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Cork City Council
Comhairle Cathrach Chorcaí

Hydrogeological Investigation of Groundwater and Plume Dynamics at Kinsale Road Landfill and its Environs, Cork City

Prepared For: -
Cork City Council
Environment Directorate
City Hall,
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Document Production / Approval Record

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Executive Summary

The Landfill at Kinsale Road was operational from 1963 to July of 2009. Landfilling at the facility has ceased and a civic amenity site continues to operate at the site. This facility operates under waste licence W0012-03 and has undergone significant environmental remediation measures including top capping since 2001. Since the site does not contain a basal liner, there has been evidence of leachate contamination of the underlying aquifer (based on results of previous geophysical surveys and groundwater borehole analysis).

Following on from a meeting with the EPA and Cork City Council management officials in November 2017, an agreement was reached whereby a series of objectives to assess the leachate plume dynamics in the vicinity of the landfill site was agreed. The study was conducted at offsite wells in Greenhills Estate, which is situated to the northeast of Kinsale Road landfill. Step tests and pumping tests investigations were conducted to assess the groundwater movement and leachate plume dynamics. Through Pumping Tests, the leachate plume was characterised based on Chloride concentrations. Due to low levels of TOC and NH_4 detected in water monitoring boreholes at Greenhills Estate (Greenhills South Deep (GHS) and Greenhills North deep (GHN)) these parameters were not used in interpretation. Chemical interpretation of the groundwater shows strong characteristics of contamination by a diffuse, chloride dominant, polluting source to the Northeast of the landfill site. A Geophysical survey conducted on the grounds at Nemo Rangers has indicated that the installation of the proposed 5 new monitoring wells proposed by the EPA would not prove useful in further interpretation of a possible leachate plume from the landfill site.

1. Introduction

The Kinsale road landfill is licensed by the EPA (Environmental Protection Agency) for the former disposal and the recovery of waste (licence no. W0012-03). The site was first issued with a waste license in February of 2000, with a licence revision in 2002. The current waste licence was issued for the facility in May 2011. The facility is now operated in accordance with Waste licence register No W0012-03.

An EPA Inspection Audit was carried out on the site in November 2010, to assess compliance with the waste license. The Agency has expressed a degree of concern regarding the elevated levels of ammonium in the groundwater at several of the groundwater monitoring boreholes around the perimeter of the site.

The Report has been conducted on foot of the request for information from the EPA. Following on from a meeting with the EPA and Cork City Council management officials in November 2017, an agreement was reached whereby a series of objectives to assess the leachate plume dynamics in the vicinity of the landfill site was agreed. The report was submitted to the EPA on the 27/11/2018. The report was returned to the licensee on the 03/11/2020 requesting a revised report that aligned with the following: In conjunction with conditions 6.16.4 and 6.16.6 of the EPA licence, the licensee previously submitted a report entitled Hydrogeological investigation of groundwater and plume dynamics at Kinsale Road Landfill and its Environs by Licensee Return on EDEN (LR037876 refers). The licensee wishes to highlight the following: on page 1 (Executive Summary) of the original submission of the Hydrogeological Investigation of Groundwater and Plume Dynamics at Kinsale Road Landfill and its Environs, it is stated that the report should be read in conjunction with the report on 'Trigger Levels, Groundwater Trends and a Review of the Conceptual Site Model (report ref.: W0012-03/002/2018). This report was submitted at the same time as the Hydrogeological report.

The EPA rejected the report as not all the objectives previously agreed with the Agency for the assessment of the leachate plume were addressed. These objectives were; 1. To investigate the groundwater migration from the site using hydrogeological methods such as step tests and pumping tests, 2. To investigate the potential for offsite migration of a leachate plume formed on site, 3. To investigate the extent of the leachate plume originating onsite and detected in offsite water monitoring wells in the Greenhills Estate (GH North and GH South), 4. Using historical data and recently collected data, comment on the longevity of the chloride plume, 5. Investigate offsite migration into the areas east of the licensed facility with the use of geophysics, and 6. Establish the feasibility of the installation of new groundwater monitoring wells. The report did not contain any information on points 1, 2 and 3, which sought for work to be completed with the view of gaining a better understanding of the hydrogeology and leachate distribution near the site boundary. The Licensee was also informed that the quality of the report needed to be improved and that it should include details of the works carried out, the findings of the work, the conclusions drawn from the work and an outline of the next steps/ proposed works. On 03/11/2020, the Agency informed the licensee that the report would not be considered further, unless the licensee provided the required information as part of a new submission, aligned with the relevant EPA guidance note.
(https://www.epa.ie/publications/compliance--enforcement/licensees/reporting/guidelinetemplate-report-for-reporting-compliance-with-the-eo-groundwater-reg.php).

On the above items, the licensee believes that it is possible that the consultants appointed by the Agency did not receive the second report (report ref.: W0012-03/002/2018).

1.1.Project Objectives

1. To investigate the groundwater migration from the site using Hydrogeological methods such as step tests and pumping tests:
2. To investigate the potential for offsite migration of a leachate plume formed on site.
3. To investigate the extent of the leachate plume originating onsite and detected in offsite water monitoring wells in the Greenhills Estate (GH North and GH South).
4. Using historical data and recently collected data, comment on the longevity of the chloride plume.
5. Investigate offsite migration into the areas east of the licensed facility with the use of geophysics.
6. Establish the feasibility of the installation of new groundwater monitoring wells offsite.

1.2. Scope Of Works

Groundwater monitoring has been carried out on the Greenhills well series from 2013 to present. Data from this period was used to establish the historical characteristics of the groundwater and contamination plume detected at this point. Newly conducted well surveys and monitoring from July 2018 were used to assess groundwater characteristics. The Hydrogeological methods were also be used to assess the longevity of the offsite plume in terms of increasing or decreasing concentrations. Water samples taken during the July 2018 pumping tests were analysed; the results of which were used in combination with the historical data to assess the longevity of the plume over time.

Geophysical techniques were used to establish the extent of the plume. However, due to the proximity of residential areas adjacent to the existing Greenhills wells (GHS and GHN series), the Nemo Rangers grounds (just south of the wells) were deemed to be the only viable area to conduct the geophysical survey.

An assessment for installing 5 new monitoring wells to be drilled off site (as proposed by the EPA) was also carried out.

1.3. Summary Of Previous Site Sampling And Monitoring Data

Previous groundwater monitoring data for the site can be referred to in previous Annual Environmental Reports. APEX Geoservices also carried out a Geophysical survey at the facility in 2010 (report ref. AGL09241_KR_03)

2. Environmental Site Setting

2.1. General Introduction

The Tramore Valley Park or the Kinsale Road Landfill is situated 3km south of Cork City out along the South Link Road (N27), in the townlands of Ballyphehane, Curraghconway and Inchisarsfield. It is contained to the south by the N40 South Ring Rd and the main body of the site is contained on the West side by the South Link Rd with Nemo Rangers playing fields and Greenhills housing estates to the east of the site. The site covers an extent of approximately 2 hectares on the Park and Ride portion and another 70 hectares on the main body of the site (CCC, 2017). The site is underlain by Waulsortian Limestone; a massive, unbedded lime-mudstone to the north and the Cuskinny Member; a flazer-bedded sandstone & mudstone; to the south. The Geological Survey of Ireland (GSI) describes the Waulsortian bedrock as a "Regionally important karstified bedrock aquifer dominated by diffuse flow" and the Cuskinny Member (Kinsale formation) bedrock as "Moderately Productive only in Local Zones". The aquifer vulnerability is described as "Moderate" across most of the site. The Quaternary Subsoils Map indicates the soil type across the site as sandstone till (GSI Online Maps). Although many of the factors of consideration outlined in the Landfill Directive 1999 regarding site selection criteria are infringed in the context of this site, it must be acknowledged that the site was constructed almost 30 years before this directive was established.

2.2. Regional Geology

The regional geology is clearly visible in the area's topography. The region is dominated by east to west trending anticlinal and synclinal structures which developed during the Variscan Orogeny due to folding and faulting. The synclinal valleys (including the Tramore river valley) were infilled with limestone deposits of varying thicknesses during the Carboniferous period. The high ground to the south of the landfill consists of older Devonian 'Old Red Sandstone' and mudstone (OCM, 2015). Other regional lithologies include Devonian and Carboniferous units such as the Waulsortian Limestone, Kinsale Formation (Fm), Ballytrasna Fm, Gyleen Fm, Ballysteen Fm, Cork Red Marble Fm, Little Island Fm and Clashavodig Fm (Figure: 1)

2.3. Site Geology and Hydrogeology

Waulsortian limestone comprises massive, horizontal, unbedded fine-grained sequence of limestones deposited in the South Munster Basin during the Carboniferous period. The lithology is highly fractured and infilled with alluvial silts in the mid to southern section of the landfill site *(FTC. 2009)*. This weathered and fractured bedrock is part of a regionally important karst limestone aquifer (Rkd) (OCM, 2012; Ryan, K., 2014). The Kinsale Sandstone Formation is a Carboniferous siltstone/mudstone unit, which is highly weathered and exhibits flazer bedding. The southernmost part of the site is underlain by the Cuskinny Member, which is the part of the Kinsale Sandstone Formation (Ryan, K., 2014). This unit consists of relatively thick, sometimes conglomeratic sandstone with thin mudstones, sandstone laminae and massive claystone (Figure 2). It occupies the high ground south of the site as it is located on the southern limb of an anticline dip steeply to the north (Ryan, K., 2014; OCM, 2015). A series of surveys conducted in November 2003 indicate a predominantly east-west trending fault zone in highly fractured bedrock in the southern section of the site. The faults are principally in the Carboniferous Limestone but do extend into the Devonian Old Red Sandstone (Ryan, K., 2014; OCM, 2015). To the south of the fault zone is the Kinsale Formation Sandstone (Cuskinny Member). To the north lies the Waulsortian Limestone (FTC, 2009).

Aquifer Classification

The karstified limestone is classified by the Geological Survey of Ireland (GSI) as a Regionally Important Karstified Aquifer (Rkd) with diffuse flow paths. The Kinsale Formation (Cuskinny Member) is classified as a Locally Important Aquifer (Ll). The Devonian slate and siltstone is classified as a Poorly Productive Aquifer that is moderately productive in local zones *(Figure 3).*

Groundwater Vulnerability

Site maps indicate mainly moderate vulnerability across the site, aside from the southern end where investigations suggest low/moderate vulnerability owing to peat and silt above the bedrock. Immediately north of the site the vulnerability becomes very high *(Figure 4).*

Groundwater Flow & Gradients

Vertical groundwater flow at the site is important since it will determine whether or not leachate will leak to the underlying bedrock aquifer. Even though the limestone bedrock aquifer is a major aquifer, the groundwater horizontal gradient is low. Gradients within the waste body are much higher because of the surface expression of the landfill, and due the low permeability of the waste body *(FTC, 2009).* Groundwater readings from site bedrock monitoring wells indicate that groundwater flow direction is generally to the east/southeast beneath the site, moving towards the Tramore River and Douglas Estuary *(OCM, 2015).*

2.4. Site Hydrology

The landfill lies in the Tramore River Valley. The Tramore River flows along the southern site boundary from the western side and is the main river draining the site *(FTC, 2009).* Historically it flowed directly east to join the Trabeg Stream *(Figure 6)* which flows along the eastern boundary to the south. The Tramore River was diverted from the centre of the site to south of the landfill in the 1980's and now flows around the southern boundary, where it joins the Trabeg Stream *(OCM, 2015) (Figure 4).* The original river channel was considered to be an environmental risk since it could be a preferential pathway for the eastward migration of leachate and landfill gas. Sheet piling was installed adjacent to the eastern intersection of the leachate collection drain and the old Tramore River channel. These works were carried out in 2001 and the sheet piles were placed across the old channel to create a barrier to potential contaminant migration (*FTC, 2009).* The new Tramore River is tidal up to the south-eastern corner of the landfill. The Trabeg Stream flows along the eastern site boundary and part of the northern boundary and meets the Tramore River at the southeast corner of the site. The lower section of the Trabeg stream was also diverted during works carried out in the vicinity of Nemo Rangers complex. The Tramore River discharges into the Douglas River Estuary, approximately 2km east of the site.

Other Site Drainage

All surface water drainage from the engineered cap is collected by drainage swales, which discharge into the stormwater pond. Reed beds are used for primary treatment of this stormwater. The paved site access roads are also drained to the stormwater pond in the southeastern corner of the site *(FTC, 2009) (Figure 7).*

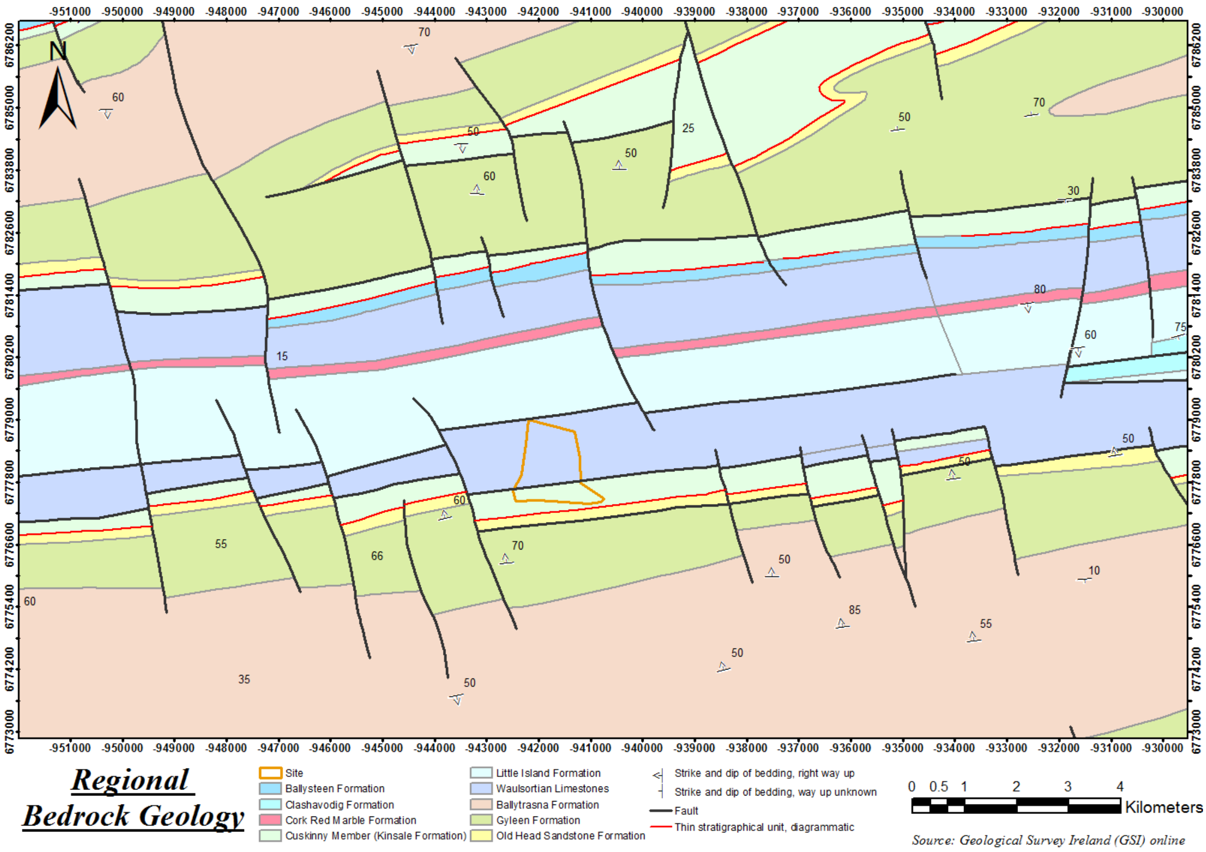


Figure 1 Regional Bedrock Geology

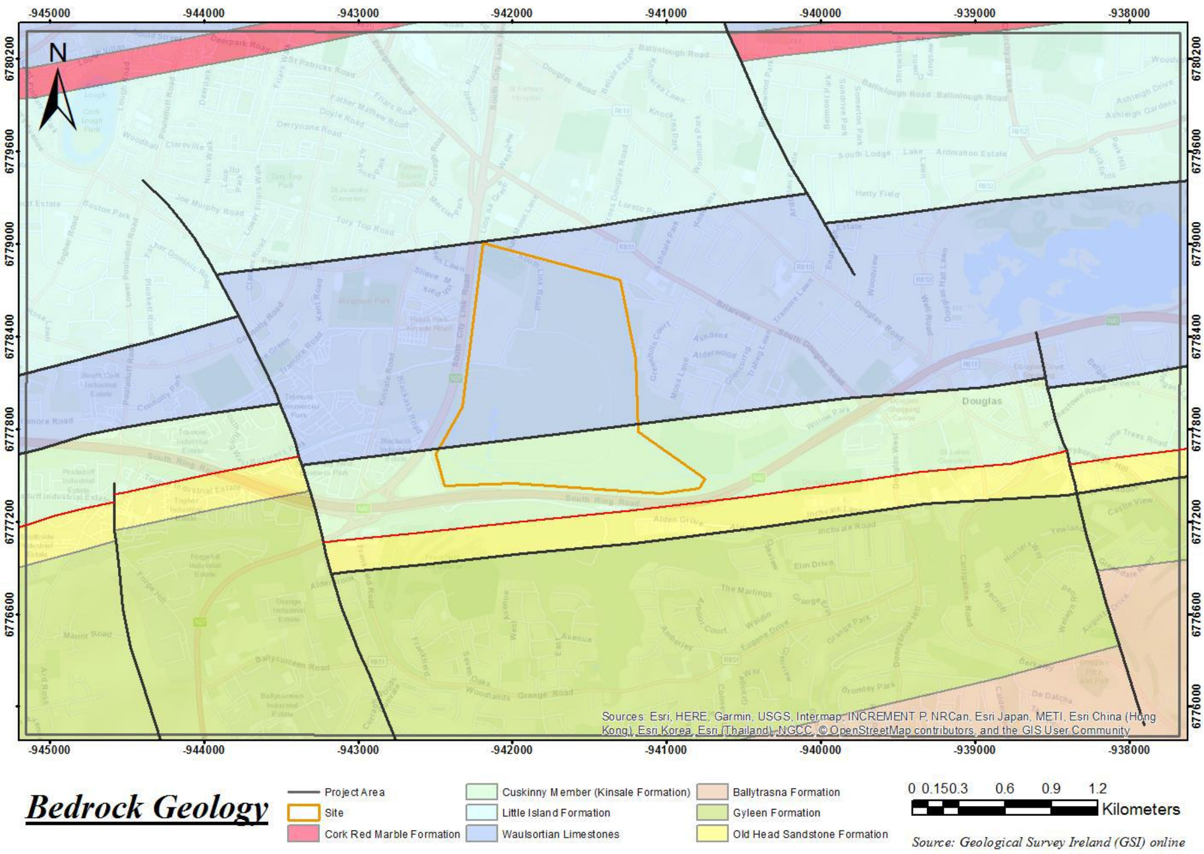


Figure 2 Local and Site Geology

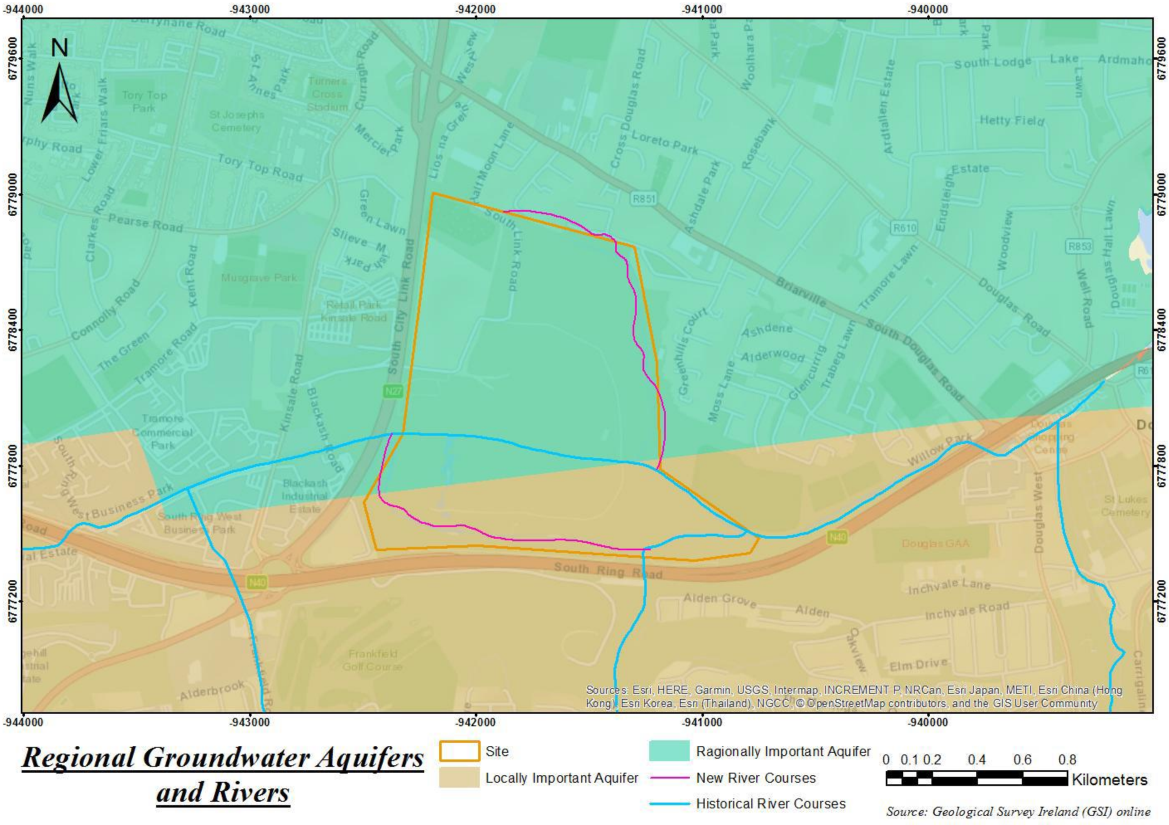


Figure 3 Underlying groundwater aquifers along the direction of the new river courses that were moved during landfilling

