundwater flow will be from the higher ground to the rivers and streams, which are considered to be in hydraulic continuity with the aquifer despite generally thick subsoils, and to the springs. Regional flow is to the east and north. Flow path lengths are likely to be considerable, up to several kilometers, although in discharge zones, flow paths will be much shorter, at around 100–300 m.

2.9 HYDRAULIC TESTING

No step testing was carried out on the trial well. Discharge from PW9 was extremely low with a flow rate of <0.5 l/s. A 3-day pumping test carried out in December 2012 by Hydro Environmental Services Ltd on behalf of Irish Drilling Ltd. The data and graphs are included in Appendix 1. There are observation monitoring data but the response is difficult to assess.

A pumping test was completed in MW9 in accordance with BS 6316 (BSI, 1992). An initial series of step tests were proposed to determine a suitable pumping rate for the constant rate test however the flow rates were very low and it was not possible to pump at more than 0.3 l/s. The pumping test was initiated at 08:50 on 11th December 2012 and ran until 10:00 on 15th December 2012. The total pumping test duration was 25 hours and 10 minutes.

Water levels in the pumping well were monitored throughout the course of the pumping test, as well as the discharge rate from the pump. When the pumping test was completed, the water level in the pumping well and observation wells was monitored until recovery close to pre-pumping water levels was achieved. Discharge from the pumping test was to the foul sewerage network near Evergreen close as no suitable surface water discharge location was available.

2.9.1 Transmissivity of PW9

Groundwater levels at the site were recorded by hand and by using water level transducers and data loggers before, during and after the pumping test. The base of the pump was set at 19 mbgl; the main inflows were associated with the highly weathered sections of the upper limestone. The pumping rate was initially set at 26 $m^3.d^{-1}$ (0.3 l/s). After the initial 2 hour of the pumping test, the pumping rate reduced to 22.5 $m^3.d^{-1}$ (0.26 l/s). The pumping rate was maintained for the remaining duration of the test however minor fluctuations were noted in flow rates. The maximum induced drawdown of 13.99 m was achieved after 72 hours.

A stable pumping water level was attained in the pumping well with slight fluctuations between 13.5 m of drawdown for the last days of test. The fluctuations in drawdown and water level observed may be attributed to influences such as slight variations in discharge and response to rainfall.

After pumping stopped, the groundwater levels in the wells recovered at a rapid rate towards the initial static water level conditions. After 88 minutes, the water level in the pumping well had recovered to within 0.4 m of the initial static water level or a 97% recovery. Further monitoring of water levels was not possible due to removal of pump and pipework from the well.

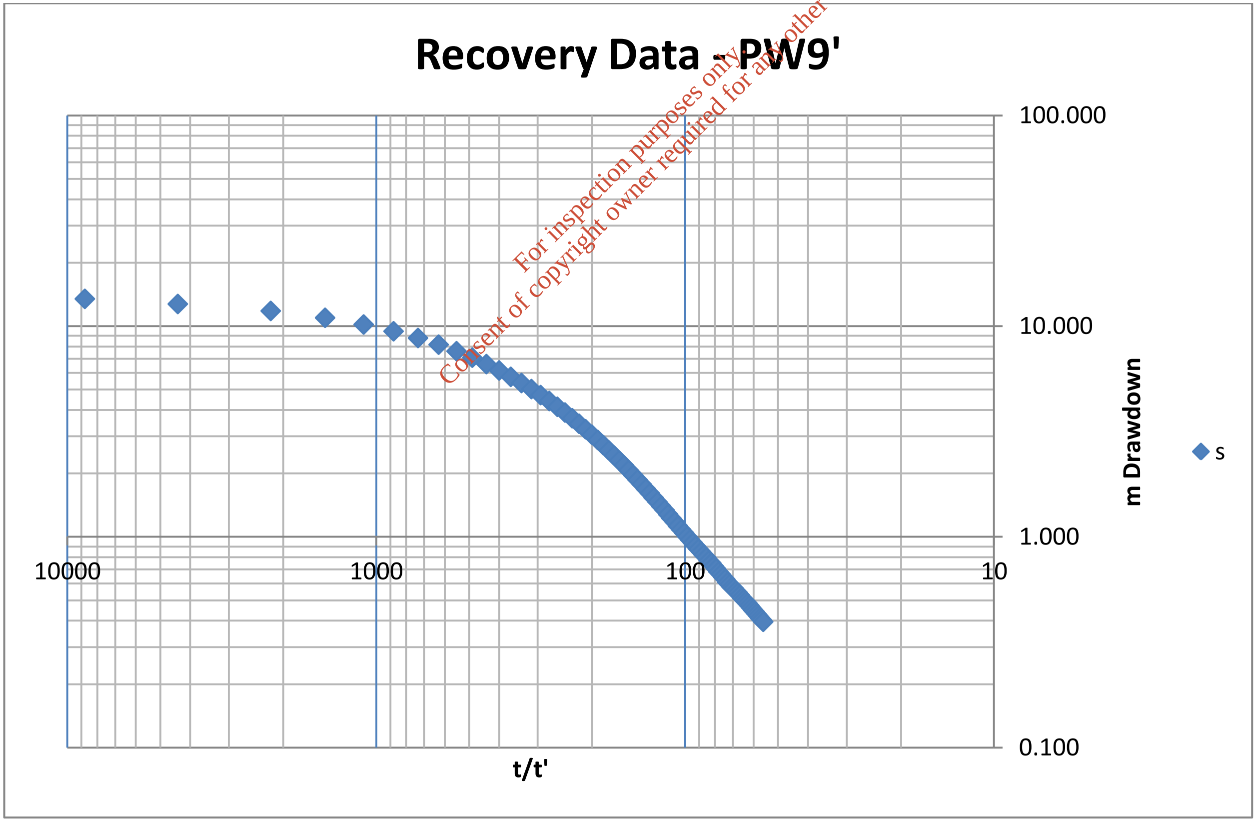
Based on the measurement taken during the course of the pump tests it is possible to calculate an estimate of the bulk transmissivity of the bedrock at each of the abstraction points. Aquifer transmissivity is defined as the rate of groundwater flow under a unit hydraulic gradient through a unit width over the entire saturated thickness of the aquifer.

The specific capacity of the pumping well is 1.61 $m^3.d^{-1}.m^{-1}$, indicating that low discharge rates induce moderate to high drawdown. The well is classed as a **Grade V** production well under the GSI classification system. Based on data from the pumping test (Appendix 2), the transmissivity (T) of the limestone aquifer is low to moderate and is estimated to be 2 $m^2.d^{-1}$ using the Logan transformation. The bulk transmissivity was also calculated using the Theis Recovery method. The Transmissivity value is assumed to be representative of the overall aquifer, and is used to deduce rock permeability. It is assumed that the saturated thickness of the aquifer is 50m.

Table 2.4: Calculated Borehole Transmissivity Values (Theis recovery)

BH ID	Abstraction Rate m3/day	Drawdown over log cycle (δs, m)	Estimated Transmissivity (sq.m/day)
MW9	23.5	5	0.86

Table 2.5: Recovery Data (Theis recovery)



The values obtained are lower than the regional values outlined in groundwater body description, local indicators of the relatively low permeability including the pumping test, borehole logs, geophysics, steep groundwater gradients and the high drainage density in the surrounding area. Based on the data from the GWB the lower values for transmissivity in the region are 20 m2/day. To be conservative values of

20m2/day are used. The permeability (k) of the limestone is also moderate, estimated to be 4.5 x 10^{-6} $m.s^{-1}$ (based on saturated thickness of approximately 50m).