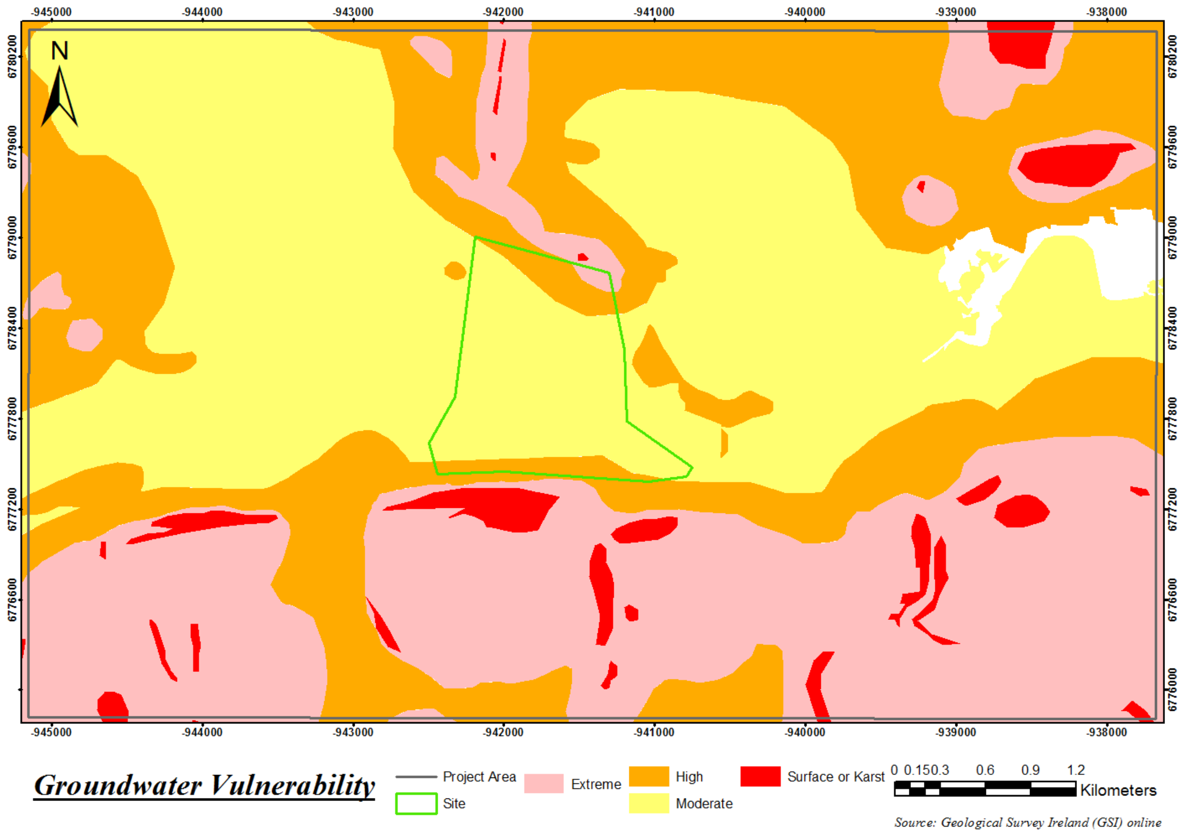


Figure 4 Groundwater vulnerability

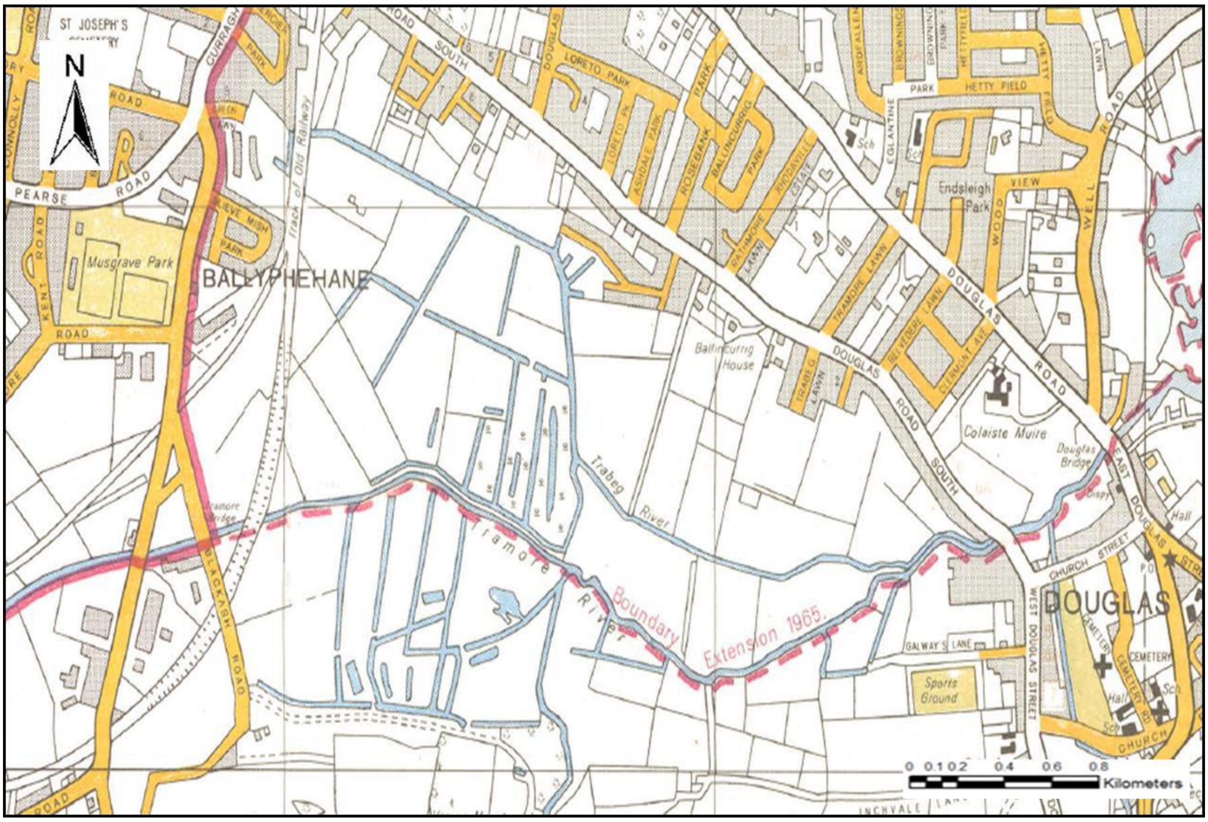


Figure 5 OSI Cork Map 1964 showing old river courses. (Green outlines site boundary)

2.5.Previous Site Operations

In 1963 the site commenced operations. The facility accepted non-hazardous municipal solid waste, with deposition beginning in the west (present day Park and Ride), progressed to the northwestern corner and then moving east and south. The landfill was developed on the principle of dilute and disperse, with waste placed directly onto unlined ground surfaces. This waste originally deposited was mainly black bottom ash. By the early 1980s, waste deposition in this area was completed, at which time the Blackash Site (Park and Ride) was capped with approximately 1 m of clay. This area was subsequently remediated with an engineered top cap and developed as a Park and Ride car/bus facility. Waste deposition then extended from the north-west corner beyond the original course of the Tramore River until the river was diverted southwards to its current route which resulted in the merging of the landfills. With the addition of the domestic and commercial waste, along with limited quantities of approved non-hazardous industrial sludge, waste deposition continued to the extent of the existing site boundaries (OCM, 2015). Landfilling at the facility came to an end on July 16th 2009. This was due to a change in the waste licensing regulations. Post-closure of the site, capping works were undertaken in a series of phases (see *Table 1 and Figure 1)*. This was carried out using standard and approved capping design and methods

Table 1 Capping/restoration phases

Phase No.	Reference	Detail	Waste Age
Phase1	Capping (O'Callaghan Contractors 2001/2002)	Capping of the landfill at the eastern side of the central dome. The area is surrounded by swales and includes gas and leachate management infrastructure.	10-20 years old
Phase 2a + 2b	Capping (O'Callaghan Contractors 2004) (2a) Blackash Park and ride Capping (Sorenson Contractors 2004) 2b	Capping to the southern side of the central area, includes landfill gas management and leachate extraction infrastructure. The Blackash Site, including gas and leachate extraction system and relate site works/parking facilities.	10-20 years old, 35 years old (2b)
Phase 3	Capping (O'Callaghan Contractors 2008)	The landfilled area to the south west of the central dome, includes gas and leachate management infrastructure	
Phase 4	Capping (Willis Brothers Contractors 2011)	The landfill to the northern and central of the dome	10-20 years old
Phase 5	Capping (Willis Brothers Contractors 2015) Playing Pitches	The area to the north of the landfill site, also included in this phase was a playing pitch, carpark, and a northern road network for the site. The underlying infrastructure included a landfill gas extraction system along with the leachate pumping system.	20–30 years old waste

2.6.Current Site Operations

An Amenity Park of approx. 72 hectares opened to the public in early 2019 at the site of the former landfill.

Faculties currently in existence are as follows:

- Park and Ride facility on the western side of the N27,
- BMX Track,
- Walking/running path and playing fields.

From the year 2000 to present, several phases of restoration have been carried out at Kinsale Road Landfill. Landfill gas is abstracted and utilised in a flare / electrical power generation unit. Water monitoring is on-going as part of the EPA license for onsite and offsite wells. This also includes the monitoring of storm-water discharges to the river. Leachate and landfill gas collection infrastructure has been across the site. Leachate management infrastructure includes a perimeter leachate collection trench with 10 no. pump sumps, 4 no. deep borehole pumps for leachate extraction for the main dome area, a leachate storage lagoon and a leachate treatment plant (air sparging – prior to sewer discharge).

A Civic Amenity area opened in 2001 continues to be used as a public recycling facility accepting household waste, recyclables, green waste, hazardous household wastes (paint and aerosols) and waste electronic equipment (OCM, 2015).

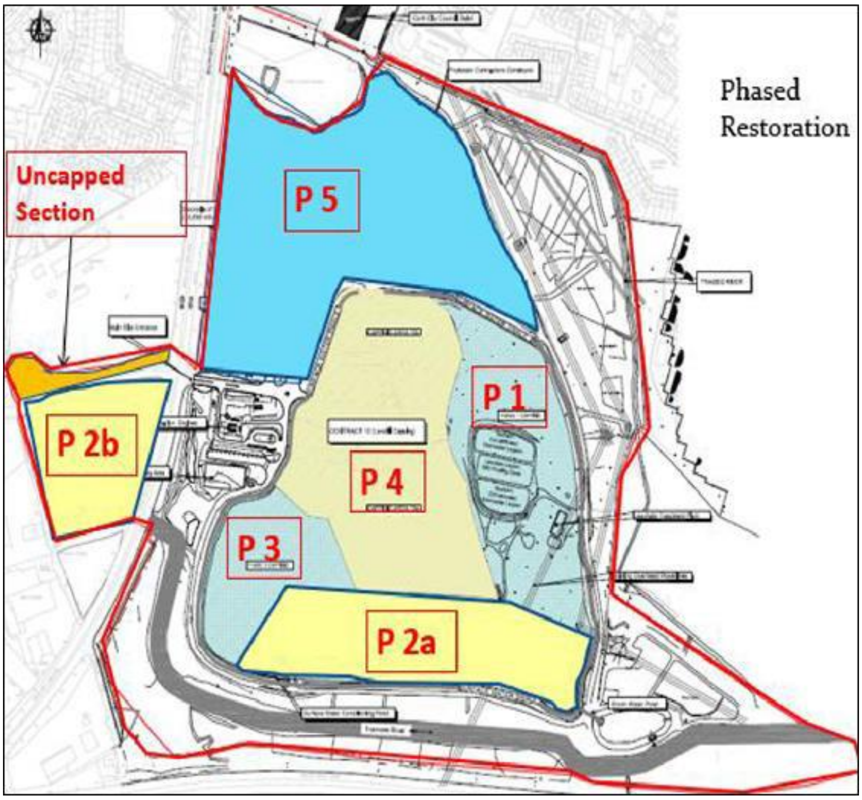


Figure 6 Capping phase son site

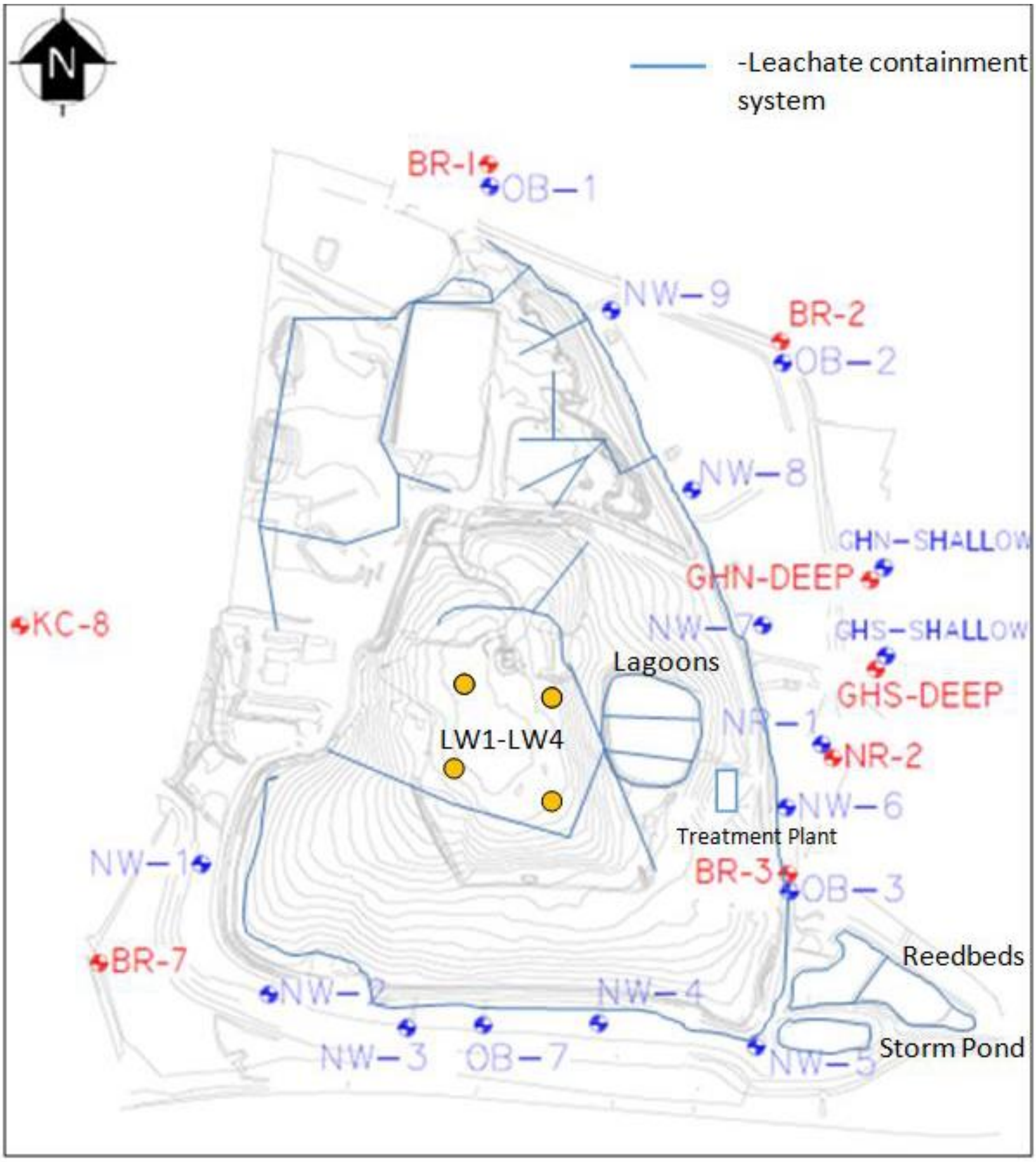
2.7.Chemicals Of Potential Concern

The generation of leachate may be defined as any liquid percolating or seeping through deposited waste, contained within, or emanating from a landfill. The liquid usually begins as water, from rain, groundwater, or surface water run-off. This leachate entrains suspended and soluble materials, extracting substances that originated from or are products of the degradation of the waste (EPA, 2003; Ryan, K., 2014). There are various processes involved, both biological and physio-chemical that can control the composition and production of landfill leachate. The composition of leachate is highly variable, and as a rule, the composition of landfill leachate is a function of its constituents. Landfill leachate is typically characterised by high concentrations of organics that may be readily biodegradable or recalcitrant i.e., ammonium, chlorides, and suspended solids. Concentrations of heavy metals and other hazardous substances may fluctuate with time within a site or be very much site specific. The major environmental concern relating to landfill leachate is its release into groundwater, surface water and soil. This may impact on water quality, resulting in impairment of ecosystem functions, closure of potable water sources and damage to agriculture.

Typical leachate composition: Major components and ions such as ammonia, chloride, magnesium, iron, sodium, carbonate and sulphate. Trace metals such as manganese, chromium, nickel and lead. Also contains wide variety of organic compounds which are usually measured as TOC (total organic carbon) and COD (chemical oxygen demand), List I & List II substances of the EU Directives on Dangerous Sub-stances (76/464/EEC) and Groundwater (80/68/EC). Other constituents include microbiological components (Landfilling Wastes. 1986) and dissolved gases.

2.8.Groundwater Monitoring Wells

Nine groundwater monitoring wells were installed (prefixed with the letters NW) as part of waste licence conditions, from which data is collected monthly *(FTC, 2004).* The NW well series are situated around the boundary of the site, on the eastern and southern margins. Additional wells were drilled off site to the east (at the request of the EPA) named the GH series, Greenhills North – shallow and deep (GHNS/GHND) and Greenhills South – shallow and deep (GHSS/GHSD) wells *(Figure 7).* The NW well series have been used to establish overburden & groundwater quality. These wells are of varying depth dependant on where bedrock was encountered during the drilling process. They consist of a main metal casing above ground level which houses the main 50mm stand pipe. This pipe penetrates to the level drilled. The base the pipe is slotted (response zone) and solid towards the surface. They are situated outside the leachate collection network. The main source of geological information is the site investigation activities carried out as part of waste licence application. This involved the installation of overburden wells 'OB' series and bedrock wells 'BR' series to monitor the effectiveness of the leachate collection drain at the site *(FTC, 2004).*



Legend
NW Series – Groundwater wells (to top of Bedrock)
BR Series (referred to a MWBR Series) – Groundwater wells (In Bedrock)
GHN – Greenhills North Wells
GHS – Greenhills South Wells
OB Series – Overburden Wells
LW1 – 4 – Leachate extraction wells in waste body

Figure 7 Onsite and offsite well series NW, GH, OB & BR.

3. Conceptual Site Model

3.1. Site Source - Pathway – Receptor

The table below (Table 2) outlines the source and possible migration pathways for contaminants. The potential Receptors are also listed.

Table 2 Sources, Pathways and Receptors.

Source	Pathway	Receptor
Leachate build up at the Eastern sheet Pile Wall	Subsoil flows around sheet pile wall	Groundwater east of the site
Leachate build up within the waste body to the south	Subsoil flow	Tramore Valley and ultimately the Douglas Estuary
The elevated leachate level within the central portion of the waste body	Subsoil and bedrock formation flow	Groundwater beneath and the east/south of the site and ultimately the Douglas Estuary
C & D waste deposited at the Greenhills estate	Rainfall infiltration	Subsoil groundwater

3.2. Source

The waste on site and the associated leachate are the contamination sources. The primary chemicals of potential concern emanating from these are ammonium and chloride and the associated elevated electrical conductivity. When waste deposition began in the northern portion of the site 30-40 years ago the area was underlain by thin subsoils which promoted the transfer of leachate to the bedrock aquifer relatively quickly. There are gravel lenses also identified in this area which would also facilitate the transfer of leachate within a perched aquifer type system. This portion of the site was permanently capped since 2013. It is believed that rainfall infiltration through the temporary cap prior to the implementation of the permanent capping system promoted the generation of leachate in this portion of the site. The leachate thought to be emanating from this area is believed to be weak given the age of the waste in the area.

To the northeast of the site (near well BR-2) that the bedrock aquifer is partially confined by peat and there is an upward hydraulic gradient which would prevent the migration of leachate to the underlying aquifer in certain months of the year. This hydraulic gradient will, however, facilitate the migration of groundwater into the waste deposit thus aiding the generation of leachate.

The rest of the site where waste deposition occurred is underlain by low permeability soil of varying thickness throughout (6-15m). This would make leachate transfer the bedrock aquifer unlikely. The effects of leachate migration in these areas is more or less confined to the overburden groundwater.

3.3. Pathways and Receptors

Potential pathways for contaminant transfer include the subsoil groundwater movement, the bedrock aquifer underlying the site and the former Tramore River channel through the central portion of the site. The Tramore and Trabeg rivers are potential receptors as is the Douglas estuary.

The preferred pathway for water movement is laterally towards the Tramore and Trabeg Rivers. Surface water recordings show that in the past the rivers were impacted by leachate. However, since the development of leachate control measures (leachate cut-off trench, pump sumps, etc.) the migration of leachate to the surface waters is no longer occurring. In the central and southern portions of the site the subsoils are thick enough or have been compacted to such a degree that they are most likely impermeable. This pathway has also been restricted due to the degree of compaction of the bottom 1-2m of waste. The combination of the low permeability soils and waste would likely eliminate the vertical migration of leachate to the bedrock in this area of the site.

There is a potential lateral pathway through the waste body which risks a breakout of leachate on the flanks of the waste mass. This could lead to run-off into the Tramore and Trabeg rivers. As previously stated, the leachate control measures of the leachate cutoff trench, associated pump sumps on the perimeter of the waste body and the four internal leachate extraction wells in the waste mass implemented in the mid to late 2000s were designed to prevent the migration of leachate to the surface waters. These measures have proven to eliminate this pathway.

The original course of the Tramore River prior to its diversion in the 1990s was through the central portion of the site where it joined the Trabeg River. The former channel was subsequently filled with waste and had been recognised as a potential conduit for leachate movement towards the Trabeg River. In 2001 Cork City Council drove a 6m deep sheet pile wall across the former channel at a point upstream of the original confluence with the Trabeg River.

There was a recorded reduction of ammonium downstream which had been attributed to the sheet pile wall. However, there was also a reduction in the upstream ammonium values which could mean that the ammonium reduction was the result of offsite upstream inputs ceasing rather than the action of the sheet pile wall.

Following its installation leachate moving along the old river channel gathered against the wall and moved laterally around the wall. This may have been the impact of leachate on the OB-3 and NW-6 wells (Fig. 7) which are to the west of the sheet pile wall and to the east of the main waste body. The groundwater levels in these wells is persistently elevated when compared to the wells immediately north and south indicating mounding or an upward hydraulic gradient.

In general, under the site groundwater flow is moving to the south-east. In the southern portion of the landfill where the regionally important limestone aquifer meets the poorly productive silt/mudstones groundwater flows to the east. The contact between the two aquifer types forms a barrier to groundwater and leachate movement and causes the groundwater to travel east discharging eventually into the Douglas Estuary and Cork Harbour. In the portion of the site to the south underlain by the silt/mudstones groundwater is believed to flow from south to north discharging into the Tramore River.

The groundwater levels for the NW wells series for the top of bedrock are generally at similar elevations. The OB well series which are overburden/subsoil wells generally have lower elevations than the NW well series which would indicate an upward hydraulic gradient.

The CSMs were developed by compiling past reports for the site. O'Callaghan, Moran and Associates developed a CSM in 2015 and this was corrected and adapted for site changes since its development. Two transect were investigated (Fig. 8). The West-East model (Fig. 9) was adapted from the OCM model, and the North-South (Fig. 10) model was reproduced to highlight the flow network through the cross-sectional area including the contact of the two aquifer types.

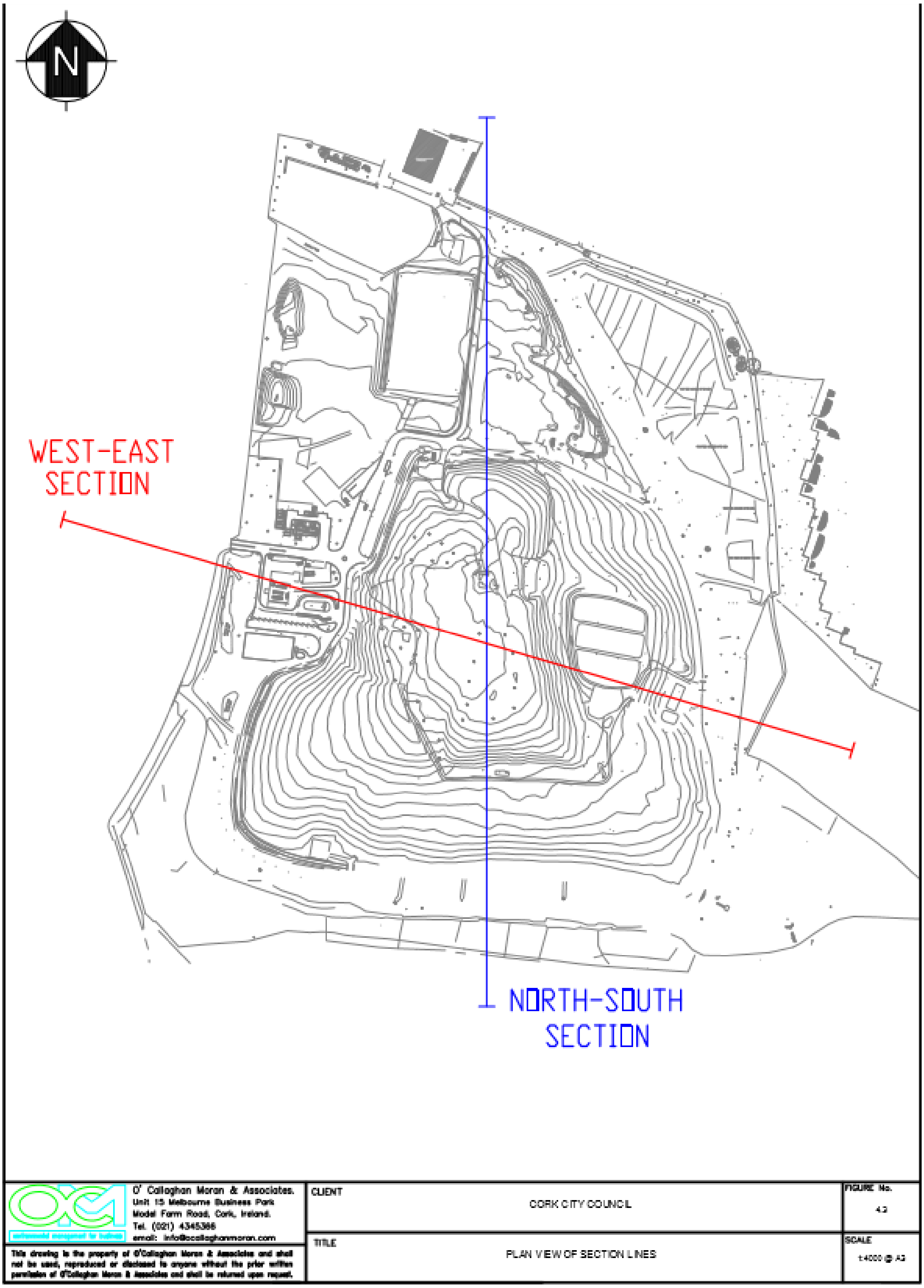


Figure 8 Site map showing the location of the transect lines of the W-E and N-S hydrogeological cross section models (OCM, 2015)

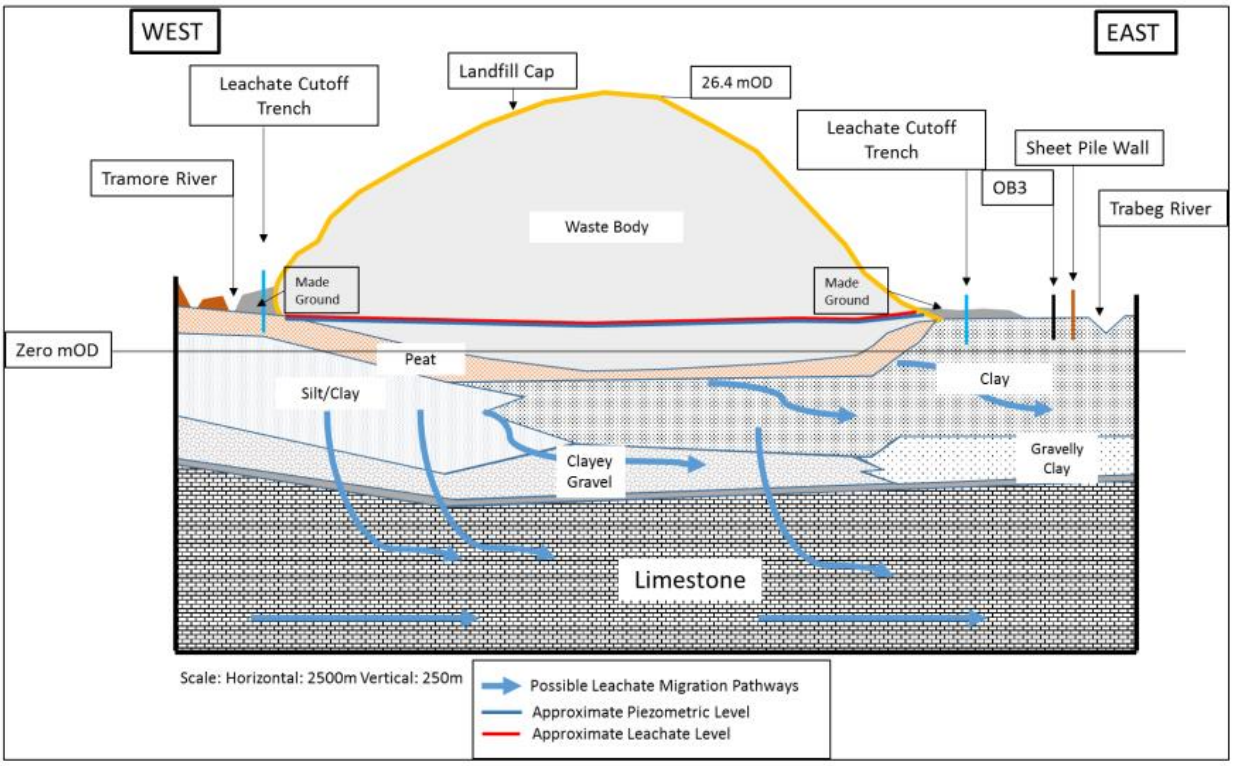


Figure 9 West- East hydrogeological CSM (adapted from OCM 2015).

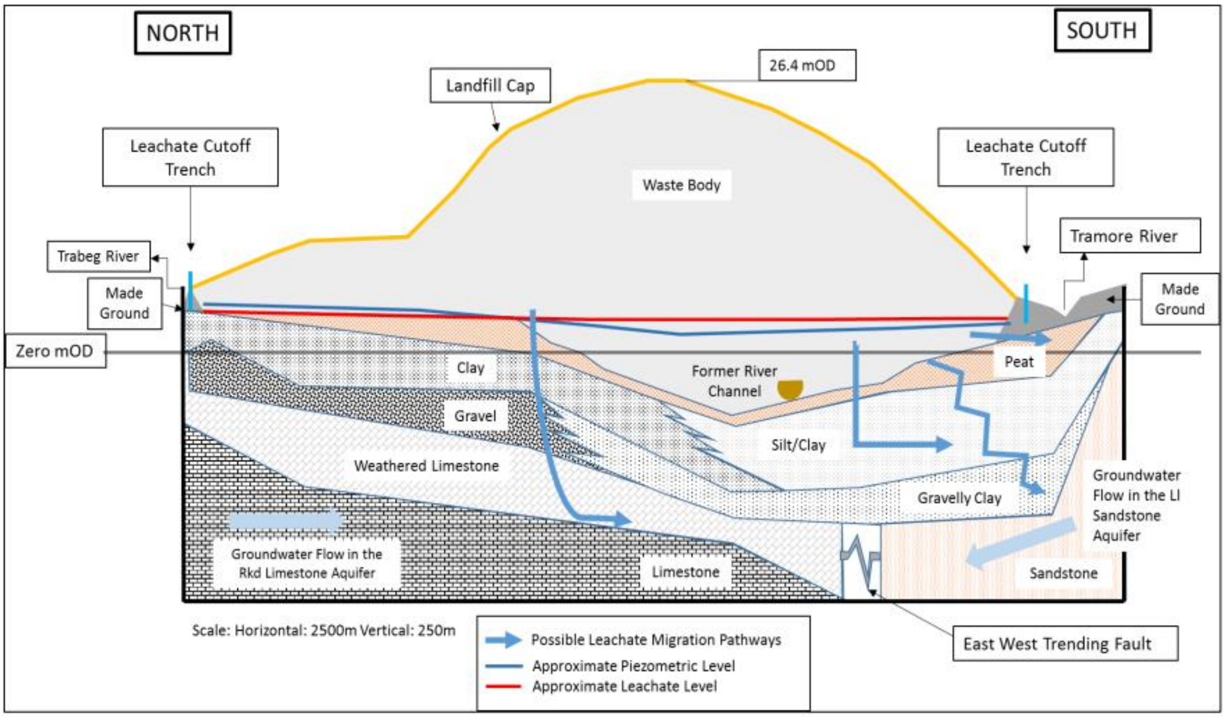


Figure 10 North-South Hydrogeological Cross Section (reproduced from OCM, 2015).

3.4.Tier assessment

This facility, as it is a licenced landfill site, falls under a Tier 3 Assessment. As such, the licensee is required to complete a Detailed Quantitate Risk Assessment at a later date in agreement with the Agency.

4. Assessment of the Groundwater Impacts

4.1.Extent Of Plumes and Trends

The investigation was carried out on the offsite wells in the Greenhills Estate and on the Nemo Rangers grounds, which are situated east of Kinsale Road landfill. Previous studies have indicated risks associated with offsite leachate migration owing to the un-engineering nature of the landfill. In this work Hydrogeological (Step and Pumping tests) and geophysical (2D Resistivity) methods were used to assess the groundwater movement and subsurface contaminant transport pathways.

Step test and pumping test investigations *(Methods set out in Appendix B)* were carried out to assess the groundwater movement and leachate plume dynamics. Through Pumping Tests, the leachate plume was characterised based on Chloride concentration levels. Due to low levels of TOC and NH_4 detected in both the deep borehole monitoring wells; Greenhills South (GHS) which is 34.7m deep and Greenhills North (GHN) which is 35m deep; these parameters were not used. Chemical interpretation of the groundwater shows strong characteristics of contamination by a diffuse, chloride dominant leachate plume at this location to the North-East of the site (Appendix D).

There are four possible sources for the contamination plume:

1. Northern portion of the landfill site
2. In situ construction and demolition waste at Greenhills estate
3. Area directly to the north of Greenhills estate (i.e., directly north of borehole well GHN Deep)
4. A combination of all the above

Geophysical Surveys

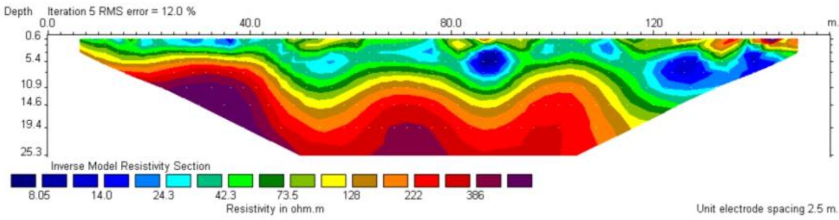
Geophysical surveys in the form of 2D Resistivity *(Appendix B)* were conducted on the southern grounds at Nemo Rangers as shown below and in Appendix *E.* The profiles generated penetrate down to 25m below ground level. The profiles do not display any signature of contamination of the subsurface within the 25m profile *(Appendix F)*. Profile Lines conducted close to site show no indication of offsite contamination migration and profile lines that were conducted further east display similar results. This section outlines the profile lines conducted through 2D resistivity with resistivity measured in Ohms/m: For clarity, larger versions of the profile lines are available in Appendix H.

Geophysical Survey Lines Conducted on the Nemo Rangers Grounds (Profile Lines 1-5)

L1, L2 & L3 – Yellow L4 & L5 – White	Blue line – Extent of survey area

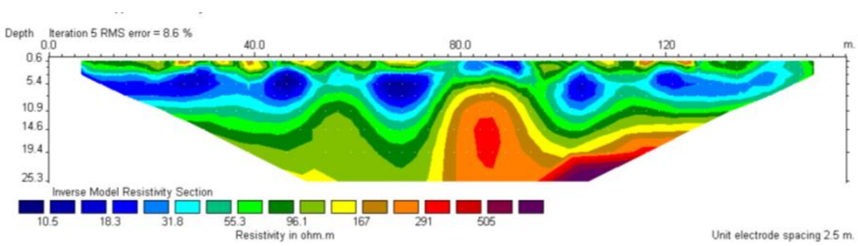
Profile Line 1

Competent Limestone (WA) bedrock is met at depths from 9-15m, overlain by a gravel layer. This is verified through ground truthing using the borehole logs for the now buried groundwater monitoring wells in Nemo Rangers *(Appendix H).* The borehole wells are situated adjacent to Line 1 prior to being buried and destroyed (due to development of the grounds). The borehole logs verify the bedrock to be Waulsortian Limestone (WA) with overlaying sediments comprised of clay and/or peat. There is no indication of contamination present.



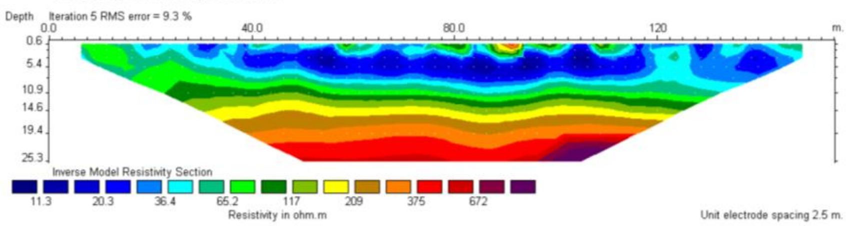
Profile Line 2

This profile is situated ~150m parallel to the south east of Line 1. The Profile displays similar lithological succession with variations seen with depth due to the undulating nature of the Waulsortian Limestone (WA) bedrock. The areas of low resistivity display identical characteristics to that of Profile Line 1. Due to the position of Line 2 in relation to Line 1, it is concluded that there is no evidence of leachate contamination present.