2.10 MONITORING WELLS

Drawdown of water level in the observation wells was observed during the pumping test. A maximum drawdown of 0.65 m and 0.61 was observed in MW3 and MW8 respectively on the 14th December 2012. Rainfall data from the nearest synoptic station and on site records indicated that minimal rainfall occurred in the days preceding the pumping test and for the first 24 hours of the test. A summary of the drawdown effects noted during the pumping test are outlined in Table 3.7 below.

Table 2.6. Summary of drawdown effects

Borehole ID	Distance from pumping well (m)	Maximum Drawdown (m)
MW9 (pumping well)	-	14
MW3	200	0.61
MW6	67	0.17
MW7	78	0.32
MW8	180	0.65
MW10	100	0.29

The water level appears to have been interrupted by rainfall events on the 14th and 15th December. Water levels appear to response rapidly to the rainfall events of the 14th Dec with water levels rising in MW3, MW7, MW8 and MW10 for the remainder of the pumping test. Levels in MW6 appear to be unaffected by rainfall events which may indicate that water levels in MW6 are isolated from the bedrock aquifer and are reflective of perched water levels in the waste material. The drawdown curves for the pumping well and observation wells are presented in Appendix 2.

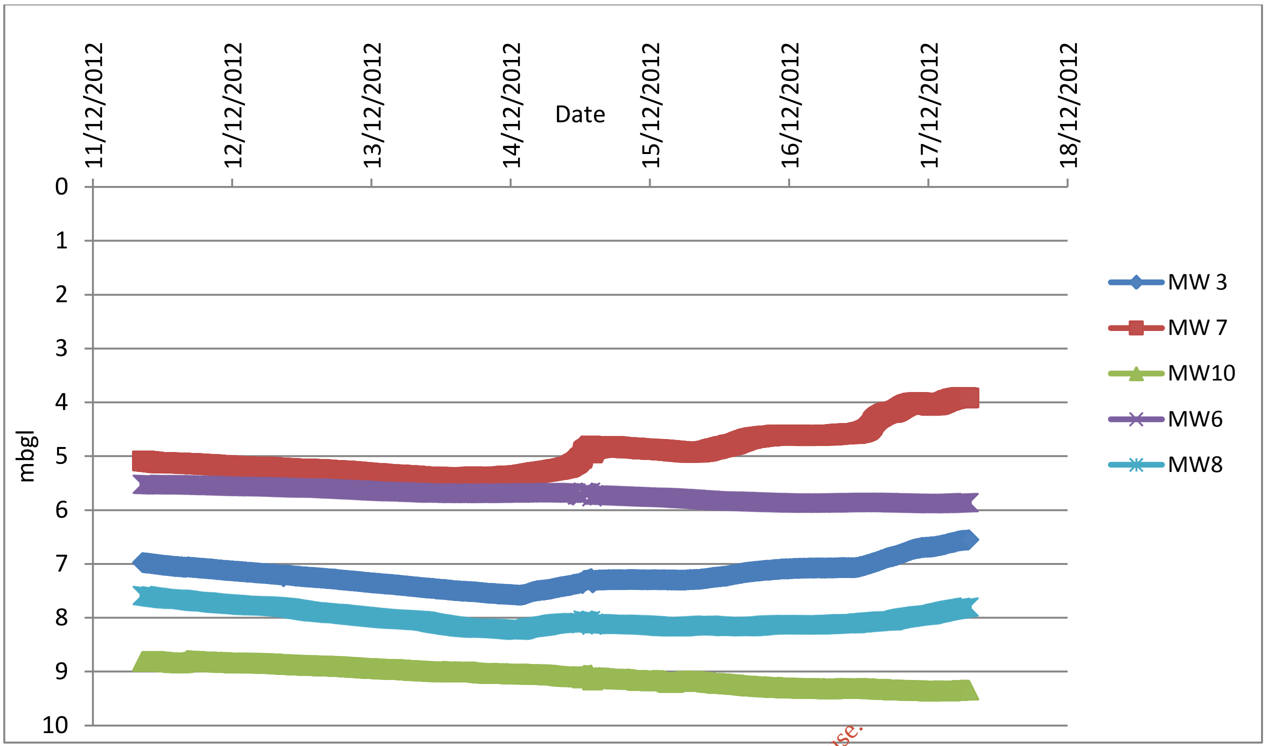


Figure 2.1 Groundwater monitoring levels – observation wells

Based on an analysis of the pumping test data, it was not possible to separate the pumping test drawdown from the natural variation in groundwater levels. Therefore it was not possible to estimate values of Transmissivity and storativity/specific yield from the monitoring well data. Based on an understanding of the groundwater body properties the *Specific yield will be low, on the order of a 1 to 2%.*

2.11 RECHARGE

The term 'recharge' refers to the amount of water replenishing the groundwater system. The recharge rate is generally estimated on an annual basis, and assumed to consist of input (*i.e*. annual rainfall) less water loss prior to entry into the groundwater system (*i.e*. annual evapotranspiration and runoff).

At Newcastlewest, the main parameters involved in the estimation of recharge are: annual rainfall; annual evapotranspiration; and a recharge coefficient.

The bulk ***recharge coefficient*** for the area is estimated to be 60%. (Guidance Document GW5, Groundwater Working Group 2005).

These calculations are summarised as follows:

Average annual rainfall (R)	1102 mm[1]
Estimated P.E.	500 mm
Estimated A.E. (95% of P.E.)	475 mm
Effective rainfall	627 mm
Potential recharge	627 mm
Runoff losses	40%

[1] Rainfall data based on Newcastlewest gauging station

Bulk recharge coefficient	60%
Recharge	**376 mm**

2.12 GROUNDWATER QUALITY

Groundwater samples were collected on the 14th and 19th December 2012, from the groundwater monitoring points installed as part of the site investigation programmes. These boreholes included the MW1, MW3 and MW7, MW9 and MW10. At the time of sampling, it was not possible to sample MW8 as the casing appeared slightly damaged preventing the pump entering the borehole. A total of 5(no.) groundwater samples were collected.

The groundwater sampling was undertaken by TOBIN personnel using dedicated submersible pump. 3(no.) piezometer volumes were purged from all of the monitoring points prior to the groundwater sample being collected. A pair of disposable latex gloves were used for each sample collected. The groundwater samples were submitted to ALcontrol Geochem Laboratories for analysis of a comprehensive suite of parameters. The groundwater analytical results are discussed below. Groundwater samples were compared to the values set out in SI 278 of 2007.

No hydrocarbon or PAH contamination was detected or observed in any of the overburden/bedrock groundwater monitoring boreholes. Phenols were not detected in any of the groundwater monitoring boreholes.

Most of the reported metal concentrations are within the corresponding parametric values. Manganese levels were elevated in MW3 and MW4 however the elevated levels could be partially the result of naturally high manganese in limestone bedrock aquifers. Nickel concentrations (23.5 µg/l) were marginally above the drinking water limits (20 µg/l) in MW6.

Based on the data available, average concentrations of sulphate, potassium, and sodium are below the groundwater values however sulphate levels are elevated in relation to national background levels.

Chloride is a constituent of organic wastes, sewage discharge and artificial fertilisers, and concentrations higher than 24 mg/l (Groundwater Threshold Value for Saline Intrusion Test, Groundwater Regulations S.I. No. 9 of 2010) may indicate contamination, with levels higher than 30 mg/l usually indicating significant contamination (Daly, 1996). Chloride concentrations range from 9.7mg/l upgradient to 27.5 mg/l in the downgradient well MW9. Chloride concentrations were highest in MW6 located within the waste body. Chloride is a mobile constituent which is often used as an indicator of contamination.

Elevated concentrations of Ammonical Nitrogen (as N) were detected in MW9 and MW6. The highest concentration of ammonical nitrogen was detected in MW9. Concentrations are likely to reflect the presence of the landfill and reducing conditions in the aquifer. Concentrations of nitrate were low at 3.63 mg/l.

No free or total cyanide contamination was detected in any of the groundwater samples submitted for analysis. Thiocyanate was not detected in any of the other groundwater samples. No visual or olfactory evidence of contamination was noted on site during the sampling of the groundwater monitoring boreholes. Concentrations of pesticides (MCPP, PAA, Atrazine, Azinphos & TBP) were above detection limits in a number of wells however it is thought that source of the pesticides is agricultural activity due to the first order decay rates and no pesticides were previously detected in the landfill or in MW6 during this round of sampling. The results of the 2012 Groundwater tests are compared to the relevant guidelines in Table 2.7 below.

Table 2.7 Maximum Groundwater concentration in landfilled area - 2012

Analyte	**Borehole Location**	**Maximum Concentration µg/l**	**Notes**
Ammonical Nitrogen	MW9, MW6	**4.57**	Samples from Mw9 taken during pumping test
Sulphate	MW6	**265**	Downgradient well
Manganese	MW9, MW6, MW1, MW7	**979**	Samples from Mw9 taken during pumping test
Nickel	MW6	**23.5**	Downgradient well

* mg/l

Table 2.8 Maximum Groundwater pesticide concentration in landfilled area - 2012

Analyte	**Borehole Location**	**Maximum Concentration µg/l**	**Threshold Values (SI 9 of 2010[2]) µg/l**	**Notes First order decay – half life**
Pesticides				
MCPP	MW9	0.0475	0.075	21
Phenoxyacetic Acid (PAA)	MW1, MW7	0.0386	-	10
Atrazine (Aatrex)	MW9	**1**	0.075	60
Azinphos-methyl (Guthion)	MW9	1.17	-	10
Tributylphosphate (Sigma Aldrich)	MW9	0.151	-	NA

*Half life estimates from WHO, 2012

2 http://www.irishstatutebook.ie/2010/en/si/0009.html

2.13 LANDFILL GAS MONITORING

A number of Landfill Gas (LFG) surveys were taken during the Tier 2 Site Investigations (2007 & 2012). The measurements were taken with a hand held gas detector. Impact bars were used to sample the subsoils and trial hole spoil heaps. Gas surveys were carried out as follows:

- Trial Hole locations during excavation;
- Trial Hole locations following backfilling;
- Subsurface levels along the eastern perimeter;
- Residential properties on the southern and eastern perimeter of the site.

The gas sampling locations are shown on Figure 3.1 below. A site investigation was undertaken on the historical landfill by BHP in Churchtown in February 2012. The investigation formed part of the Tier 2 Risk Assessment in accordance with the EPA CoP. Trial holes were excavated in 4 locations TH2 to TH5 down to 6 mbgl. Based on the results of the February 2012 investigations no elevated gas concentrations were detected in the Trial Holes. Additionally a number of sampling points were completed in nearby housing. All results were below detection limits <0.1%v/v methane. The sampling of housing was again undertaken in December 2012 with all results <0.1%v/v methane.

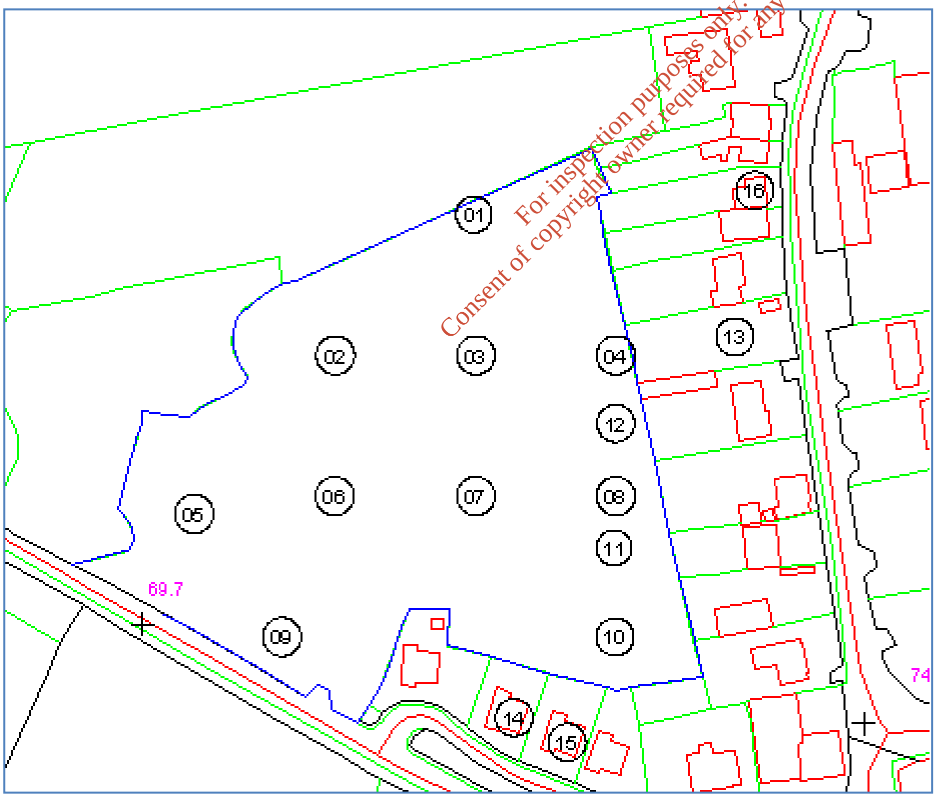


Figure 2.2 Landfill Gas Monitoring locations

The Landfill Gas sampling results found no evidence of landfill gas within the site or inside nearby dwelling houses. The landfill site is very unlikely to be producing significant quantities of landfill gas due to the age and advanced decomposition of the waste. As the majority of houses were constructed after the 1997, the houses are likely to contain a radon/gas membrane to prevent ingress of vapours into the houses in accordance with the 1997 Building Regulations (S.I. No. 497 of 1997). All houses to the south of the landfill were constructed post 2005.

3 TIER 3 REVISED CONCEPTUAL SITE MODEL

The EPA Code of Practice indicates that the use of a Generic Risk Assessment is appropriate in this instance - *'a Generic Risk Assessment may be used at less sensitive locations and/or where the information is available to suggest that the level of risk is low. It is generally a deterministic (i.e. resulting in a pre-determined outcome given particular conditions) and conservative approach, which uses generic guideline values (i.e. values which are generally applicable to an entire group e.g. based on the proposed future land use of the site)'.*

An initial Conceptual Site Model (CSM) was presented as part of the Tier 1 and 2 Environmental Risk Assessments and was based on information from Limerick City Council, historical data, site location and the overall risk it presented to the identified receptors through various pollution pathways.

The Tier 3 Revised Conceptual Site Model (CSM) is presented on Figure 3.1 below. The subsoils at the site consist of a thin layer of till deposits (where present) with a substantial increase in till depths to the north. Based on the field observations, ground and geophysics investigations, the tills appear to be underlain by an unbedded Waulsortian Formation. The bedrock aquifer is mapped as a Regionally Important Karst bedrock (Rkd).

A revised CSM was developed and presented in this report. TOBIN has reassessed the risk categorization based on the Tier 3 findings. The changes are highlighted in red. Four pathways were identified as High Risk in the Tier 2 site investigations, namely SPR3, SPR5, SPR 10 and SPR 11.