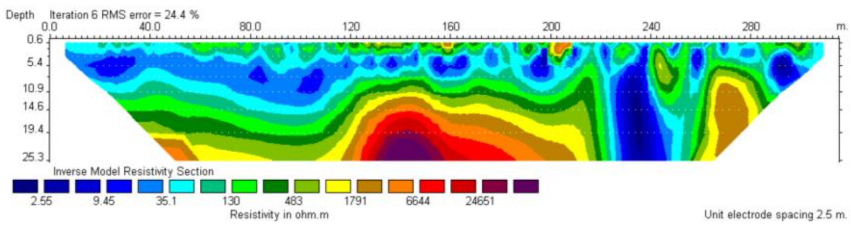
<u>*Profile Line 3*</u>

This profile shows limited undulation of the bedrock topography, indicating that this line is likely to be in the Cuskinny member of the Kinsale Sandstone/siltstone formation. This was preceded by fractured bedrock or a gravel layer with the overlaying sediment comprising of made ground, clay and peat. There is no indication of contamination present



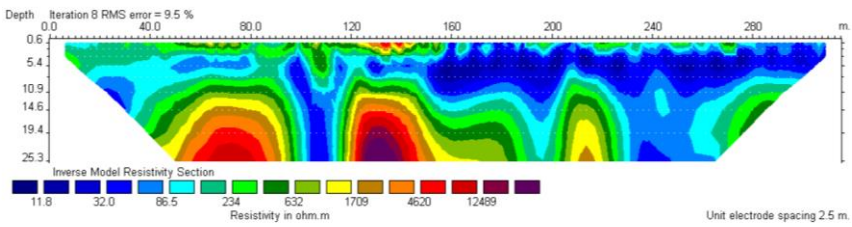
<u>*Profile Line 4*</u>

Due to the high error level of this line section, the interpretation of this profile can only be used to verify the presence of the faulted contact between the Waulsortian Limestone (WA) and the Cuskinny Member. This is displayed as the vertical area of Low resistivity present to the right of the profile line section.



<u>*Profile Line 5*</u>

This line displays the faulted contact of the undulating Waulsortian Limestone (WA) bedrock and the bedrock Cuskinny member of the Kinsale Sandstone/siltstone formation. This boundary shows a strike slip movement with pressure existing between the 2 blocks. To the right of this fault, the overlaying sediment of clay/peat and/or made ground is consistent throughout. There is no indication of contamination present.



4.2. Impact On Receptors

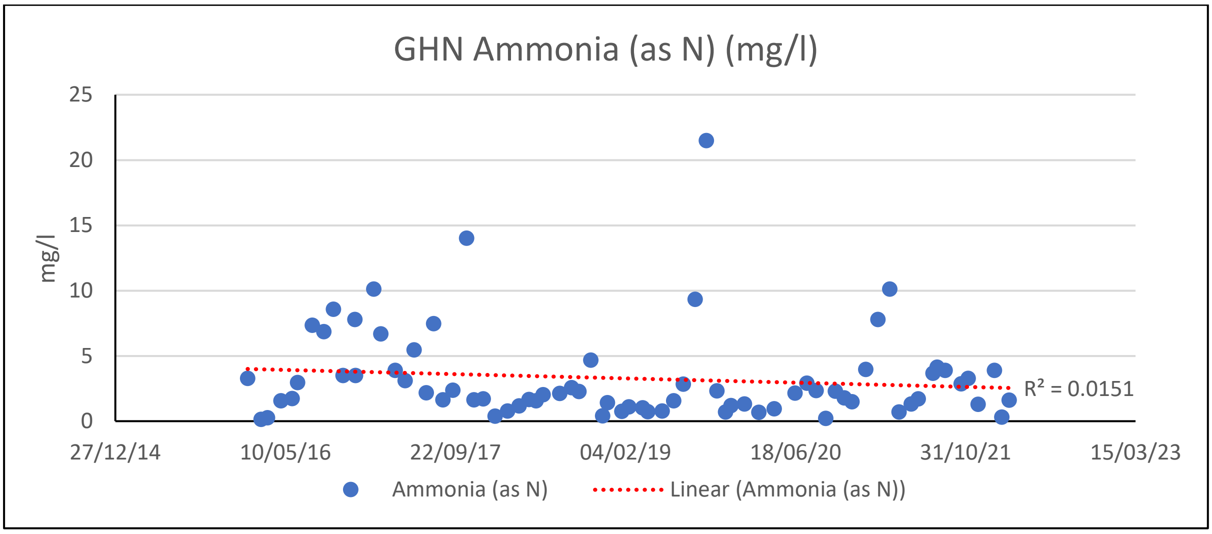
This facility, as it is a licenced landfill site, falls under a Tier 3 Assessment. As such, the licensee is required to complete a Detailed Quantitate Risk Assessment at a later date in agreement with the Agency.

4.3. Chemical Status of Groundwater

Chemical interpretation of the groundwater wells at GHS and GHN showed strong characteristics of contamination by a diffuse, chloride dominant leachate plume at the Northeast perimeter of the site *(Appendix C)*. Due to the increasing trends in chloride, all be it a slight increase with R^2 at 0.0443 and 0.05540 observed historically and with levels at present being greater than that of previous years it could be suggested that the longevity of the plume at Greenhills is on the rise However, this is a weak correlation and statistically insignificant. It cannot be concluded that the plume is on the rise, but rather that it seems to be stable. *(Figures 11 and 12 and Appendix D).*

Correlation Strength	**r^2 (%)**
Perfect Correlation	100
Strong Correlation	36- <99.9
Average Correlation	16-<35.9
Weak Correlation	0-<15.9
No Correlation	0

(OCM, 2015)



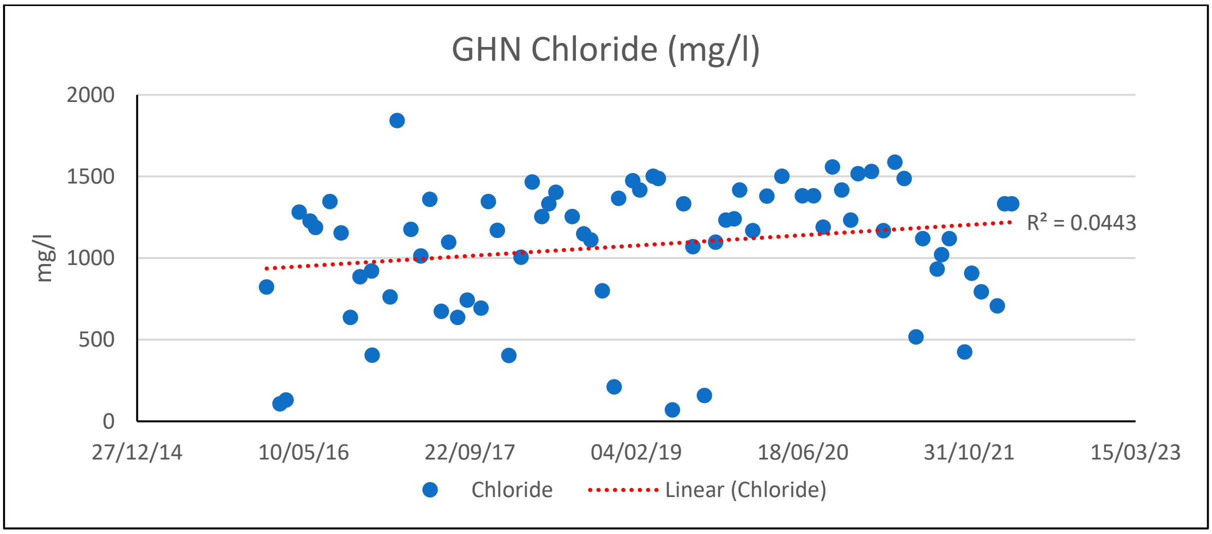
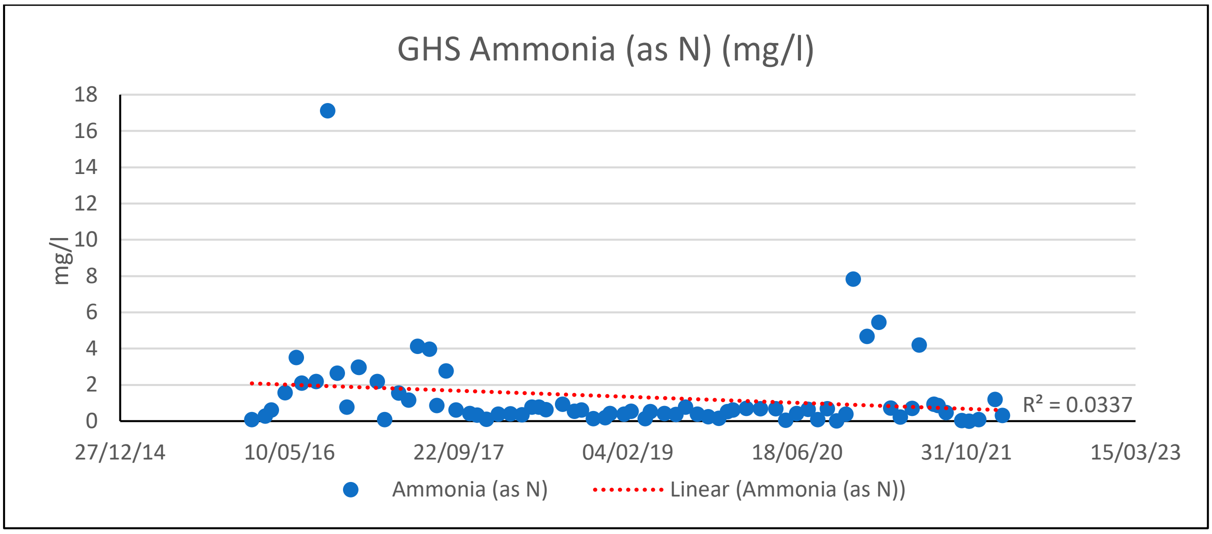


Figure 11 Ammonia and Chloride levels at the Greenhills North Deep Well



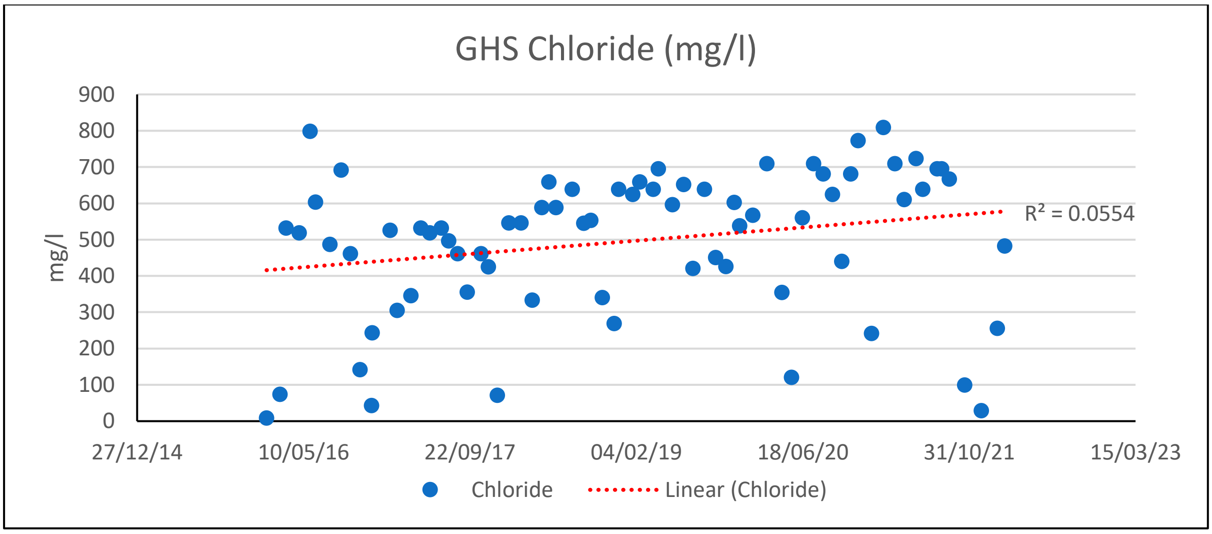


Figure 12 Ammonia and Chloride levels at the Greenhills South Deep Well

5. Remedial Strategy

Many of the works carried out since 2001 were put in place to prevent or limit the contamination of the groundwater in and around the site. This work included sheet piling installed adjacent to the eastern intersection of the leachate collection drain and the old Tramore River channel. These works were carried out in 2001 and the sheet piles were placed across the old channel to create a barrier to potential contaminant migration and to ensure stability of the waste mass to the immediate west (*FTC, 2009).* The remediation and restoration works that have been carried out have been outlined in Table 1, Section 2.5 of this report. The current strategy is to continue monitoring the plume at the Greenhills wells. In the groundwater wells at Greenhills estate, the chloride plume cannot be traced any further East. Due the built-up nature of the area and the residential properties adjacent to the site (immediately to the east) it is not possible to drill additional groundwater monitoring wells beyond those already in existence. Thus, establishing the nature and extent of the contamination plume east of the landfill site is not feasible utilising existing monitoring infrastructure.

6. Groundwater Compliance Monitoring

The Greenhills wells are currently sampled and tested monthly. The parameters tested include temperature, pH, Conductivity, Ammonium, Chloride, Oxygen, COD, TOC, TON, and suspended solids. These results are submitted to the Agency on a quarterly basis. The results are assessed against the corresponding trigger levels as accepted and approved by the Agency in Quarter 1, 2022.

7. Summary and Conclusion

This Report has been conducted on foot of a request for information from the Environmental Protection Agency, specifically:

1. To investigate the groundwater migration from the site using Hydrogeological methods such as step tests and pumping tests:
2. To investigate the potential for offsite migration of a leachate plume from on site.
3. To investigate the extent of the leachate plume originating onsite and detected in offsite water monitoring wells in the Greenhills Estate (GH North and GH South).
4. Using historical data and recently collected data, comment on the longevity of the chloride plume.
5. Investigate offsite migration into the areas east of the licensed facility with the use of geophysics.
6. Establish the feasibility of the installation of new groundwater monitoring wells offsite.

<u>Response</u>

1. Investigate the ground water migration from the site using the hydrological methods such as step testes and pumping tests

Step test and pumping test investigations were carried out to assess the groundwater movement and leachate plume dynamics. Through pumping tests, the leachate plume was characterised based on Chloride concentration levels. Due to low levels of TOC and NH_4 detected in both GHS and GHN monitoring wells these parameters were not used. Chemical interpretation of the groundwater shows strong characteristics of contamination by a diffuse, chloride dominant leachate plume to the North-East of the site There are four possible sources for the contamination plume:

- Northern portion of the landfill site,
- *In situ* construction and demolition waste at Greenhills estate,
- Area directly to the north of Greenhills estate (i.e., directly north of borehole well GHN Deep)
- Combination of all the above.

2. ***To investigate the potential for offsite migration of a leachate plume formed on site.***
3. ***'To investigate the extent of the leachate plume originating onsite and detected in offsite water monitoring wells in the Greenhills Estate (GH North and GH South)''***

In the groundwater wells at Greenhills estate, the chloride plume cannot be traced any further east as the Greenhills estate was built on Construction & Demolition waste, and this can contribute a number of chemicals being present in the subsoils and in the underlying groundwater bodies. Due to the built-up nature of the area and the residential properties immediately adjacent to the site to the east, it is not possible to drill additional groundwater monitoring wells beyond those already in existence. Therefore, establishing the nature and extent of the contamination plume, east of the landfill site is not
Feasible

Due to low levels of TOC and NH_4 detected in both GHS and GHN monitoring wells these parameters were not used. Chemical interpretation of the groundwater shows strong characteristics of contamination by a diffuse, chloride dominant leachate plume to the North-East of the site. There are four possible sources for the contamination plume:

- Northern portion of the landfill site,
- *In situ* construction and demolition waste at Greenhills estate,
- Area directly to the north of Greenhills estate (i.e., directly north of borehole well GHN Deep)
- Combination of all the above.

4. ***Using historical data and recently collected data, comment on the longevity of the chloride plume.***

Due to the increasing trends in chloride, all be it a slight increase with R^2 at 0.0443 and 0.05540 observed historically and with levels at present being greater than that of previous years it could be suggested that the longevity of the plume at Greenhills is on the rise However, this is a weak correlation and statistically insignificant. It cannot be concluded that the plume is on the rise, but rather that it seems to be stable. *(Figures 11 and 12 and Appendix D*

5. ***Investigate offsite migration into the areas east of the licensed facility with the use of geophysics.***

Geophysical surveys in the form of 2D Resistivity *(Appendix B)* were conducted on the southern grounds at Nemo Rangers *(Appendix E).* The profiles generated penetrate down to 25m below ground level. The profiles do not display any signature of contamination of the subsurface within the 25m profile *(Appendix F)*.

6. Establish the feasibility of the installation of new groundwater monitoring wells offsite.

It is not possible to suggest the drilling of new groundwater monitoring wells at this point for the following reasons:

- Much of the ground is in private ownership and includes playing pitches, housing estates, commercial premises etc. There is also a lack of access and site suitability of publicly owned grounds in the area.
- In the past when wells were placed on private grounds i.e. Nemo Rangers Complex, they were buried and destroyed *(Appendix H)*, therefore security and integrity of any wells placed east of the landfill site cannot be guaranteed (e.g. vandalism, grounds works etc.)
- There is one private well on the grounds of the Nemo Rangers Complex. This is only used for non-potable water for changing room showers. Data from a single sampling event (November 2017) displays no evidence for any major contamination *(Appendix I)*.

Drilling further wells to the southeast and south of the faulted contact between the Waulsortian Limestone (WA) and the Cuskinny member (sandstone/siltstone) as identified in the Nemo Rangers complex will unlikely reveal the leachate plume in this area. This faulted boundary extends East – West and acts as a barrier for groundwater and contamination movement from one lithology to the other *(Appendix H Line 4 & 5 and Appendix B Figure. 3)*. This is displayed in the Conceptual Block Model for Greenhills Estate and Nemo Rangers Complex (*Appendix J)*.

8. Recommendations

- This facility, as it is a licenced landfill site, falls under a Tier 3 Assessment. As such, the licensee is required to complete a Detailed Quantitate Risk Assessment at a later date in agreement with the Agency.
- There will be continued monitoring of the wells at Greenhills (GHS and GHN).
- Further investigation of possible locations for additional monitoring wells east of the site.

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10. Appendices

Appendix A– Apex Geoservices Report (AGL09241_KR_03)

Appendix B – Methodologies

Appendix C – Pumping test data for Greenhills South and North and chloride graphs

Appendix D – Chloride Data 2013-2017

Appendix E – Geophysical Surveys - Local Setting and Positions

Appendix F – Geophysical Surveys - Original Inversions Profile Lines 1-5

Appendix G – Geophysical Surveys - Interpreted Profile Lines 1-5

Appendix H – Nemo Rangers Borehole Logs

Appendix I – Nemo Rangers Analysis of Non-Potable Groundwater Extraction Point

Appendix J – Conceptual Block Model for Greenhills Estate and Nemo Rangers Complex

AGL09241_KR_03

W0012-02

KINSALE ROAD LANDFILL

REPORT

ON THE

GEOPHYSICAL SURVEY

FOR

THE EPA

UNDERTAKEN 16TH & 17TH DECEMBER 2009

28TH SEPTEMBER 2010

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PRIVATE AND CONFIDENTIAL

THE FINDINGS OF THIS REPORT ARE THE RESULT OF A GEOPHYSICAL SURVEY USING NON-INVASIVE SURVEY TECHNIQUES CARRIED OUT AT THE GROUND SURFACE. INTERPRETATIONS CONTAINED IN THIS REPORT ARE DERIVED FROM A KNOWLEDGE OF THE GROUND CONDITIONS, THE GEOPHYSICAL RESPONSES OF GROUND MATERIALS AND THE EXPERIENCE OF THE AUTHOR. APEX GEOSERVICES LTD. HAS PREPARED THIS REPORT IN LINE WITH BEST CURRENT PRACTICE AND WITH ALL REASONABLE SKILL, CARE AND DILIGENCE IN CONSIDERATION OF THE LIMITS IMPOSED BY THE SURVEY TECHNIQUES USED AND THE RESOURCES DEVOTED TO IT BY AGREEMENT WITH THE CLIENT. THE INTERPRETATIVE BASIS OF THE CONCLUSIONS CONTAINED IN THIS REPORT SHOULD BE TAKEN INTO ACCOUNT IN ANY FUTURE USE OF THIS REPORT.

PROJECT NUMBER	AGL09241_KR		
AUTHOR	**CHECKED**	**REPORT STATUS**	**DATE**
EURGEOL YVONNE O'CONNELL P.GEO., M.SC. (GEOPHYSICS)	EURGEOL PETER O'CONNOR P.GEO., M.SC. (GEOPHYSICS), DIP. EIA MGMT.	V.01	4TH MARCH 2010
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1. Introduction

APEX Geoservices Ltd. was requested by The Environmental Protection Agency (EPA) to carry out a geophysical survey at Kinsale Road Landfill (Licence W0012-02) in Co. Cork.

Kinsale Road Landfill site (Licence W0012-02) is located west of Douglas in the south of Cork City. It is bounded to the south by the N25. The Trabeg River runs along the eastern boundary and the Tramore River runs along the southern boundary of the site. Groundwater flow is thought to be from west to east.

The landfill site is an unlined facility. Elevated conductivities have been recorded in wells to the east and southeast prior to the geophysical survey.

1.1 Project Objectives

The objectives of the survey at Kinsale Road Landfill were as follows:

- To collate the geophysical survey results with existing geophysical, groundwater monitoring and site investigation data;
- To study leachate movement at the site;
- To confirm the suitability or otherwise of the existing groundwater monitoring well network at the site;
- To evaluate the effectiveness of geophysics as a tool for the assessment of any leachate at the site.

1.2 Survey Rationale

The following techniques have been employed to achieve the objectives of the survey:

- EM31 ground conductivity mapping has been carried out on the 16th December 2009 in accessible areas adjacent to and down hydraulic gradient from the landfill in order to investigate the presence of any shallow leachate plume.

- Two standard and two long resistivity profiles have been carried out on the 16th and 17th December 2009 at locations based on the previous geophysical survey and in accessible areas adjacent to and down gradient from the landfill. The geometry and acquisition parameters of the resistivity profiles have been decided by the project team.

- One seismic refraction profile has been carried out on the 17th December 2009 along a resistivity profile. The results of the seismic survey have been used to outline the overburden stratigraphy and the depth to bedrock.

- Downhole conductivity and temperature readings have been recorded on the 17th December 2009 at the down gradient monitoring wells NW4, NW5, NW6, NW7, NW8 and NW9 using a downhole resistivity/ temperature probe following the resistivity survey.

2. Desk study

2.1 Site Background

The Geological Survey of Ireland (GSI) geological map for the area indicates that Kinsale Road Landfill site is underlain by Waulsortian Limestone massive unbedded lime-mudstone in the north and Cuskinny Member flaser-bedded sandstone & mudstone in the south.

The GSI aquifer map for the area describes the Waulsortian bedrock as a “Regionally important karstified bedrock aquifer dominated by diffuse flow” and the Cuskinny Member bedrock as “Moderately Productive only in Local Zones”. The GSI vulnerability map for the area classifies the aquifer vulnerability as “High“ across most of the site.

The GSI Teagasc Subsoils Map indicates the soil type across the site as sandstone till. The historic 6 inch geological mapping sheets from the GSI indicate limestone outcropping north of the landfill and outcropping grits (sandstone), shale and slate south of the landfill.

2.2 EPA files

The January-June 2009 Biannual Report indicates the highest conductivity values were recorded in OB3 to the east. Groundwater flow is to the east. The report states that bedrock well BR3 had very high concentrations of pollutants, conductivity levels of 6950 µS/cm on the 1st April 2009 and the report also notes abnormal levels of ammonia and chloride in BR3.The report states that this well is inside the sheet pile wall where leachate is collected, therefore it is not representative of the down gradient impact of the landfill.

2.3 Reprocessing of Previous Geophysics

Geophysical surveying has been carried out in the east of the landfill on three known occasions; by BMA in 1997 and by APEX Geoservices Ltd. in 2003 and 2006.

A geophysical survey of the site was carried out in 1997, (BJ Murphy & Assoc., 1997). A number of N-S trending 2D Resistivity profiles were recorded across the site. The survey outlined the location of an E-W fault between the Cuskinny Member and the Waulsortian Limestone. A further possible fault zone was also indicated to the north of the main fault zone.

A geophysical survey was carried out by APEX Geoservices Ltd. in 2003 along the north eastern boundary of the landfill as part of a ground investigation being carried out for the construction of a sheet pile wall at the north-eastern boundary of the landfill. Nine 2D Resistivity profiles were recorded The survey objective was to delineate a N-S fault running along the eastern boundary of the existing landfill site in order to assist in the design of sheet pile containment wall along the north-eastern boundary of the site.

Nine 2D Resistivity profiles were recorded in the east and northeast of the landfill. These showed the main fault zone running from N-S along the eastern boundary of the site. A probable north-westerly splay from the main N-S fault was also interpreted, running parallel to the road along the NW boundary of the landfill area. The expression of this splay on the resistivity profiles is shallower than on the main N-S branch. Two zones of shallow and deep low resistivity sediments, interpreted as overburden containing leachate material were also outlined by the resistivity data.

A geophysical survey was also carried out in by 2006 APEX Geoservices Ltd. in the Civic Amenity Site in the northwest of the landfill to investigate the thickness and stiffness of the landfill material and to investigate the depth to rock head in that area.

3. Results

3.1 2009 Geophysics

The geophysics have been recorded in accessible locations down gradient of the landfill. Fieldwork was carried out on the 16th and 17th December 2009.

3.1.1 EM31 Electromagnetic Conductivity Mapping

A small area of EM31 conductivity surveying was recorded east of the landfill between the Trabeg River and Greenhills Housing Estate. The locations are shown on Drawing 9241_KR_01: Figure 1. The recorded conductivity values ranged from 10–33 milliSiemens/metre (mS/m). There are two pylons in this area indicated on Figure 1.

The inphase values indicate some elevated values in the locations of the pylons with other spurious values across the survey area indicative of fencing or buried services. The elevated inphase values and their corresponding conductivity values were removed from the dataset. The remaining conductivity data are contoured on Drawing 9241_KR_01: Figure 1.

There are two zones of elevated conductivity values (>22mS/m) adjacent to the Trabeg River (Drawing 9241_KR_01: Figure 1). These two zones have been interpreted as indicating the probable presence of near surface leachate (within upper 6m).

Further EM31 surveying was not carried out within the bounds of the landfill site as suitable locations were not accessible e.g. the overgrown area northeast of the landfill was water logged.

3.1.3 2D Resistivity Profiling

Four resistivity profiles (two double cable and 2 single cable) were recorded parallel to the Trabeg River. The locations are indicated on Drawing 9241_KR_01: Figure 1. Interpreted cross sections were compiled for the 2D-resistivity profiles and are presented on Drawing 9241_KR_01: Figures 2, 3 & 4.

The resistivity values have been interpreted as follows:

Resistivity (Ohm-m)	Interpretation
10-30	LANDFILL/ LEACHATE
30-60	Possible PEAT/CLAY/SILT or MADE GROUND (some Domestic Waste)
60-160	Gravelly CLAY/Clayey GRAVEL
80-1300	Low resistivity bedrock, probable fault zone
160-4000	High resistivity bedrock (WA)

3.1.4 Seismic Refraction Profiling

One seismic refraction profiles was recorded along KR-R3. The location is indicated on Drawing 9241_KR_01: Figure 1 and the results are included on the interpreted cross sections in Drawing 9241_KR_01: Figure 4.

The seismic velocities have been interpreted as follows:

Layer	Velocity (m/s)	Average Velocity (m/s)	Interpretation
1	500-667	592	Soft to firm overburden
2	1076-1300	1212	Highly weathered rock
3	2999-3381	3179	Slightly weathered to Fresh rock

3.1.5 Groundwater Wells

Conductivity and temperature measurements were recorded at the down gradient monitoring wells NW4, NW5, NW6, NW7, NW8 and NW9. The boreholes were not purged prior to the recording of the measurements. The measurements are as follows:

	Depth (m BGL)	Conductivity µS/cm	Temp °C
NW4	0.91	1300	10.4
NW5	3.83	990	10.7
NW6	0.0	4400	9.4
NW7	0.67	420	10.8
NW8	0.92	500	10.2
NW9	0.0	1200	8

Conductivity levels above the recommended EPA guideline of 1000 µS/cm have been recorded in NW4, NW6 and NW9 northeast of the landfill.

3.2 Discussion of Results

2009 profiles KR-R2 and KR-R4 both show very low resistivities in the upper 5 to 10m indicating leachate.

3.2.1 Comparison with Previous Site Investigation

2009 profile KR-R1 replicates 2003 2D Res 5. Both profiles and interpretations are presented on Drawing 9241_KR_01: Figure 3. The profile recorded in 2009 has been affected by cultural interference possibly from the foundations of the pylons or buried services that have been placed between 2003 and 2009. As a result no comparison can be made at the deeper levels. Resistivities in the upper 5m show a similar pattern but with lower resistivities in 2009 suggesting increased leachate content.

2009 profile KR-R3 replicates 2003 2D Res 6. Both profiles and interpretations are presented on Drawing 9241_KR_01: Figure 4. 2009 profile KR-R3 suggest that there is a significant infiltration of leachate into the bedrock.

3.2.2 Scale of any Leachate Plumes

At present the geophysical data indicates that the leachate plume appears to be extensive.

3.2.3 Relation of Geophysics to GW Quality

NW4 and NW6 agree with the geophysical results however NW7 does not appear to agree as the resistivity data suggests the presence of leachate while the conductivity values in the well were 420 µS/cm.

3.2.4 Evolution of Plume over Time

2009 profile KR-R3 suggests that the extent of the leachate plume appears to be increasing over time.

3.2.5 Effectiveness of Remediation & Mitigation Measures

The remediation and mitigation measures do not appear to be very effective in the area northeast of the landfill and south of the landfill (KR-R4).

3.2.6 Effectiveness of GW Monitoring Network

The plume appears to extend eastwards across the Trabeg River. However there are no boreholes east of the river to monitor leachate levels. Monitoring wells should be considered at the two locations indicated on Drawing 9241_KR_01: Figure 1.

3.2.7 Effectiveness of Geophysics

The geophysics has been effective in comparing ground conditions between 2003 and 2009 apart from the problems with interference from buried services/foundations. Parts of the site were also inaccessible due to waterlogging.

Additional geophysical surveying could be carried out to give a more detailed picture of leachate levels surrounding the landfill. Repetition of the survey should be considered in the future to examine any changes in leachate levels and following remediation measures.

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'SURFER 7 Surface Mapping System Users Manual', Golden Software, CO., USA.

Hagedoorn, J.G., 1959;
'The plus - minus method of interpreting seismic refraction sections', Geophysical Prospecting, 7, 158 - 182.

Palmer, D., 1980;
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Redpath, B.B., 1973;
'Seismic refraction exploration for engineering site investigations', NTIS, U.S. Dept. of Commerce

Soske, J.L., 1959;
'The blind zone problem in engineering geophysics', Geophysics, 24, pp 359-365.

Appendix I METHODOLOGY

M1. Electromagnetic Conductivity Mapping

This is an electromagnetic technique used to investigate lateral variations in overburden material, waste extent and shallow leachate zones. This method operates on the principle of inducing currents in conductive substrata and measuring the resultant secondary electro-magnetic field. The strength of this secondary EM field is calibrated to give apparent ground conductivity in milliSiemens/metre (mS/m). Readings over material such as organic waste and peat give high conductivity values while readings over dry materials with a low clay mineral content such as gravels, limestone or quartzite give low readings.

The EM31 survey technique determines the apparent conductivity of the ground material from 0-3 m or 0-6m bgl depending on the dipole mode used. Depending on the dipole mode used, the measured conductivity is a function of the different overburden layers and/or rock from 0 to 3m below ground level or 0 to 6m below ground level.

The EM31 equipment used was a GF EM31 Conductivity meter equipped with data logger. This instrument features a real time graphic display of the previous 20 measurement points to monitor data quality and results. Conductivity and in-phase values were recorded at accessible locations outside the bounds of the landfill. Local conditions and variations were recorded.

The conductivity and inphase field readings were downloaded, contoured and plotted using the SURFER 8 program (Golden Software, 2008). Data which was affected by metallic objects was removed. Assignation of material types and possible anomaly sources was carried out, with cross-reference to other data.

M2. 2D Resistivity Profiling

This technique utilizes pairs of current and potential electrodes inserted into the ground. By measuring the voltage between the potential electrodes the apparent resistivity of the subsurface can be determined. By taking a large number of resistivity readings using different geometrical arrays a 2-dimensional profile of the subsurface can be generated. Typically leachate produces a very low resistivity response (<20 Ohm-m) which enables the resistivity technique to be widely used in the mapping of leachate plumes.

The geometrical array used for the survey was the Wenner resistivity array. The setup involved up to 32 electrodes connected to a Campus Tigre resistivity meter, using Imagepro 2006 computer software to control the process of data collection and storage. The recorded data was processed and viewed immediately after the survey.

The field readings were stored in computer files and inverted using the RES2DINV package (Campus Geophysical Instruments, 1997) with up to 5 iterations of the measured data carried out for each profile to obtain a 2D-Depth model of the resistivities.

The inverted 2D-Resistivity models and corresponding interpreted geology are displayed Drawing 9241_02, Figures 2, 3 & 4. The distance is indicated along the horizontal axis of the profile. All profiles have been contoured using the same contour intervals and colour codes.

M3. Seismic Refraction Profiling

Seismic Refraction Profiling measures the velocity of refracted seismic waves through the overburden and rock material and allows an assessment of the thickness and quality of the materials present to be made. Stiffer and stronger materials usually have higher seismic velocities while soft, loose or fractured materials have lower velocities. The results of the seismic survey are used to outline the overburden stratigraphy and the depth to bedrock. Without the seismic profiles it can be difficult, using the resistivity data only, to determine the stratigraphy within leachate plumes due to the low resistivity values of the leachate masking low soil or rock resistivity values.

Readings are taken using geophones connected via multi-core cable to a seismograph. A Geode high resolution 24 channel digital seismograph, 24 10HZ vertical geophones and a 10 kg hammer were used to provide first break information, with a 24 take-out cable (3m geophone spacing) and a trigger geophone.

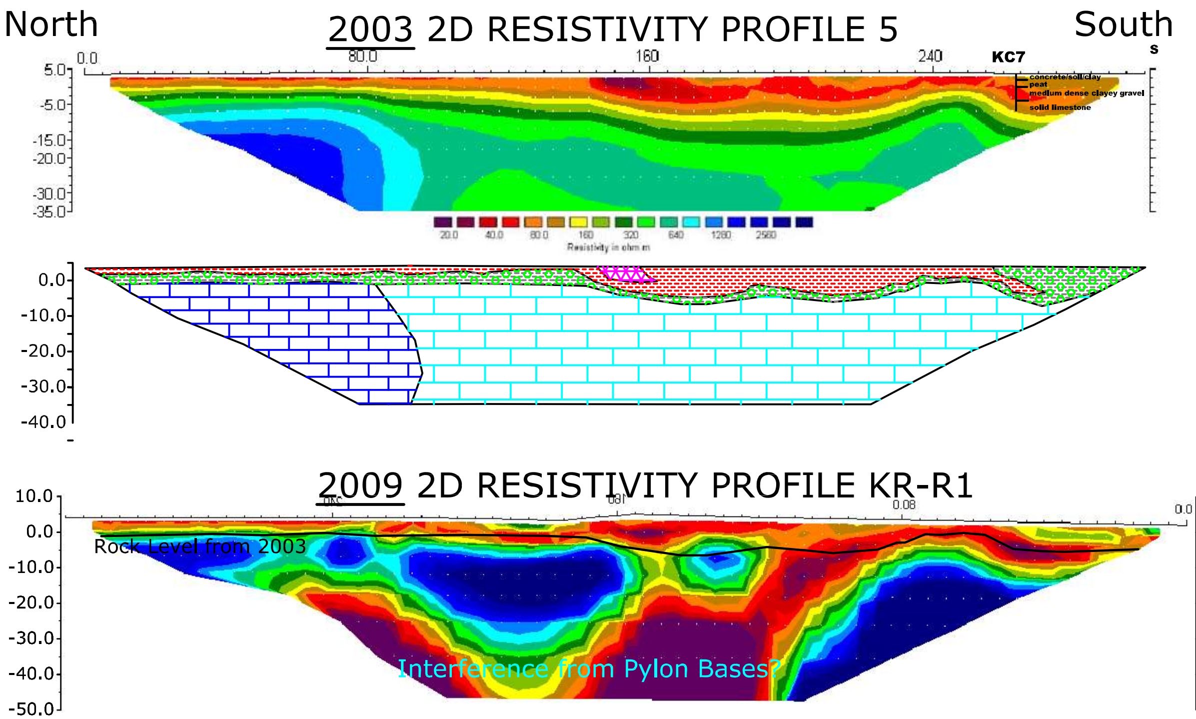
First break picking in digital format was carried out using the FIRSTPIX software program to construct traveltime plots for each spread. Velocity phases were selected from these plots using the GREMIX software program and were used to calculate the thickness of individual velocity units. Topographic data were input. Material types were assigned and estimation made of material properties, cross-referenced to the 2D Resistivity data. The processed seismic data are displayed in on the relevant 2D resistivity profiles.

Approximate errors for Vp velocities are estimated to be +/- 10%. Errors for the calculated layer thicknesses are of the order of +/-20%. Possible errors due to the "hidden layer" and "velocity inversion" effects may also occur (Soske, 1959).

M4. Borehole Conductivity Measurements

The conductivity equipment used was a WTW LF318 waterproof portable conductivity meter. The instrument comprises a four-electrode conductivity cell which assures accuracy will not be affected by dirty or difficult measuring conditions. This instrument features a real time graphic display of conductivity and temperature values.