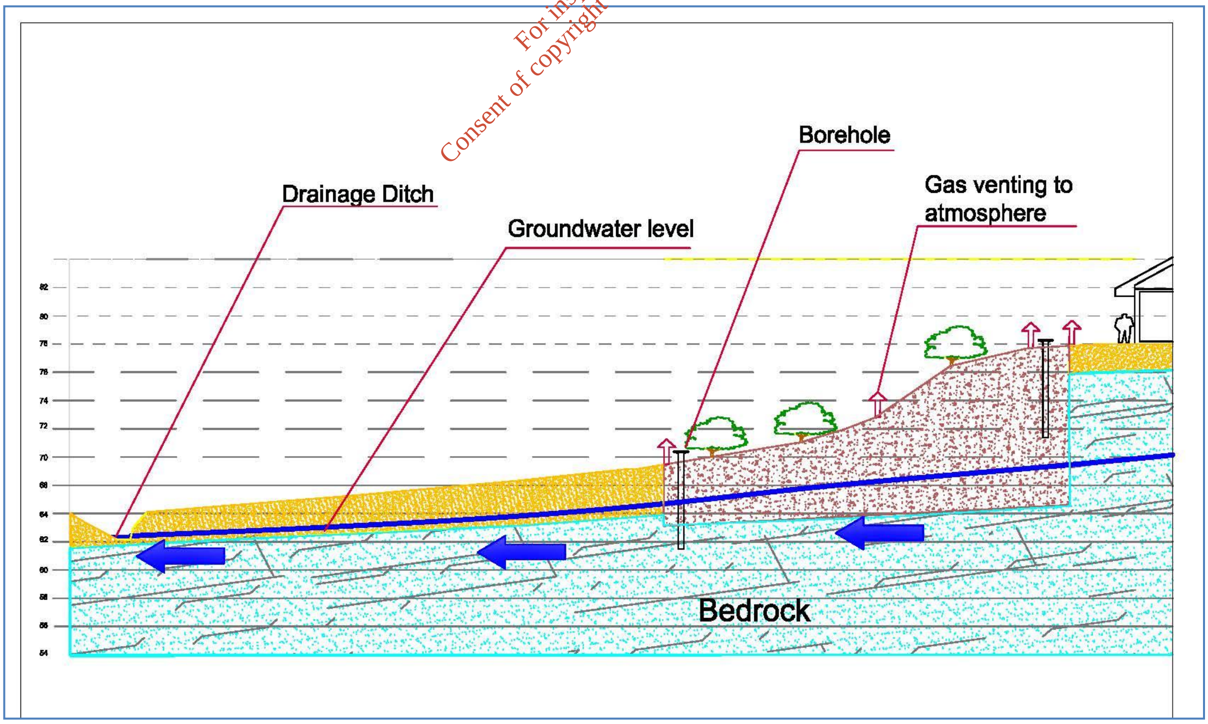


Figure 3-1 Conceptual cross section

Based on the revised Tier 3 - CSM, the site remains a HIGH Risk site based on EPA CoP for Historical landfills for the following groundwater Source-Pathway-Receptors:

The understanding of the geological and hydrogeological situation is given as follows:

- The landfill site is located on a former limestone quarry, which operated in the period 1840 to 1913;
- Dumping of waste commenced in 1935 and continued until the closure of the site in 1986;
- Limerick County Council acquired the site in the early 1950's and operated a landfill site at this location until 1986; The site contains a combination of domestic, commercial and inert wastes (including C&D waste and soil & stones).
- There is no official leachate collection system at the site, however some leachate is collected at a sump and discharged to the foul sewer and treated at the WwTP.;
- The capping layer is of poor quality, with large variations in depth and composition. The capping layer varies in depth from 0 to 2 metres with an average depth of 500mm and consists mainly of gravel, silt and clay;
- Over the landfill, an average estimated recharge rate of 376 mm/year is used, which is approximately 60% of the total potential recharge. The remaining 40% of potential recharge is rejected and discharge may be via land overflow during the winter months. Recharge is predominantly diffuse.
- Groundwater flow based on monitoring data is from the site, towards the Dooally Tributary approx 200m to the south. Groundwater recharge is primarily through the surface and some waste is below the water table.
- Ammonia and Nickel concentrations are above their respective MAC within the landfill. Manganese concentrations are elevated in the landfill. Ammonia concentrations are elevated in the Dooally tributary but are below the salmonid regulations.
- No hydrocarbon or PAH contamination was detected or observed in the overburden/bedrock groundwater monitoring boreholes however benzene was detected off site. Phenols were not detected in any of the groundwater monitoring boreholes.
- Elevated concentrations of landfill gases are present within the landfill area however no landfill gas has been detected at the nearest sensitive receptors.

3.1 EPA CODE OF PRACTICE – SPR LINKAGES

Outlined below is the site screening process as per the EPA code of practice. Tables 1a, 1b, 2a to 2e, 3a to 3f are reproduced below.

Table 1a

Leachate Source Hazard Scoring Matrix

Waste Type	<1Ha	>1 Ha <5 Ha	>5 Ha
C&D	0.5	1	1.5
Municipal	5	7	10
Industrial	5	7	10
Pre 1977 Sites	1	2	3

Site Rating	**7**

Table 1b

Landfill Gas: Source/Hazard Scoring Matrix

Waste Type	<1Ha	>1 Ha <5 Ha	>5 Ha
C&D	0.5	0.75	1
Municipal	5	7	10
Industrial	3	5	7
Pre 1977 Sites	0.5	0.75	1

Site Rating	**7**

Table 2a

Leachate Migration: Pathways

Groundwater Vulnerability (Vertical Pathway)	**Points**
Extreme Vulnerability	3
High Vulnerability	2
Moderate Vulnerability	1
Low Vulnerability	0.5
High - Low Vulnerability (use where vulnerability not in GIS)	2

Site Rating	**3**

Table 2b

Leachate Migration:

Pathways

Groundwater Flow Regime	Points
Karstified Groundwater Bodies (Rk)	5
Productive Fissured Bedrock Groundwater Bodies (Rf & Lm)	3
Gravel Groundwater Bodies (Rg & Lg)	2
Poorly Productive Bedrock Bodies (LI,PI,PU)	1

Site Rating	5

Table 2c

Leachate Migration: Pathways

Surface Water Drainage (Surface Water Pathway)	Points
Is there a direct connection between drainage ditches associated with the waste body and adjacent water body? Yes	2
If no direct connection	0

Site Rating	0

Table 2d

Landfill Gas: Pathways

Landfill Gas Lateral Migration Potential	Points
Sand and Gravel, Made ground, urban, karst	3
Bedrock	2
All other Tills (including limestone, sandstone etc - moderate permeable	1.5
All Namurian or Irish Sea Tills (low permeability)	1
Clay, Alluvium, Peat	1

Site Rating	3

Table 2e

Landfill Gas: Pathways

Landfill Gas Lateral Migration Potential	Points
Sand and Gravel, Made ground, urban, karst	5
Bedrock	3

All other Tills (including limestone, sandstone etc - moderate permeable	2
All Namurian or Irish Sea Tills (low permeability)	1
Clay, Alluvium, Peat	1

Site Rating	**5**

Table 3a

Leachate Migration : Receptors

Human Presence (presence of a house indicates potential private wells)	**Points**
On or within 50m of the waste body	3
Greater than 50m of the waste body	2
Greater than 250m but less than 1km from waste body	1
Greater than 1km of the waste body	0

Site Rating	**3**

Table 3b

Leachate Migration : Receptors Protected Areas (SWDTE or GWDTE)	**Points**
Within 50m of waste body	3
Greater than 50m but less than 250m of the waste body	2
Greater than 250m but less than 1km from waste body	1
Greater than 1km of waste body	0
Undesignated sites within 50m of waste body	1
Undesignated sites greater than 50m but less than 250m	0.5
Undesignated sites greater than 250m of the waste body	0