Appendix II INDIVIDUAL 2D-RESISTIVITY PROFILES



Interpretation Legend:

- LANDFILL / LEACHATE
- Possible LEACHATE in bedrock
- PEAT/SILT/CLAY
- Gravelly CLAY/clayey GRAVEL
- Low Resistivity LIMESTONE
- High Resistivity WAULSORTIAN LIMESTONE

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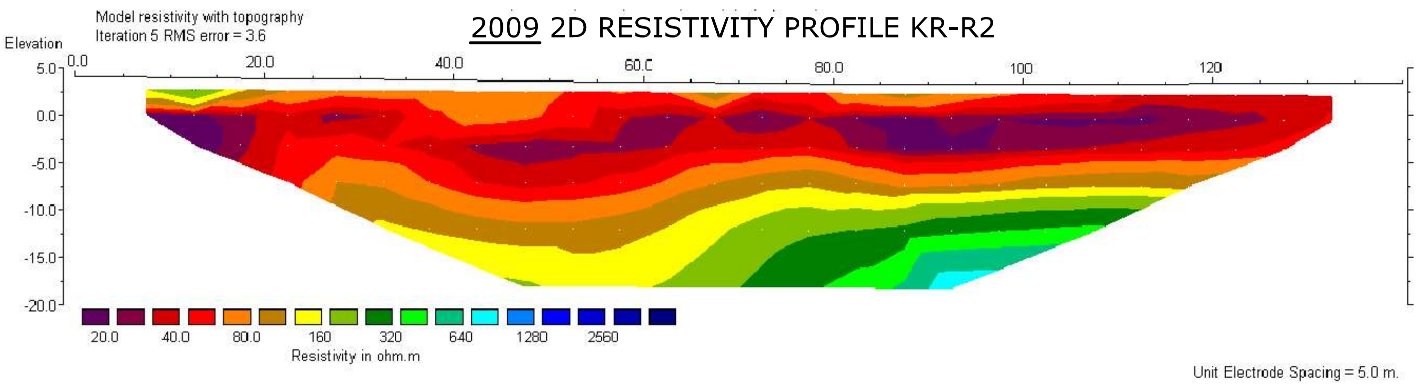
PROJECT:	EPA LICENCED LANDFILLS
DRAWING No.:	9241_KR
DATE:	28th September 2010
CLIENT:	EPA
SCALE:	1:2000 @A4

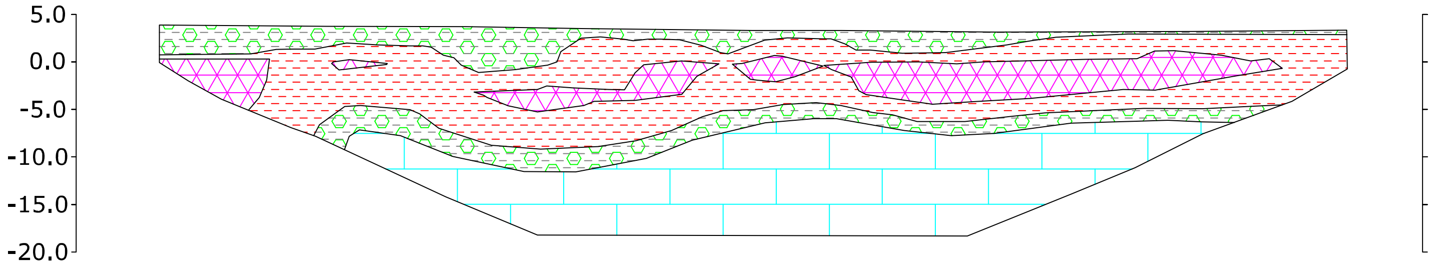
Version:	Date:	Drawn By:	Checked:

South

North

2009 2D RESISTIVITY PROFILE KR-R2





Interpretation Legend:

- LANDFILL / LEACHATE
- Possible LEACHATE in bedrock
- PEAT/SILT/CLAY
- Gravelly CLAY/clayey GRAVEL
- Low Resistivity LIMESTONE
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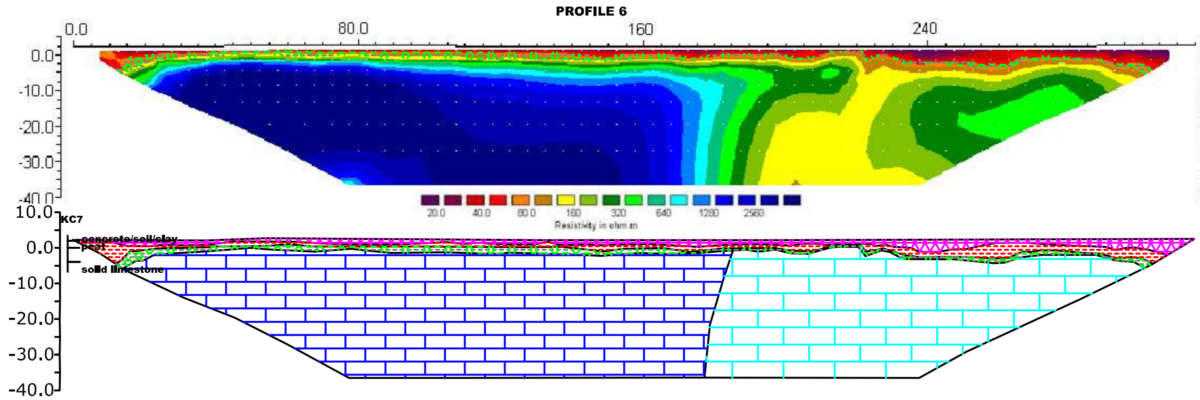
PROJECT:	EPA LICENCED LANDFILLS
DRAWING No.:	9241_KR
DATE:	28th September 2010
CLIENT:	EPA
SCALE:	1:750 @A4

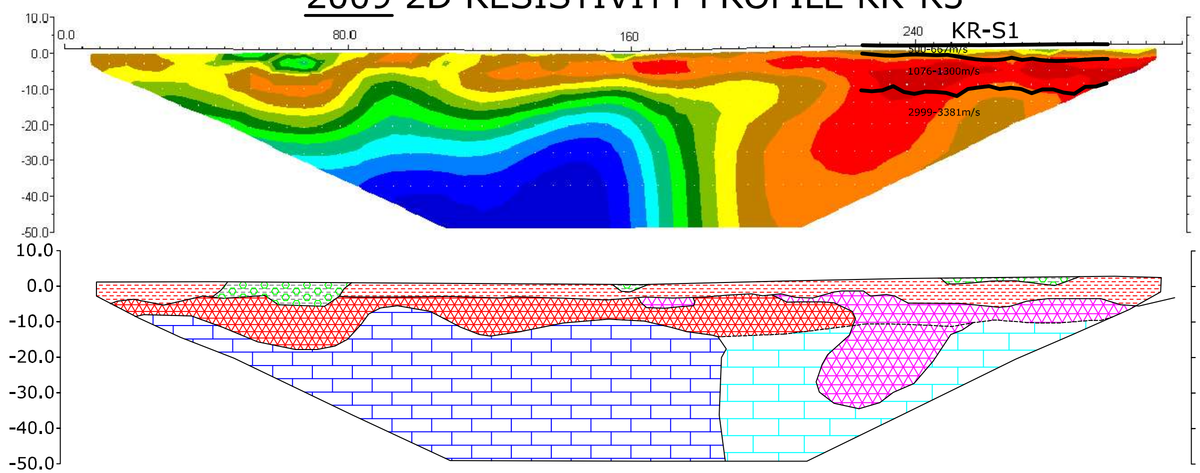
Version:	Date:	Drawn By:	Checked:

2003 2D RESISTIVITY PROFILE 6

North | South



2009 2D RESISTIVITY PROFILE KR-R3



Interpretation Legend:

- LANDFILL / LEACHATE
- Possible LEACHATE in bedrock
- PEAT/SILT/CLAY
- Gravelly CLAY/clayey GRAVEL
- Low Resistivity LIMESTONE
- High Resistivity WAULSORTIAN LIMESTONE

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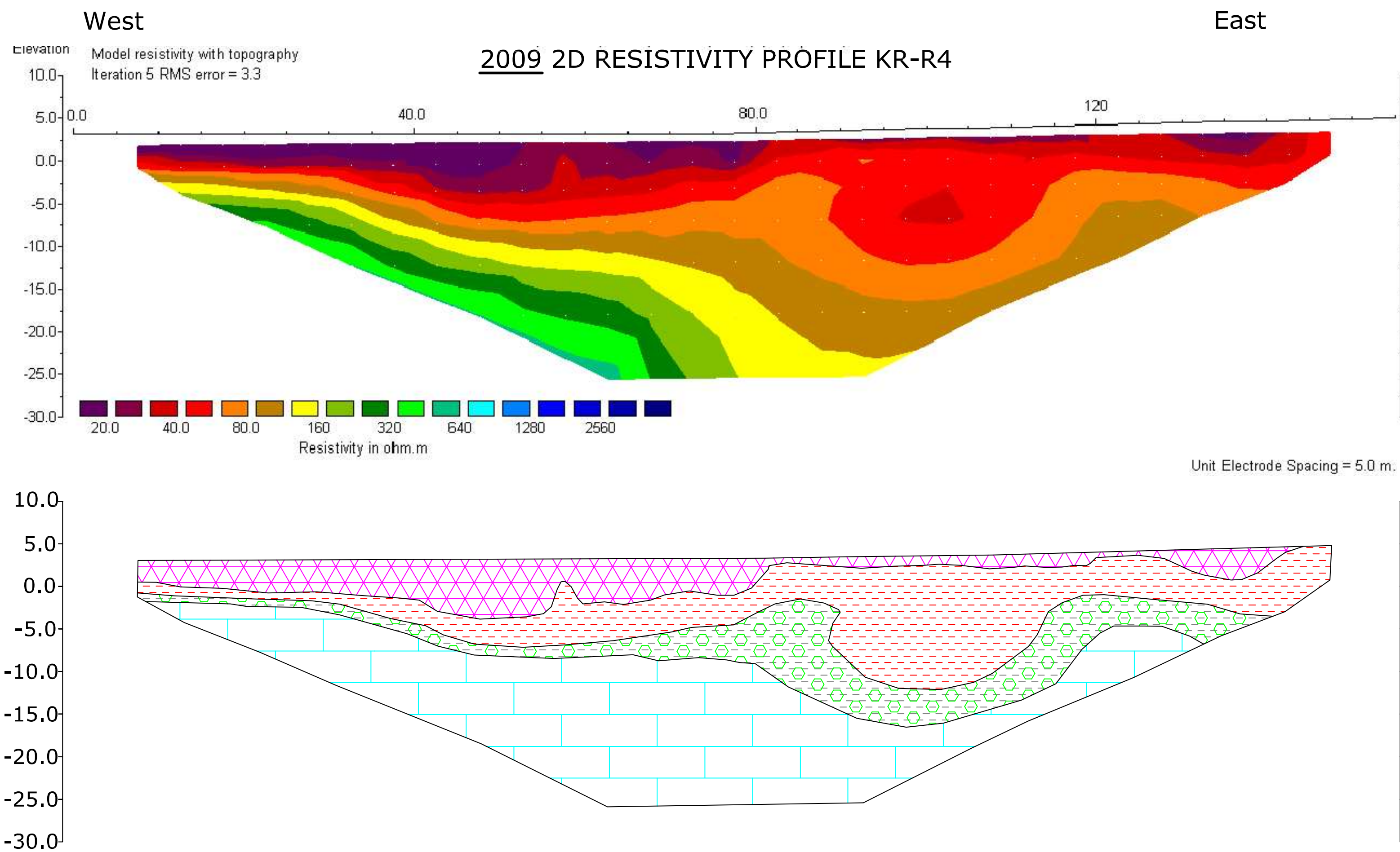
PROJECT:	EPA LICENCED LANDFILLS
DRAWING No.:	9241_KR
DATE:	28th September 2010
CLIENT:	EPA
SCALE:	1:2000 @A4

Version:	Date:	Drawn By:	Checked:

2009 2D RESISTIVITY PROFILE KR-R4



Interpretation Legend:

- LANDFILL / LEACHATE
- Possible LEACHATE in bedrock
- PEAT/SILT/CLAY
- Gravelly CLAY/clayey GRAVEL
- Low Resistivity LIMESTONE
- High Resistivity WAULSORTIAN LIMESTONE

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PROJECT:	EPA LICENCED LANDFILLS
DRAWING No.:	9241_KR
DATE:	28th September 2010
CLIENT:	EPA
SCALE:	1:750 @A4

Version:	Date:	Drawn By:	Checked:

FIGURE 1: Geophysical Survey Locations
Scale 1:2500

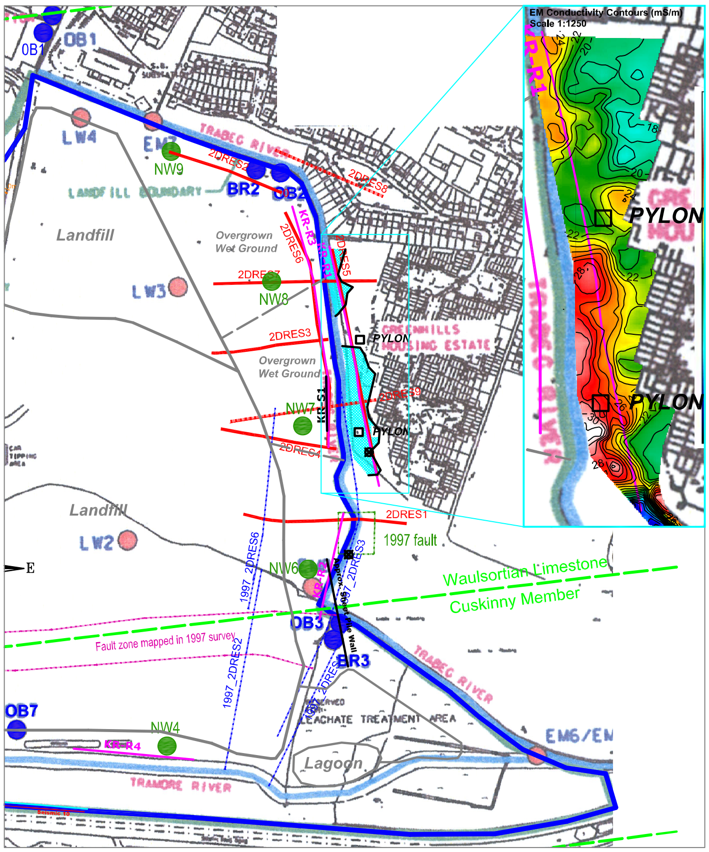


FIGURE 2: Interpreted Geophysical Sections KR-R2 & KR-R4
Scale 1:1000

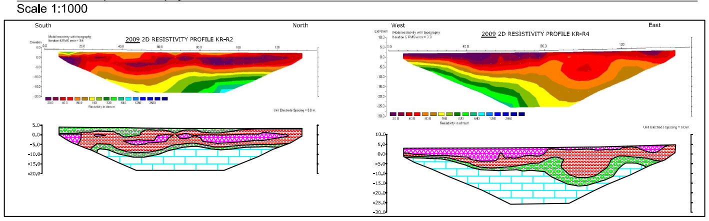


FIGURE 3: Interpreted Geophysical Sections KR-R1
Scale 1:1000

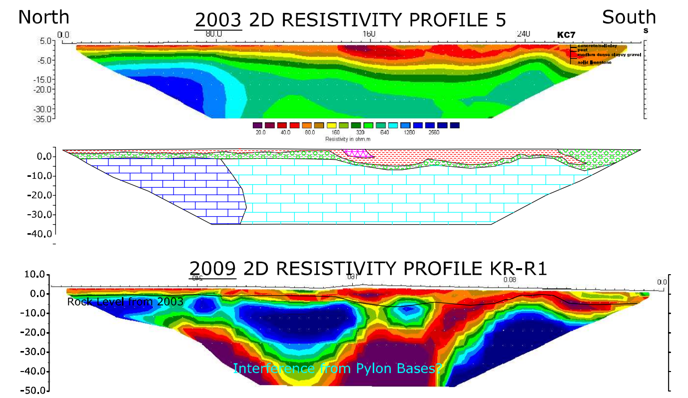
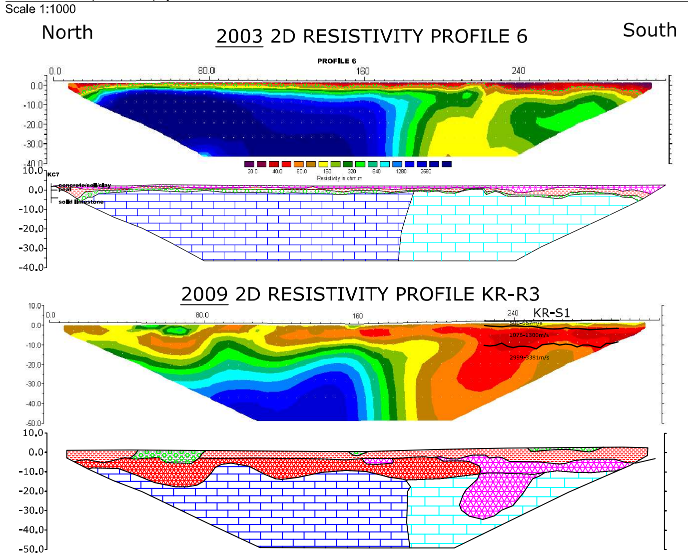
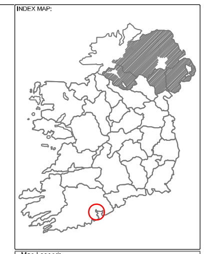


FIGURE 4: Interpreted Geophysical Sections KR-R3
Scale 1:1000



INDEX MAP:



Map Legend:
- Landfill Site Boundary
- Geological Boundaries
- 2009 Apex conductivity station
- 2009 Apex 2D resistivity profile
- 2009 Apex Seismic profile
- 1997 BMA Survey profiles
- 2003 Apex Survey profiles
- 2006 Apex Survey profiles
- NW4 Groundwater Monitoring Well
- BR1 Bedrock Monitoring Well
- OB1 Overburden Monitoring Well
- KC2 Bedrock Monitoring Well
- BH1 BH1 & BH12 removed due to construction works at Black Ash site
- High Conductivity Zones
- Proposed Borehole Location

Interpretation Legend:
- LANDFILL / LEACHATE
- Possible LEACHATE in bedrock
- PEAT/SILT/CLAY
- Gravelly CLAY/clayey GRAVEL
- Low Resistivity LIMESTONE
- High Resistivity WAULSORTIAN LIMESTONE

NOTES:

TITLE: GEOPHYSICAL SURVEY

PROJECT: EPA LICENCED LANDFILLS

CLIENT: EPA

DRAWING: W0012-02 KINSALE ROAD MAPS & SECTIONS

DRAWING NUMBER: 9241_KR_01

SCALE: AS SHOWN @ A1

DATE: 4th March 2010

DRAWN: YOC | CHECKED:

REVISION:	DATE:	DRAWN:	CHECKED:
V2	23-04-10	YOC	

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APPENDIX B – METHODOLOGIES

Step Tests

Step tests or step drawdown tests are single-well pump tests used to investigate, under controlled variable discharge conditions, the performance of a pumping well. Step tests have a number of applications and are performed for several reasons including; estimation and evaluation of well performance, well loss and efficiency, selection of suitable extraction rates for wells, and/or estimation of hydraulic properties of an aquifer system such as transmissivity and hydraulic conductivity *(Louwyck, Vandenbohede, and lebbe 2009).* The discharge rate in the pumping well is steadily increased from an initially low constant rate through a sequence of pumping steps or intervals of gradually higher rates of extraction and subsequently discharge volumes. In order to allow dissipation of wellbore storage effects, the step intervals should be of sufficient duration. Each step lasts from approximately 30 minutes to 2 hours and their durations are at consecutive time intervals during the pumping *(Kruseman and de Ridder 1994).* The aquifer properties and well-loss coefficients that are estimated from a step-drawdown test are fitted to mathematical models (type curves) and to drawdown data through a procedure known as curve matching.

Pumping Tests

A pumping test is a field experiment which stresses an aquifer by pumping a test well at a controlled rate, while water levels are measured in the observation wells (drawdown). Pumping tests, when carried out carefully can contribute data giving a deep insight into aquifer properties and groundwater flow. Pumping test data can be difficult to interpret as a result of varied geological conditions and the complex groundwater flow systems *(Brassington, R. 2017).* Therefore, it is essential to carefully measure, control and record the flow rate throughout the test. A constant-rate test is the most commonly performed pumping test.; Step-drawdown tests are for assessing well performance or designing a constant-rate test and are sometimes used to establish the best rate of water extraction prior to the beginning of the pump test.

Groundwater Pumping tests are conducted to estimate the hydraulic properties of aquifer systems as well as identify aquifer boundaries and are a well-established tool to estimate the mean hydraulic conductivity of the area of influence of the pumped test drawdown. Pumping tests can identify and locate recharge and no-flow boundaries that may limit the lateral extent of aquifers. They can also be used to determine transmissivity, hydraulic conductivity (horizontal and vertical) and storativity (storage coefficient).

The most common curve matching procedure used by hydrogeologists, for estimating aquifer properties from pumping tests was proposed by Theis (1935). Theis (1935) developed the first transient model for groundwater flow to a pumping well in a homogeneous, horizontally isotropic, laterally unbounded confined aquifer with a constant rate of abstraction. In Theis' model, several assumptions were used to simplify the flow system and to make the model mathematical tractable *(Wen et al 2017).* The Theis method allows one to estimate the transmissivity, hydraulic conductivity and storativity of a confined or unconfined aquifer having infinite extent by means of matching the Theis type curve to water-level changes (drawdowns) measured in wells during a constant-rate pumping test. The two inflection points in the drawdown-time curves are used to estimate the aquifer parameters. Many theoretical models for pumping tests have been developed since the classical work of Theis *(Wen et al 2017) (Theis, 1935, Cooper and Jacob, 1946, Papadopulos and Cooper, 1967, Hantush, 1960).*

Resistivity

"Geophysical resistivity techniques are based on the response of the earth to the flow of electrical current."

Subsurface resistivity is a function of the magnitude of an electrical current passed through the ground and two potential electrodes to calculate the resultant potential between. A direct measurement can be obtained of the electrical impedance of the subsurface material. Resistivity measurements are associated with varying depths and can be interpreted in terms of a lithologic and/or geohydrologic subsurface. (*Cardimona.S, 2002)*

Equipment:

Resistivity meter	Induces an electrical current into the ground and takes measurements of resistivity
Electrode	A conductor planted into the ground through which current is passed, or which is used to measure the voltage caused by the current.
Multi-core cable	Connects the resistivity meter to the electrodes
Computer	Contains the software for collecting the data

Conducting a survey

Wenner array configuration, potential electrodes between current electrodes with an equal lateral distance between adjacent electrodes. The electrodes in a Wenner array can be expanded about a centre point at equally interval spacing for larger survey lines, like the one which was conducted on this site. The current therefore progressively passes into deeper layers, giving the deeper overall profile. (*Cardimona.S, 2002)*

This method is done by running an electric current into the ground and measuring the resistance of the material in the ground to that current. This will then be represented on a graph showing the variations in the underlying material. By injecting an electrical current into the ground we can map the subsurface resistivity.