Site Rating	**0**

Table 3c

Leachate Migration : Receptors

Aquifer Category (resource potential)	**Points**
Regionally Important Aquifers (Rk, Rf,Rg)	5
Locally Important Aquifers (LI,Lm,Lg)	3
Poor Aquifers (PI,Pu)	1

Site Rating	**5**

Table 3d

Leachate Migration : Receptors

Public Water Supply (Other than private wells)	**Points**
Within 100m of site boundary	7
Greater than 100m but less than 300m or within Inner (SO) for GW supplies	5
Greater than 300m but less than 1km or within Outer (SO) for GW supplies	3
Greater than 1km (karst aquifer)	3
Greater than 1km (no karst aquifer)	0

Site Rating	**3**

Table 3e

Leachate Migration : Receptors

Surface Water bodies	**Points**
Within 50m of site boundary	3
Greater than 50m but less than 250m	2
Greater than 250m but less than 1km	1
Greater than 1km	0

Site Rating	**2**

Table 3f

Landfill Gas : Receptors

Human Presence	**Points**
Within 50m of site boundary	5
Greater than 50m but less than 150m	3
Greater than 150m but less than 250m	1
Greater than 250m	0.5

Site Rating	**5**

The Risk screening process aims to determine whether a development or site represents or potentially represents a risk to receptors. It also identifies possible Source-Pathway-Receptor (S-P-R) linkages through the development of a conceptual site model (CSM). It provides a preliminary or qualitative risk assessment of the site. It includes an assessment of the likelihood and magnitude of any effects of each linkage.

3.2 SCREENING PROCESS

The initial screening process above allows for the prioritisation of sites into high, moderate and low risk and focus upon the examination of the associated S-P-R linkages at each of the sites.

Table 3.1 SPR linkages as %

OUTPUT	% SPR RISK LINKAGE	
SPR 1	37.33	
SPR 2		0
SPR 3	70.00	
SPR 4		0
SPR 5	70.00	
SPR 6	30	
SPR 7	46.67	
SPR 8		0
SPR 9		0
SPR 10	70.00	
SPR 11	70.00	

S-P-R linkages in High pathway linkage – SPR 3, SPR 5, SPR 10, SPR 11
S-P-R linkages in Moderate pathway linkage – SPR 1, SPR 7, SPR 8,
S-P-R linkages in Low pathway linkage – None

PRIORITISATION CATEGORY – HIGH- CLASS A

4 LANDFILL GAS RISK ASSESSMENT

SHOULD WE ADD (AS IN GROUNDWATER SECTION BELOW??)

The conceptual model of groundwater risk has been developed using available data.

For a particular contaminant to present a risk to receptors, three components must be present:

Source An entity or action which releases contaminants to the environment.

Pathway A mechanism by which receptors can become exposed to contaminants.

Receptor The component at risk of experiencing an adverse response following exposure to a contaminant.

If one of these three is missing, then there can be no risk.

Defining the conceptual model of risk requires identification of all potential sources, pathways and receptors of contamination and identifying plausible combinations of these three components. Potential pollutant linkages are then qualitatively assessed to identify plausible scenarios. The key sources, pathways and receptors are discussed below.

The scope of this risk assessment is to identify plausible linkages that may give rise to an unacceptable risk to receptors. Quantitative risk assessment is then used to establish remediation targets protective of the identified receptors. The quantitative risk assessment methodologies are presented in this report.

Significant sources, pathways and receptors are shown on the site conceptual model, Figure 3.1, Appendix 1.

In general, there are two pathways by which landfill gases may migrate offsite either vertically through the cover or horizontally through the soil. The two pathways are not mutually exclusive; the landfill gases will follow the path of least resistance.

Typically, vertical migration is not a concern unless structures have been built on the cover or public access is unrestricted. The gases tend to dissipate in the open environment. However, for people living or working on or adjacent to the landfill, the concentration of landfill gases in the ambient air may pose a concern and may contribute to local air quality and odour problems. It should be noted that no odour issues are reported at the landfill at present. If the gases enter a structure built on the landfill cover, the contaminants can collect in the structure, and the resulting concentrations can reach a level of potential health concern. Depending on the size of the structure and the volume of confined space in relation to the volume of landfill gas entering the structure, a fire or explosion hazard could develop.

Horizontal migration is usually a concern, primarily for off-site structures. The landfill gases will follow the horizontal path of least resistance until they find an avenue to the surface. Because a major constituent of landfill gas is methane, that gas will usually be detected first. If the avenue to the surface accesses the open environment, the gases will dissipate, as they do in the vertical migration pathway. If the avenue intercepts a structure, the gases can build up in the structure as described.

When landfills are uncovered or covered with permeable material such as soil or sand, landfill gas is able to escape through the landfill cover and migration through the ground around the site is often limited. Regulations requiring that landfills must be capped with low permeability material to prevent rainwater penetration are common. Capping confines the landfill gas, increasing the tendency for it to migrate underground unless systems are in place to prevent it.

Significant gas production is generally completed within about 30 years of deposition, but every site is different. Where gas production is slow, the period of significant gas production may extend for 40 or 50 years. It should be noted that no odours or noxious smells were detected at the landfill during the site walkovers or by local residents. A moderate methane/landfill odour was detected during the installation of the monitoring locations at the landfill area.

4.1.1 Landfill Gas Pathways

A number of factors may influence landfill gas behaviour, making it difficult to predict behaviour at any particular location. Landfill gases escape, because of differences in pressure and density, through the top surface or through cracks that may be present in capping materials or because of diffusion through permeable strata bordering the site. A number of the main factors are outlined below.

Barometric and Soil Gas Pressure:

The migration of gases through the soil is a result of two processes: diffusion in response to a concentration gradient, and convection, due to a pressure gradient. Under ideal conditions, the gas moves preferentially along paths of lowest resistance and is eventually discharged to the atmosphere. The difference between the soil gas pressure and barometric pressure affects the behaviour of landfill gas. When barometric pressure is falling, landfill gas will tend to escape from the landfill. During periods when barometric pressure is rising, landfill gas may be retained temporarily in the landfill until a new pressure balance is established. Monitoring results were undertaken during both high and low pressures events. Based on the monitoring conducted at the landfill, no pressure gradient was detected between the gas monitoring wells and the atmosphere.

Landfill Cover:

When landfills are uncovered or covered with permeable material such as soil or sand, landfill gas is able to escape through the landfill cover and migration through the ground around the site is often limited. Due to the limited depth of cover, preferential pathways are likely to occur in the capping layer and the vast majority of landfill gas will vent to the atmosphere.

From the site investigation data, it has been proven that the capping material is moderately to highly variable. The capping material is assumed to be moderately to highly permeable to gas. Based on the shallow subsoil cover and the absence of a geotextile cover, the potential for vertical migration appears greater than horizontal migration.

Man-made & Natural Pathways:

If the landfill gas escapes from the landfill into the surrounding ground; drains, trenches, and buried utility corridors can act as conduits for gas movement. The natural geology often provides underground pathways, such as fractured rock, porous soil, and permeable strata. If the ground in which the landfill is constructed is more permeable than its surface cap, then gas may migrate laterally. Impervious materials such as clays will minimise the potential for lateral migration.

Leachate – Landfill Gas Migration:

Landfill Gas can contaminate the underlying aquifer. If contaminated groundwater migrates offsite, gas volatilizing from the top of the water table can migrate up and into buildings. Landfill gas contains a range of components that can dissolve in landfill leachate. Changes to temperature and pressure can result in the production of a gas containing gases/compounds that were formerly in the leachate plume. Methane is slightly soluble in water (35 ml methane/litre water at $17^{o}C$). Landfill leachate can act as a pathway for the migration of dissolved methane. Once the diffusing gases reach the subsurface, they are drawn into the building by advection through cracks or openings in the building foundation.

Based on the previous site investigation works the direction of groundwater flow is towards the River Dooally. Leachate abstraction from the sump along the western boundary limits the potential for offsite migration of leachate/dissolved landfill gas. Additionally, groundwater monitoring at GW-06 does not indicate the presence of methane in groundwater downgradient of the site.

4.1.2 Landfill Gas Receptors

Potential receptors of the Landfill Gas and their perceived sensitivity, are summarised below.

Nearby Residential Housing:

The gas surveys completed in 2012 and 2013 found no landfill gas in the adjoining properties. These results replicate the results of the gas survey carried out in 2007, when no landfill gas was detected in houses surrounding the site. A theoretical GasSim model indicates that the landfill is now producing very low volumes of gas (i.e. ca. $20m^3$/hour). Notwithstanding the above, a precautionary approach is required in assessing the current risk of gas migration due to the proximity of the houses to the waste body.

Structures Above Existing Waste:

One structure (shed) is located on the eastern boundary of the former landfill footprint. The shed appears to have been affected by the settlement of the landfill waste with some large cracks in the structure. The gas surveys in 2007, 2012 and 2013 found no landfill gas in the structure.

4.2 LANDFILL GAS MODELLING AND MONITORING DATA

4.2.1 Landfill Gas GasSim Model (2012)

In order to look at the potential LFG production from Churchtown landfill over time, TOBIN were commissioned by Limerick County Council to run a model using GasSim (Version 2.00.0078), for which Tobin have a licence and are appropriately trained. The GasSim software was developed by Golders Associates for the Environment Agency of England and Wales and is the recognised accepted software package for LFG modelling. This model was run in April 2012, with the model inputs and results discussed below.

4.2.1.1 Model Input Data & Assumptions

The full data inputted to the GasSim software for Churchtown landfill is summarised on the GasSim 2.0 Model - Project Details Printout, attached in Appendix 7. The GasSim 2.00.0078 model studied the landfill as one phase – 'Waste Body'. The model uses information on waste composition and quantity, landfill engineering, and landfill gas management techniques, to estimate the quantity of landfill gas generated from the landfill. Table 12 overleaf lists the years of waste deposition associated with the Waste Body, the quantities of waste deposited per year and the waste breakdown per year, all of which were inputted to the GasSim Model.

The GasSim model results for Churchtown Landfill are presented in Appendix 7. The results show a peak in LFG production for the landfill facility in 1987 (53.8 m^3/hr). A total bulk LFG of 20.9m^3/hr was predicted for 2012 and 19.7 m^3/hr in 2014 with a slow decline over the following years.

4.2.2 Landfill Gas Investigation (IDL) 2012

Following the outcome of the Gassim Model, further testing was commissioned and completed in December 2012 by Irish Drilling Ltd. (IDL) This involved the installation of 3 gas monitoring wells (GW1, GW2 and GW3) to the north of the site which correspond to the deepest part of the landfill. The monitoring wells were completed to 6 mbgl and bentonite sealed in the upper 2m of the wells. No water was encountered in the gas wells. Monitoring results indicated that elevated concentrations of gas were detected in GW1-GW3. Monitoring of GW1-GW3 continued throughout 2013 with results detailed below.

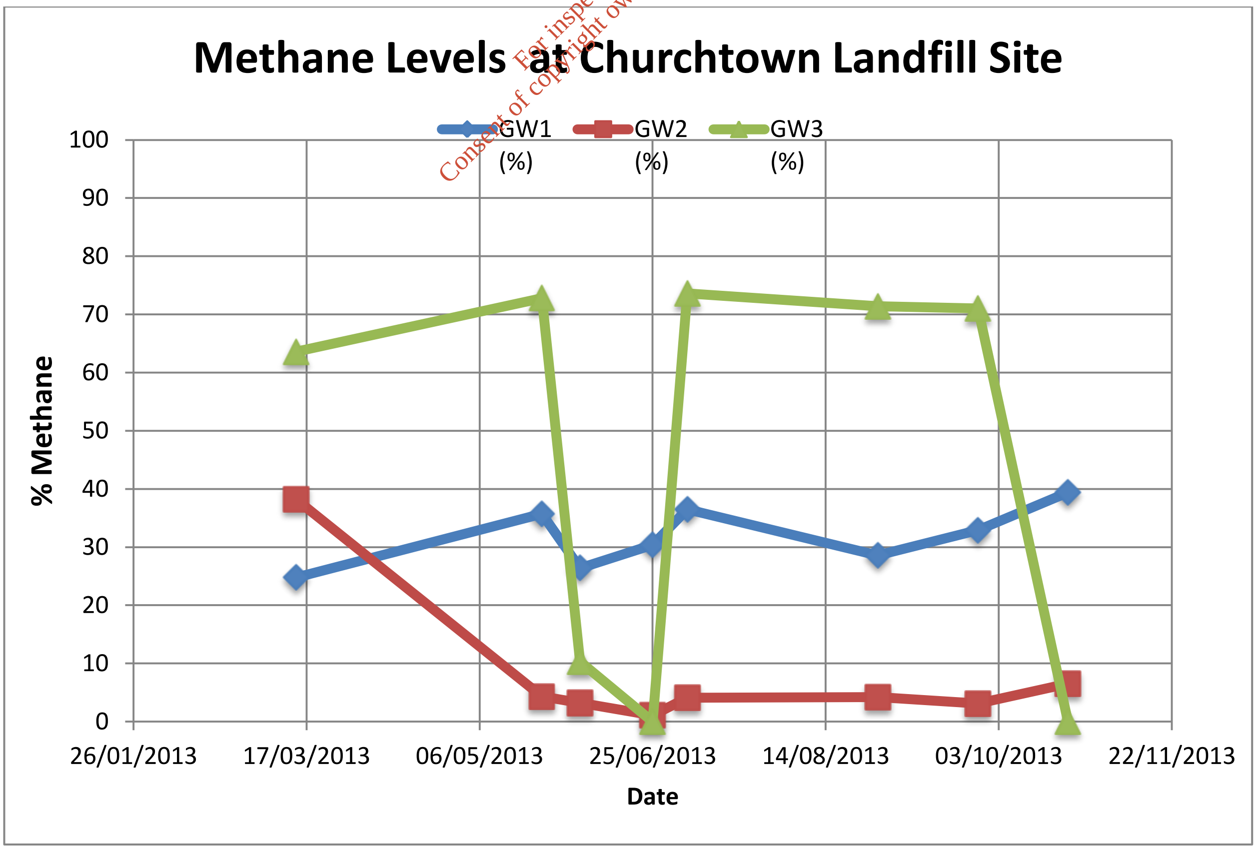


Figure 4.1 Methane results from GW1-GW3

4.2.3 Landfill Gas Survey (OMI) 2013

Tobin Consulting engineers commissioned Odour Monitoring Ireland to perform a survey of landfill gas surface emissions and a flux box survey at the Landfill Site in 2013.

Gas flow measurements were attempted on GW1, GW2 and GW3 (See Appendix 7). However no adequate measurement was recorded due to absence of sufficient differential pressure. This may indicate that the levels of methane generated are limited at these locations.

A surface survey using a FID was completed to detect non specific VOCs (methane and other hydrocarbons) was undertaken by OMI. A FID is widely used for detection of hydrocarbon in soil gas and compounds that ionise in a hydrogen flame and is ideal for use as a primary investigating device for screening soils for many VOCs. The presence of elevated concentrations indicates need for further investigation.

Four zones of surface emissions were identified within the landfill site that exceeded 500 ppv for non specific VOCs. These zones are identified geographically on a site map contained in Appendix 7. Flux chamber monitoring was carried out at eight distinct locations within the landfill footprint. The survey suggested that locations 1, 2 and 8 were in excess of the recommended guideline surface emission flux levels for such locations.