Started first by placing out our Multi cord over the intended area of survey and at each nodes there is a metal rods connected and inserted into the subsurface. These were inserted in order 1,2,3 etc., along with noting if they came in contact with any stones or pebbles close to the surface, if so it was then repositioned. The contact with the rock would have disrupted the survey and created an inaccurate reading of the underlying material. An electrical current is passed though the nodes into the ground and put though a computer software i.e. Imager Pro. This computer software offer processing for many different arrays the one that was used in the case of this survey was Wenner, which is one of the most commonly used software's. These readings are displayed on an ERT – electrical resistivity tomography, shown as an inverse Triangular data set.

APPENDIX C – PUMPING TEST DATA FOR GREENHILLS SOUTH AND NORTH AND CHLORIDE GRAPHS

Table of Pumping Test Data for Greenhills South

GHS	Deep		TOC	Conductivity	Alkalinity	Ammonium	Chloride
Sample No.	Date	Time	mg/L	uS/cm Tref 25	As CaCO3 mg/L	As NH_4 mg/L	Cl- mg/L
1	18/07/2018	11:10	**1.0**	**2,190**	**190**	**1.6**	**589**
2	18/07/2018	11:25	**1.0**	**2,180**	**190**	**1.6**	**600**
3	18/07/2018	11:40	**0.5**	**2,170**	**189**	**2.1**	**595**
4	18/07/2018	11:55	**0.5**	**2,140**	**189**	**1.9**	**586**
5	18/07/2018	12:25	**0.5**	**2,110**	**189**	**1.6**	**577**
6	18/07/2018	12:55	**0.5**	**2,130**	**191**	**1.7**	**577**
7	18/07/2018	13:25	**0.5**	**2,130**	**191**	**1.7**	**577**
8	18/07/2018	13:55	**0.5**	**2,140**	**192**	**1.9**	**595**
9	18/07/2018	14:55	**0.5**	**2,150**	**193**	**1.9**	**604**
10	18/07/2018	15:55	**0.5**	**2,130**	**193**	**1.9**	**595**

Chloride Data for Pumping Tests of Greenhills South

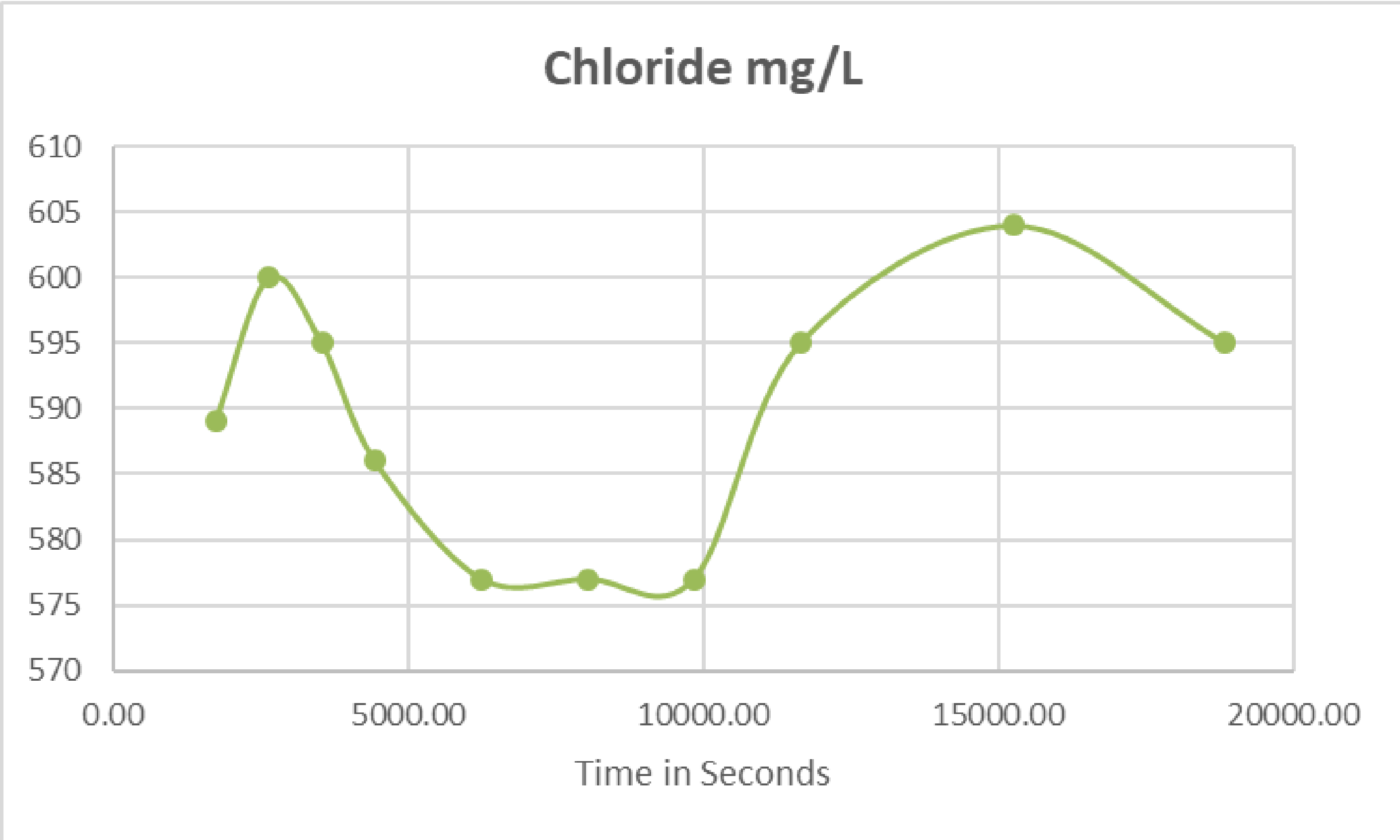


Figure depicting Pumping Tests conducted on 18/07/2018 10am-4pm

Table of Pumping Test Data for Greenhills North

GHN	Deep		TOC	Conductivity	Alkalinity	Ammonium	Chloride
Sample No.	Date	Time	mg/L	uS/cm Tref 25	As CaCO3 mg/L	As NH_4 mg/L	Cl- mg/L
1	19/07/2018	11:00	**1.0**	**4,200**	**146**	**1.1**	**1,315**
2	19/07/2018	11:15	**1.5**	**4,140**	**147**	**0.5**	**1,297**
3	19/07/2018	11:30	**0.5**	**4,130**	**147**	**1.1**	**1,279**
4	19/07/2018	11:45	**0.5**	**4,140**	**149**	**0.8**	**1,315**
5	19/07/2018	12:15	**0.5**	**4,090**	**147**	**0.7**	**1,279**
6	19/07/2018	12:45	**0.5**	**4,030**	**142**	**0.4**	**1,315**
7	19/07/2018	13:15	**0.5**	**3,990**	**150**	**0.8**	**1,288**
8	19/07/2018	13:45	**0.5**	**4,010**	**151**	**0.8**	**1,243**
9	19/07/2018	14:45	**0.5**	**4,010**	**149**	**0.5**	**1,270**
10	19/07/2018	15:45	**0.5**	**4,010**	**148**	**1.1**	**1,270**

Chloride Data for Pumping Tests of Greenhills North

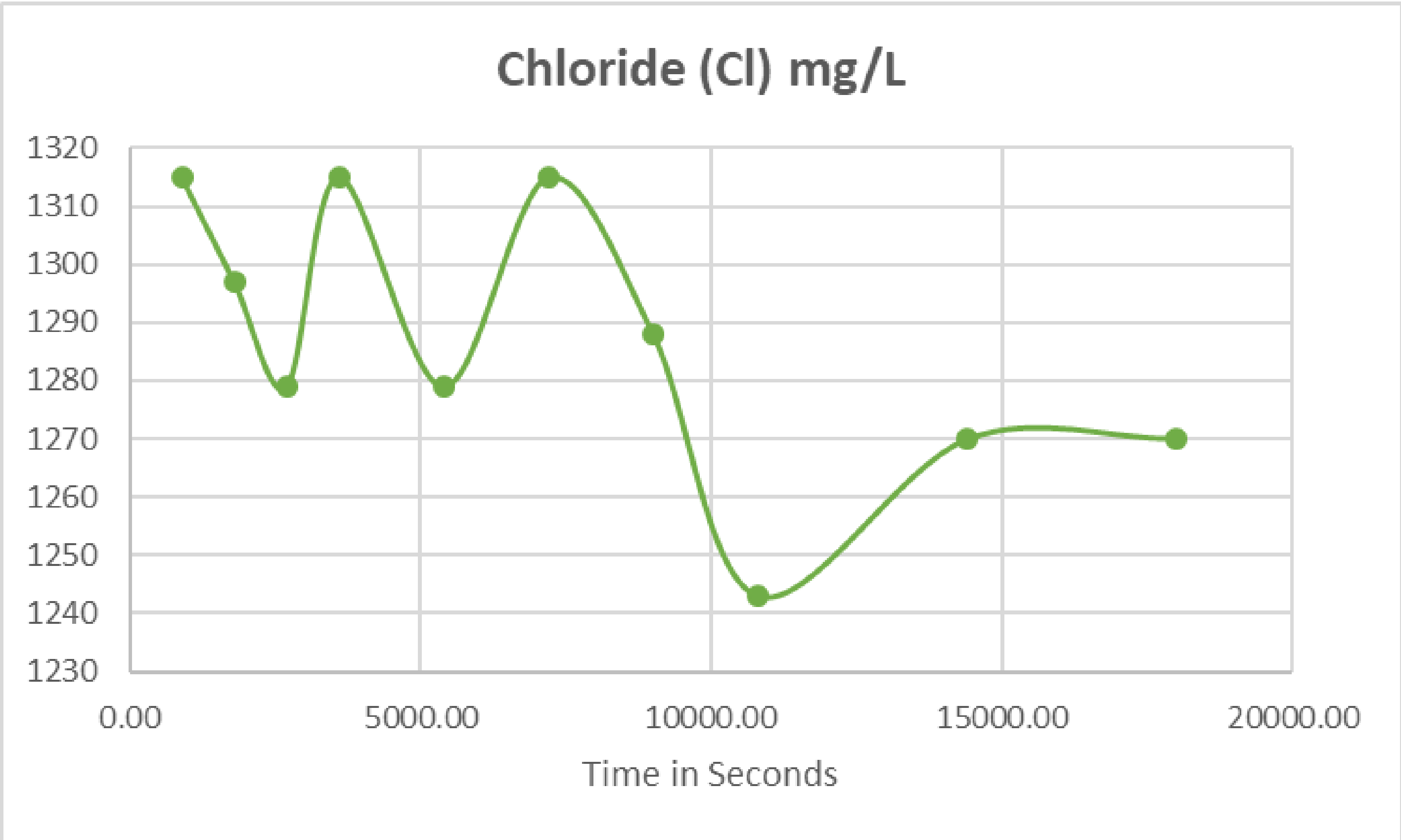


Figure depicting Pumping Tests conducted on 19/07/2018 10am-4pm

APPENDIX D – CHLORIDE DATA 2013-2017

Table of Groundwater Sampling for Chloride 2013-2017 Greenhills North Deep

Chloride mg/L -		Greenhills North Deep		
2013	**2014**	**2015**	**2016**	**2017**
489	452	921	824	762.45
28	86	1028	108	1843.4
1223	84	1106	132	1176
795	996	1240	1282	1014
898	1329	1226	1227	1361.28
574		1389	1188	674
815	28	744	1347	1099
503	28	1063	1156	638
69.4	725	37	638	744
971	1070	27	886	695
	126	1048	922	1347
	605		406	1170

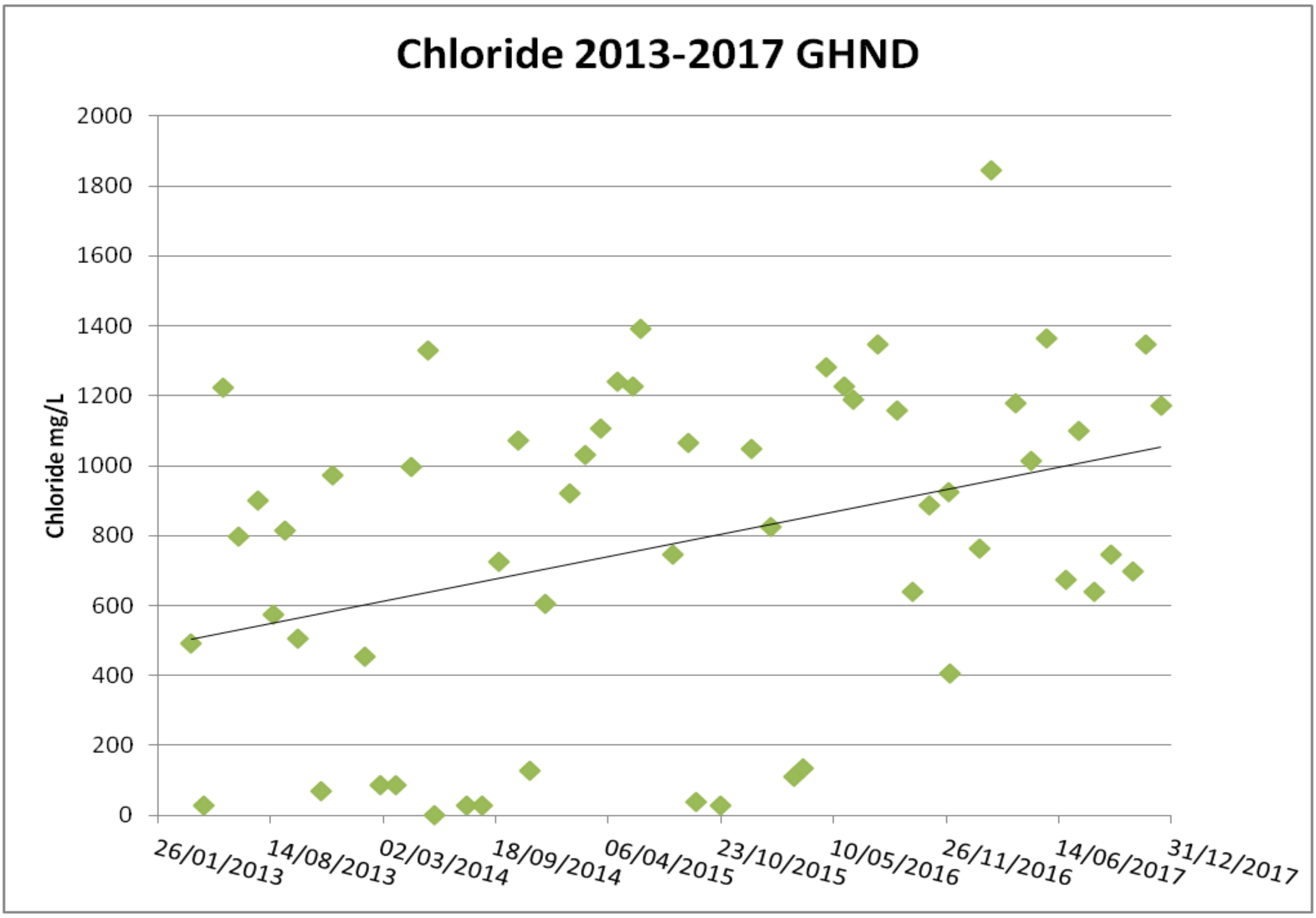


Figure depicting Groundwater Sampling for Chloride 2013-2017 Greenhills North Deep

Table of Groundwater Sampling for Chloride 2013-2017 Greenhills South Deep

Chloride mg/L -	Greenhill South Deep			
2013	2014	2015	2016	2017
239	207	397	269	243
58	69	365	8.51	525
616	193	268	74	305
418	535	469	532	345
432	553	100	518	532
364		415	798	518
383	478	260	603	532
383	444	248	487	496
39.7	540	47	691	461
244	319	98	461	355
	81	325	142	461
	455		43	425

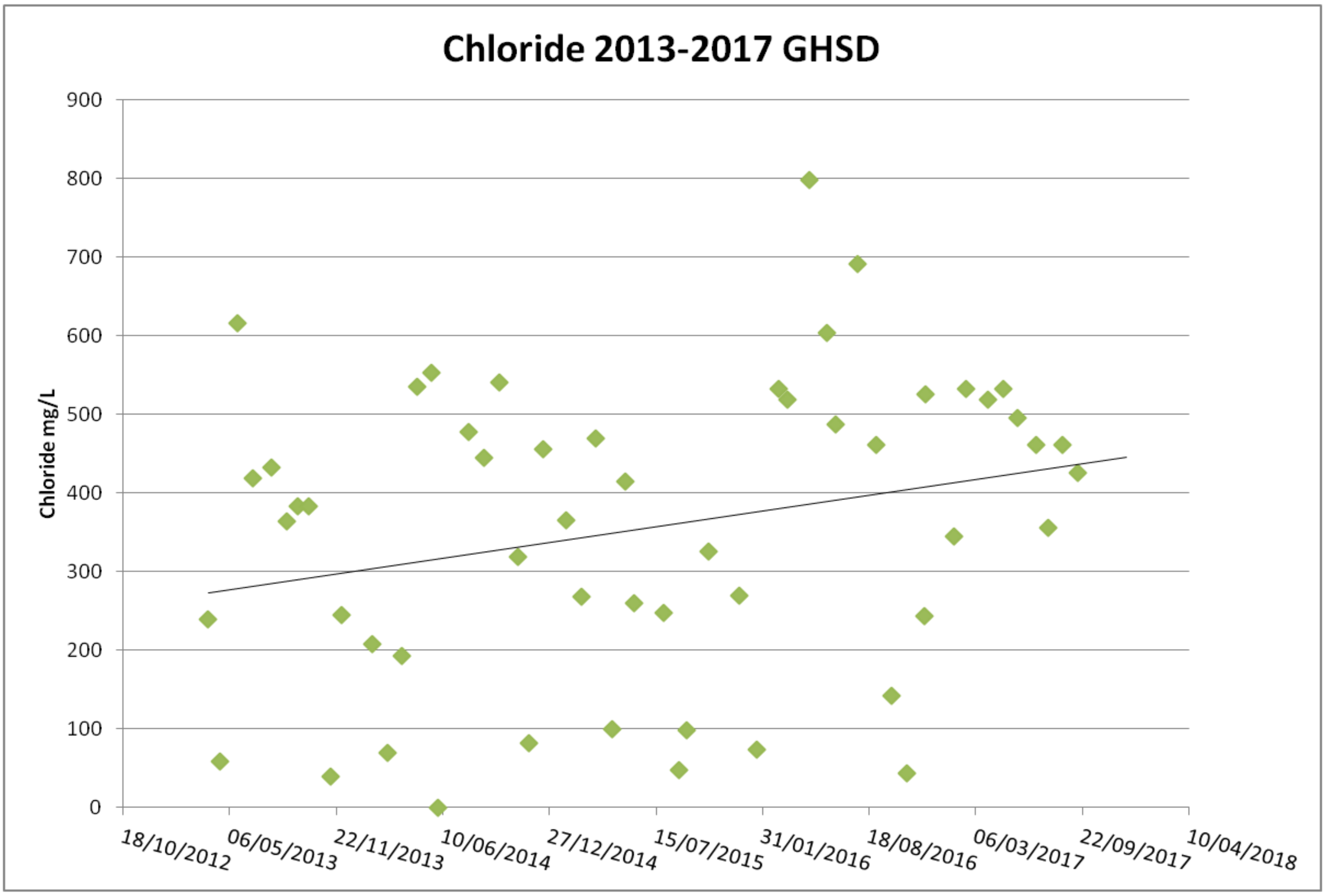


Figure depicting Groundwater Sampling for Chloride 2013-2017 Greenhills South Deep