Gas flow measurements were attempted on GW1, GW2 and GW3. However no adequate measurement was recorded due to absence of sufficient differential pressure.

4.2.4 VOC Monitoring (AWN) 2013

AWN Consulting was commissioned by Tobin Consulting Engineers to carry out follow up VOC monitoring at five locations adjacent to the landfill in June/July 2013 (See Appendix 7). Active monitoring over a 2 hour period was carried out at each location and passive monitoring over a 30 day period was carried out at three of the five locations.

Council Directive 2008/50/EC has set a benzene ambient air quality standard of 5 $\mu g/m^3$ as an annual mean. Benzene concentrations over the 30 day sampling period were found to exceed this annual mean ambient air quality standard at Location 1 and Location 2. The concentration of benzene at Location 1 was 60 $\mu g/m^3$ which is 1200% of the ambient mean air quality standard. The concentration of benzene at Location 2 was 5.9 $\mu g/m^3$ which 118% of the ambient mean air quality standard. Extended monitoring over a longer period would be required in order to determine compliance with the annual mean air quality standard for benzene at both Location 1 and Location 2. No elevated levels of Benzene were detected in GW1 – GW3 in June 2013. Furthermore no benzene was detected in the Landfill during the initial Tier 2 site investigations (2007). The presence of elevated benzene off site over a 1 month period may suggest that either cross contamination has occurred or an offsite source is responsible for the contamination. Further testing should be completed to identify the source.

With regards to all other VOCs assessed and all other sampling locations, measured levels of VOCs were below the respective Environmental Assessment Levels over both the short-term and long-term sampling periods.

4.3 GROUNDWATER RISK ASSESSMENT

The conceptual model of groundwater risk has been developed using available data.

For a particular contaminant to present a risk to receptors, three components must be present:

Source An entity or action which releases contaminants to the environment.

Pathway A mechanism by which receptors can become exposed to contaminants.

Receptor The component at risk of experiencing an adverse response following exposure to a contaminant.

If one of these three is missing, then there can be no risk.

Defining the conceptual model of risk requires identification of all potential sources, pathways and receptors of contamination and identifying plausible combinations of these three components. Potential pollutant linkages are then qualitatively assessed to identify plausible scenarios. The key sources, pathways and receptors are discussed below.

The scope of this risk assessment is to identify plausible linkages that may give rise to an unacceptable risk to receptors. Quantitative risk assessment is then used to establish remediation targets protective of the identified receptors. The quantitative risk assessment methodologies are presented in this report.

Significant sources, pathways and receptors are shown on the site conceptual model, Figure 3.1

4.3.1 Sources

Sources are described in more detail in the Tier 1 and Tier 2 Environmental Risk Assessment Reports. The sources of contamination at this site are Dissolved contaminants in groundwater and potential impacts on the River Dooally.

4.3.2 Pathways

The pathways by which the contamination discussed above could reach potential receptors are described below.

Leaching of Contaminants:

The made ground contains limited elevated concentrations of leachable contaminants that may contribute to the overall dissolved contaminant load of groundwater.

Migration of Dissolved-Phase Contaminants in Groundwater:

Contaminated groundwater may migrate off-site via the subsoil and upper weathered bedrock and into the River Dooally.

Migration via Pipes and Service Corridors:

Services may act as conduits for contamination, particularly vapours, to migrate across the site. This could occur through the services (*e.g.* drains and pipes) or along the more permeable fill material (*e.g.* made ground, sand and gravel) into which the services have been laid.

4.3.3 Receptors

Potential receptors of the identified contamination, and their perceived sensitivity, are summarised below.

Groundwater Wells:

Dissolved contamination may be migrating off-site, thus creating a risk to off-site groundwater wells. However, no groundwater wells are located between the site and the River Dooally. Thus viable pathways are unlikely to be present to link these sources of contamination to these off-site receptors. These receptors are not considered further.

Bedrock Aquifer:

The bedrock aquifer is interpreted to be hydraulically connected to the waste material; hence it is likely that contaminated groundwater emanates the site. The River Dooally is a sensitive receptor as no boreholes are located between the site and Leonards Stream.

River Dooally:

The subsoil and weathered bedrock are interpreted to be hydraulically connected to the River Dooally, hence it is likely that contaminated groundwater from the site may discharge to the river. The River Dooally is a sensitive receptor.

The identified pollutant linkages for the site are discussed and summarised below. The River Dooally could be at risk from the migration of dissolved contaminants in groundwater. Risk quantification methodologies have been used to assess the remediation or mitigation measures for pollutant linkage.

4.3.4 Risk to Leonards Stream – groundwater contaminants

The objective of this assessment is to evaluate whether there is a significant risk to the River Dooally tributary from dissolved phase contaminants present in the landfill area. If the risk is significant, then groundwater remediation may be required to protect the river tributary. A detailed discussion of the risk quantification method is provided below. This section provides a summary of the methodologies used and key outcomes of the assessment.

A tiered approach was used to assess risk to the river, where groundwater conditions were compared with water quality standards described in section 3 to identify chemicals of potential concern. This process has identified the following as COPCs for groundwater: ammonical nitrogen and nickel.

The pathway that is considered via perched water leached from the made ground and migrating through the made ground and underlying/surrounding subsoils. Given that the source material, soil medium and distance to receptor, the P20 model assessment is applicable. The source concentrations for the modelling are groundwater concentrations, in the dissolved phase and are then able to migrate along the groundwater flow path.

Table 4.1 Groundwater Screening based on 2012 data[3]

COPC	Drinking water Regs (µg/l)	Justification	Average Site concentrations MW6 & MW9 µg/l
Arsenic	10	S.I. 122 of 2014	0.98
Cadmium	5	S.I. 122 of 2014	0.66
Chromium (total)	50	S.I. 122 of 2014	4.41
Lead	10	S.I. 122 of 2014	0.15
Mercury	1	S.I. 122 of 2014	0.0107
Selenium	10	S.I. 122 of 2014	3.75
Copper	2000	S.I. 122 of 2014	4.61
Nickel	20	S.I. 122 of 2014	21
Ammonium	0.3*	S.I. 122 of 2014	2.9*
Sulphate*	200*	S.I. 122 of 2014	141.2*

* mg/l

This process has identified the following as COPCs for groundwater:

- **Nickel;** and
- **Ammonium;**

Manganese was not considered as a major contaminant in the groundwater due to naturally elevated concentrations in the limestone bedrock aquifers in Ireland.

Table 4.2 Non-Contaminant Specific Parameter Values

Parameter	Value	Justification
Dry bulk density	2.2 g cm^{-3}	Typical value for subsoil deposits
Effective Porosity	0.02	Typical value for limestone bedrock aquifer
Mixing Zone thickness (Mz)	50	Assumed to be the thickness of the aquifer
Length of site parallel to direction of flow (L)	165 m	Maximum width of source area within the site

[3] See Appendix A

Parameter	Value	Justification
Infiltration (Inf)	0.001 m/d	Met Eireann/GSI data
Hydraulic Conductivity (K)	0.5 m/d	Calculated from on pumping tests and aquifer properties
Gradient (i)	0.02	Gradient from waste material to Dooally tributary
Dilution factor (DF)	1.22	DF = 1 + $\frac{K.i.Mz}{Inf.L}$

Table 5.3 Determination of Level 2 remediation targets

Contaminant	Level 2 remedial target (µg/l)	Average test concentration	Maximum test concentration (µg/l)
Nickel	24.1	21	23.5
Ammonium	0.36	**2.9**	**4.57**

The predicted concentration at the compliance point is above the guideline values for ammonium. Ammonium concentrations exceed the Level 2 remedial target. Sampling in Leonard's stream indicated elevated levels of ammonia in the surface water stream. Previous investigations in 2012 had uncovered a red staining in the stream, possibly due to a change in oxidative state (redox) and subsequent precipitation of iron or manganese in the drainage ditch.

It is not possible to accurately model the concentrations of ammonium in the groundwater due to highly variable biotic and abiotic processes. For example, in *nitrification*, the microbial conversion of ammonia to nitrate, ammonia provides the energy and bicarbonate ion contributes carbon. Concentrations of total ammonium in the Leonard Stream (0.43 mg/l) are below the Salmonid regulations (1 mg/l) but are above the drinking water regulations (0.3mg/l).

Given the location of the stream in an outer urban area, potential sources of ammonium include agricultural, sewerage networks, septic tanks and other waste disposal sites, the landfill area and cemeteries. In groundwater, nitrogen species consist of ammonical nitrogen (NH_4.N), nitrite (NO_2.N), nitrate (NO_3.N), organic nitrogen and nitrogen gas (N_2). The predominant form present is determined by the environmental conditions of the water body particularly pH, temperature, oxygen and microorganism activity coupled with the mineralization rates of labile organic nitrogen. Seasonal changes can be a control of the speciation balance regardless of the total nitrogen concentration of the water body (Burt et al., 1993).

Sampling and monitoring in the Leonard's stream indicated nickel concentrations were below detection limits (<1 µg/l) therefore the Level 2 assessment is conservative and does not require further analysis.

Sampling and monitoring in the Leonard's stream indicated sulphate concentrations were below guideline limits (<200 mg/l) therefore the Level 2 assessment is conservative and does not require further analysis.

4.3.5 Water Framework Directive

Surface Water Regulations - SI 272 of 2009

The Dooally River is located in the Shannon Estuary South Unit of Management (hydrometric area 24), within the Shannon RBD. The total area of Dooally River is approximately 13.6 km^2. The River Dooally rises in the Mullaghareirk Mountains. It flows roughly in a south-easterly direction though the mountains, where it is joined by numerous tributaries, which drains the lands upstream of Churchtown. Downstream of Churchtown, the River Dooally is joined by the rivers Arra which also drain the steep topography of the Knockanimpaha Mountains which bound the west of the catchment. Where the River Deel enters the Shannon Estuary, the catchment area is approximately 486.1 km2.

The ammonium standard as set out in the S.I. 272 of 2009 requires good status for the Dooally River by 2021. The ammonium standards as set out are 0.065 mg N/l based on the mean flow. The landfill area (0.0176 km2) potentially contributes 0.1% of the flow to the Dooally River (13.6km^2). Based on an attenuation factor of 1000 the landfill area contributes less than 4.5% of the overall ammonium loading on the River Dooally assuming no biodegradation offsite or <0.7% based on the concentrations monitored in the drainage ditch. Given concentrations in the landfill area are likely to reduce further away from the landfilling area concentrations are likely to decrease over time. Reductions in ammonium are likely to occur immediate downstream in the tributaries hyporheic zone therefore the above assessment is conservative. In a low nitrate environment, the Hyporheic zone often functions as an oxidation reactor where nitrification and aerobic respiration dominate, oxidizing surface water ammonia. Further monitoring of the stream was undertaken in March 2013 which indicated the ammonium concentrations were low downgradient. Biological Q values on the Dooally and Dooally Tributary were also undertaken which confirms the high water quality in the stream.

Based on an analysis of the groundwater at the Newcastlewest pre 1977 landfill, the following is concluded.

- Site investigation works indicated the bedrock is comprised of unbedded limestones with some minor karst features and no evidence of dolomitization. Most karst features are clay filled;
- A pumping test carried out in December 2012 indicated a limited permeability of 0.05 m/day possibly as a result of clay filled fractures;
- Groundwater flow is towards the southwest. The groundwater gradient is steep between 0.015 and 0.022 and likely to reflect the moderate permeability of the bedrock;
- Rainfall on the landfill area is likely to percolate through the waste, into the groundwater and discharge at the Dooally Tributary.
- Concentrations in the landfill are below the drinking water limits with the exception of manganese, nickel and ammonium.
- Concentrations of metals in the River Dooally tributary are below the drinking water limits with the exception of ammonium.
- Concentrations of ammonium were detected in the landfill area were elevated however concentrations in the Dooally tributary were below the Salmonid standards. Given the extra-urban location, a number of potential sources of ammonium such as agriculture, waste and wastewater could be contributing to the concentrations detected in the Dooally tributary.
- In relation to the surface water regulations S.I. 272 of 2009 the River Dooally is currently good ecological status – Q4 (see Appendix 5). Based on an area calculation, the landfill area is likely to contribute <0.7% of the ammonium concentrations to the Dooally River.

Therefore, it can be concluded that the risk to the River Dooally tributary while present is not having a major impact on the Dooally River. The removal of the waste material may create a greater environmental hazard to locals and in the short term to the environment.

5 CONCLUSION AND RECOMMENDATIONS

The Tier 3 Environmental Risk Assessment has identified the risk is negligible to low for all groundwater contaminants except ammonia, for which the potential risk is considered to be low, although any impact is confined to a drainage ditch to the south of the landfill. Based on the age of the landfill, monitoring results on the River Dooally and an assimilate capacity assessment, the potential impacts on the River Dooally are low. In accordance with EPA cop the site however will need to be remediated due to its Class A rating. Further details of the remedial options considered are discussed in Appendix 6.

Based on the groundwater flow direction data, groundwater is moving from the landfill area and discharging into a drainage ditch connected to the River Dooally. The surface water run-off from the landfill and some groundwater is collected at sump on the western boundary and is pumped for treatment at the WwTP.

The capping process involves the creation of a 0.4 metre cap over the site. The cap will comprise of a liner, drainage layer, subsoil and topsoil. The drainage layer, subsoil and topsoil are placed over an impermeable liner which does not allow water to permeate down to the landfill (thus reducing the potential for groundwater pollution). The area of landfill to be capped is 16,700 m^2 (approx.1.67 hectares). The areas capped will be planted with grass once capping is complete.

Methane and carbon dioxide are still being generated within the waste body; however there is no evidence of any significant migration of gas away from the landfill area. The EPA COP also references the Ministerial Direction (WIR 04/05) stating that sites proximate to residential development should at all times be remediated. However, because capping of the fill area is likely, remedial action will be required to mitigate the risk of landfill gas migration which may increase due to the buildup gases beneath the cap. Based on a review of the remedial options with Limerick County Council, it is proposed to install a 0.4m capping layer and passive venting.

Passive vent systems rely on natural pressure and convection mechanisms to vent the landfill gas to the atmosphere. Shallow gas venting trenches, or gas venting pipes, will be installed within the landfill and vented to the atmosphere, have been used to allow gas from interior regions of the landfill to escape.

It is proposed to install passive trenches approximately 500m long along the entirety of the landfill to the east and south east. The trenches will also connect to existing gas wells to enhance the gas collection potential. While the radius of influence of a passive vent is relatively small the transport of landfill gas is multi-dimensional and will take the path of least resistance. This may be problematic if relatively high concentrations of VOCs in the Landfill Gas are located in perimeter sections of the landfill near potential receptors.

It is proposed to install a groundwater collection trench along the southern boundary to intercept groundwater from the site. The groundwater will be directed to the onsite sump and ultimate treated at the WwTP.

Testing would indicate that VOC concentrations are low within the landfill however this will be further assessed prior to undertaking the works. Offsite issues in relation to benzene require further investigation of potential sources.

APPENDIX 1

APPENDIX 2

APPENDIX 3

APPENDIX 4

APPENDIX 5

APPENDIX 6

APPENDIX 7