APPENDIX E – GEOPHYSICAL SURVEYS - LOCAL SETTING AND POSITIONS

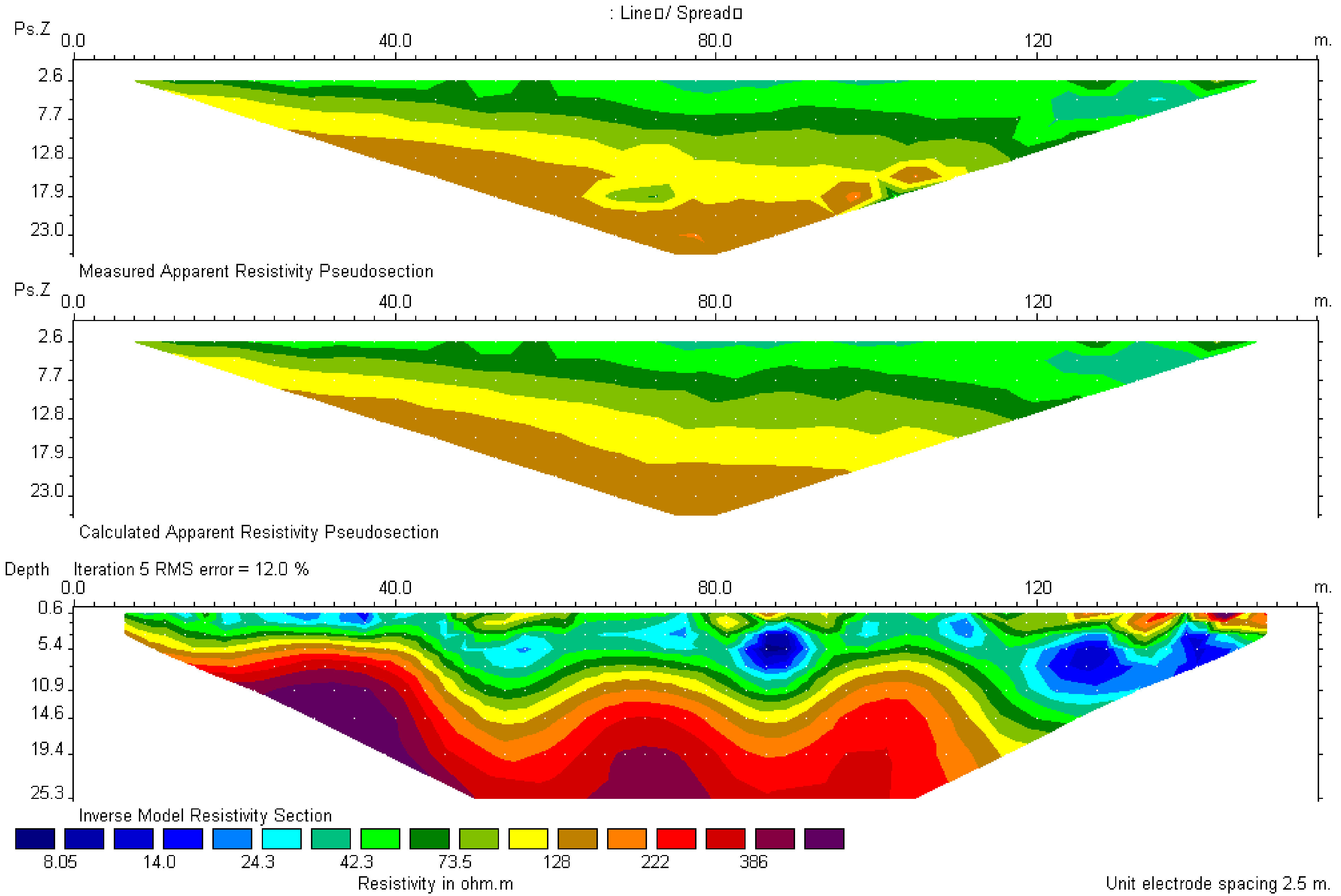
Local setting where the geophysical survey was carried out (Yellow) in relation to the Kinsale Road Landfill Site boundary (Red)

Geophysical Survey Lines Conducted on the Nemo Rangers Grounds (Profile Lines 1-5)

L1, L2 & L3 – Yellow	Blue line – Extent of survey area
L4 & L5 – White	

APPENDIX F – GEOPHYSICAL SURVEY - ORIGINAL INVERSIONS PROFILE LINES 1-5

Line 1



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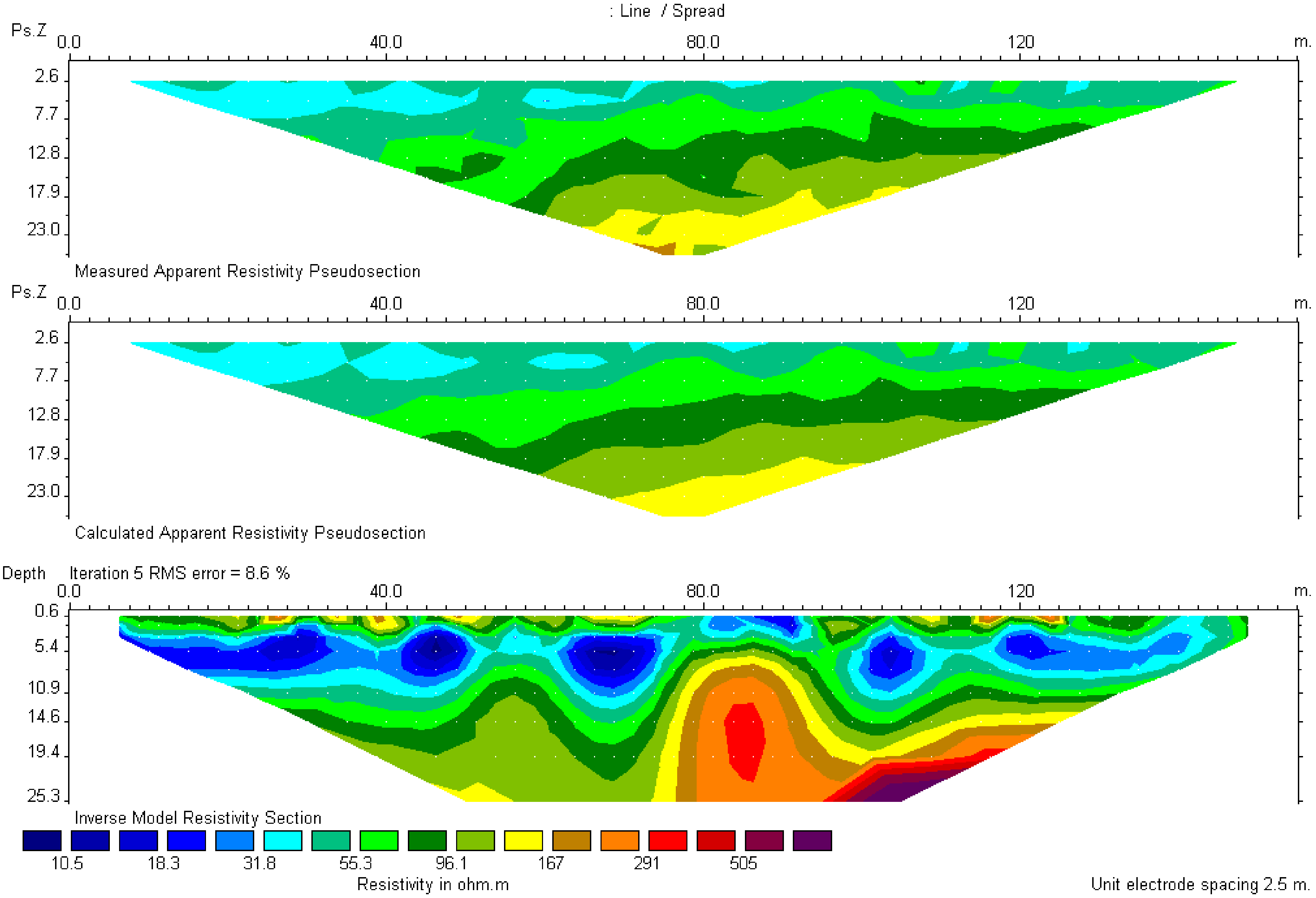
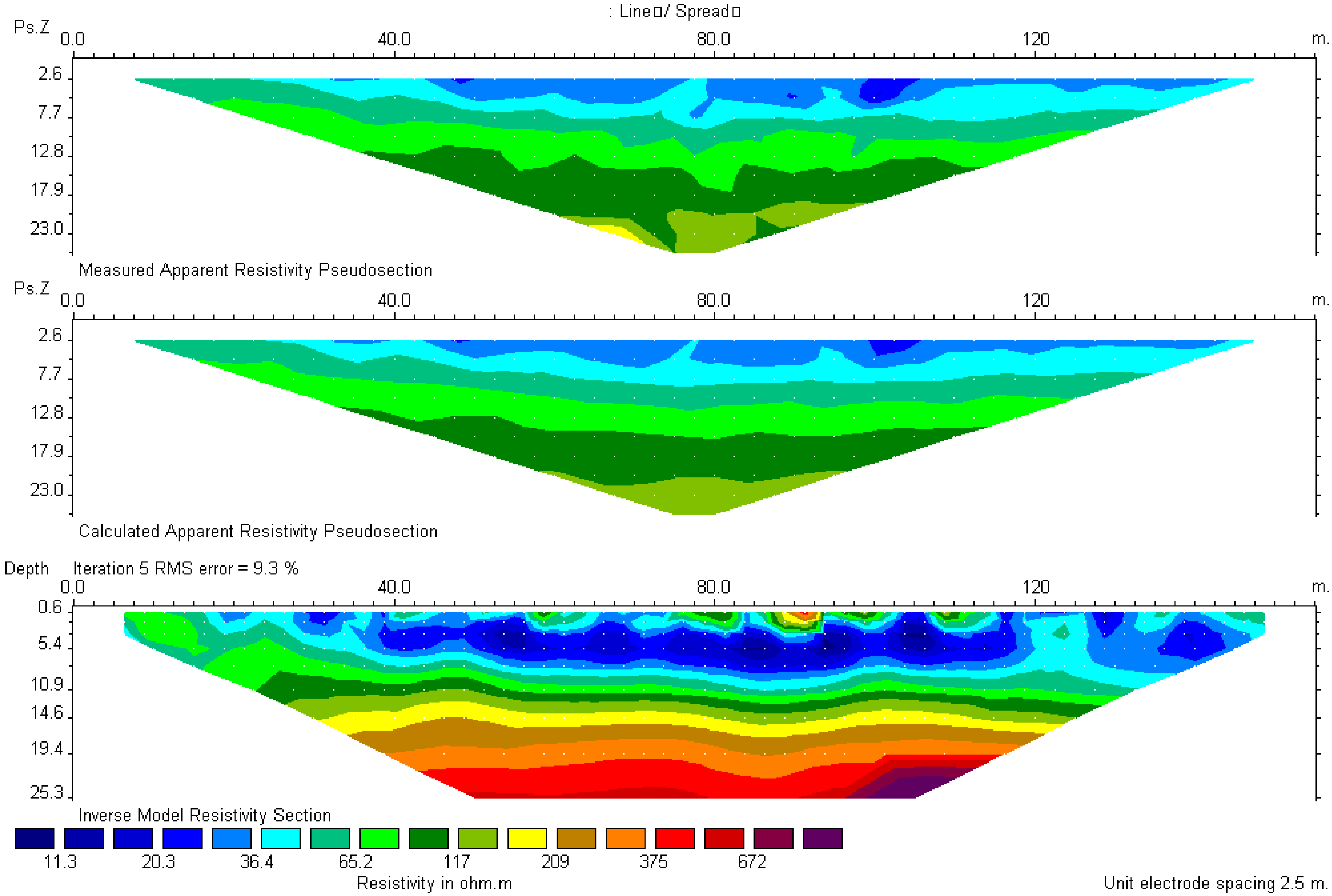
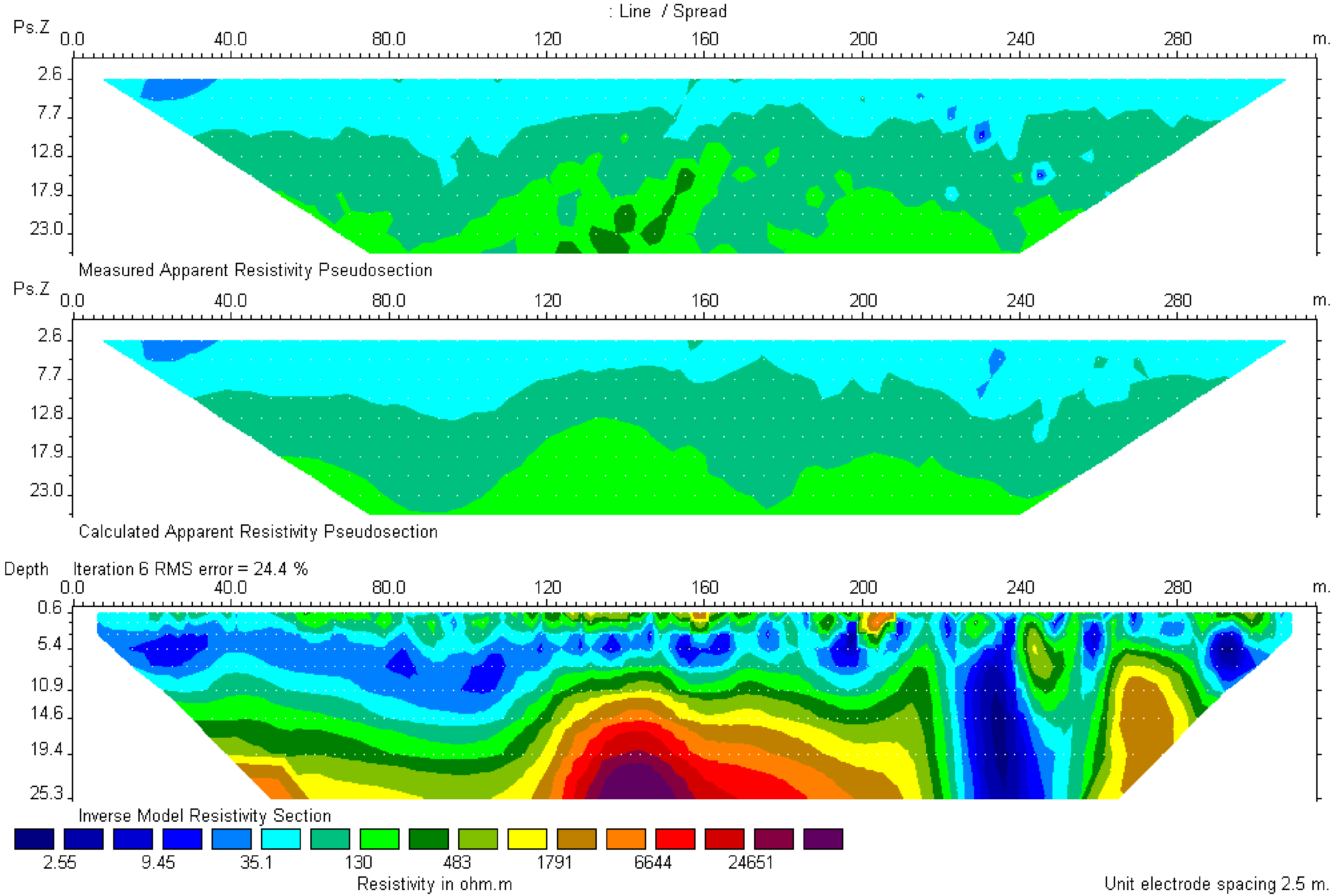

: Line / Spread
Ps.Z
0.0
40.0
80.0
120
m.
2.6
7.7
12.8
17.9
23.0
Measured Apparent Resistivity Pseudosection
Ps.Z
0.0
40.0
80.0
120
m.
2.6
7.7
12.8
17.9
23.0
Calculated Apparent Resistivity Pseudosection
Depth
Iteration 5 RMS error = 8.6 %
0.0
40.0
80.0
120
m.
0.6
5.4
10.9
14.6
19.4
25.3
Inverse Model Resistivity Section
10.5
18.3
31.8
55.3
96.1
167
291
505
Resistivity in ohm.m
Unit electrode spacing 2.5 m.

Line 3

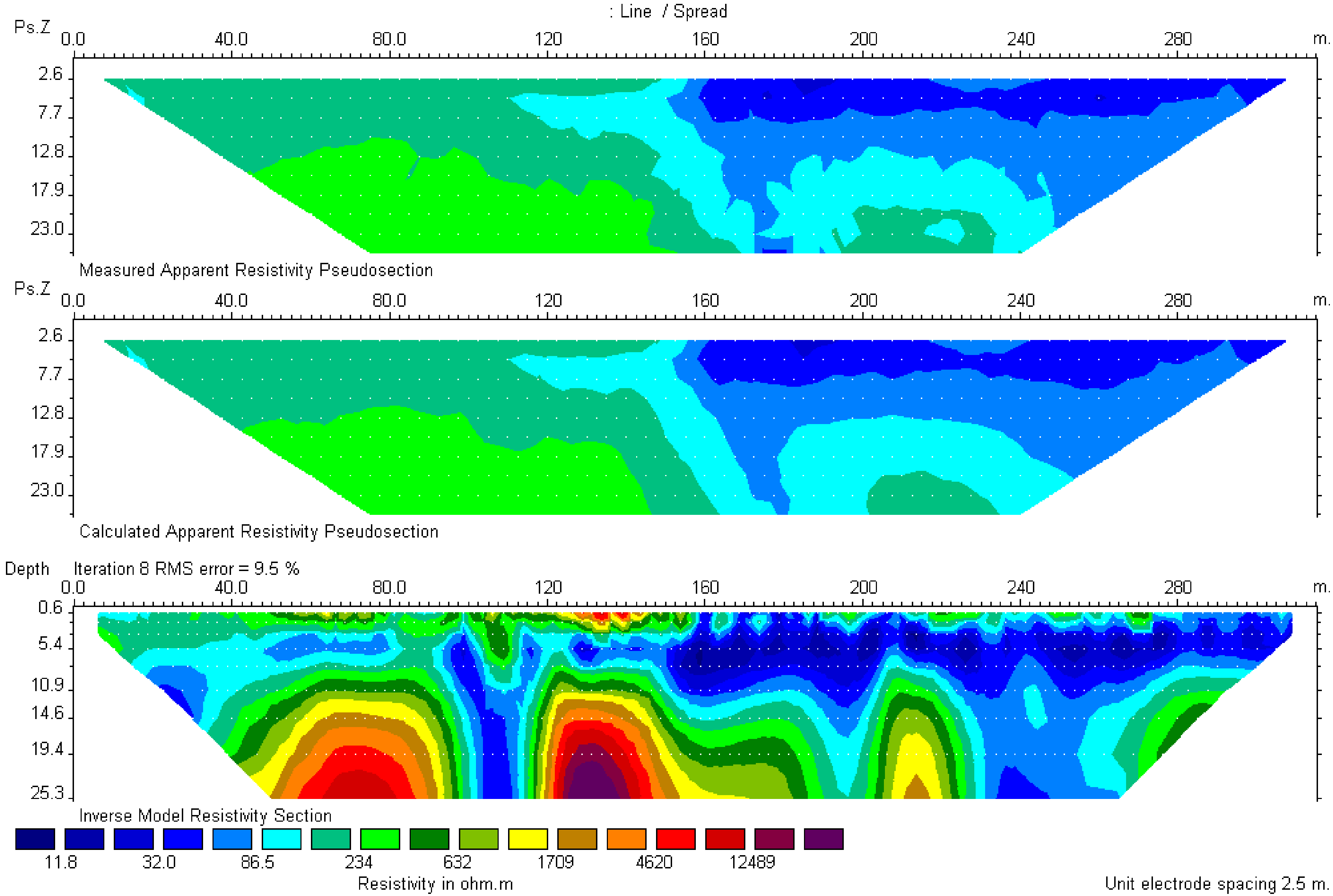


: Line□/ Spread□
Ps.Z
0.0
40.0
80.0
120
m.
2.6
7.7
12.8
17.9
23.0
Measured Apparent Resistivity Pseudosection
Ps.Z
0.0
40.0
80.0
120
m.
2.6
7.7
12.8
17.9
23.0
Calculated Apparent Resistivity Pseudosection
Depth
Iteration 5 RMS error = 9.3 %
0.0
40.0
80.0
120
m.
0.6
5.4
10.9
14.6
19.4
25.3
Inverse Model Resistivity Section
11.3
20.3
36.4
65.2
117
209
375
672
Resistivity in ohm.m
Unit electrode spacing 2.5 m.

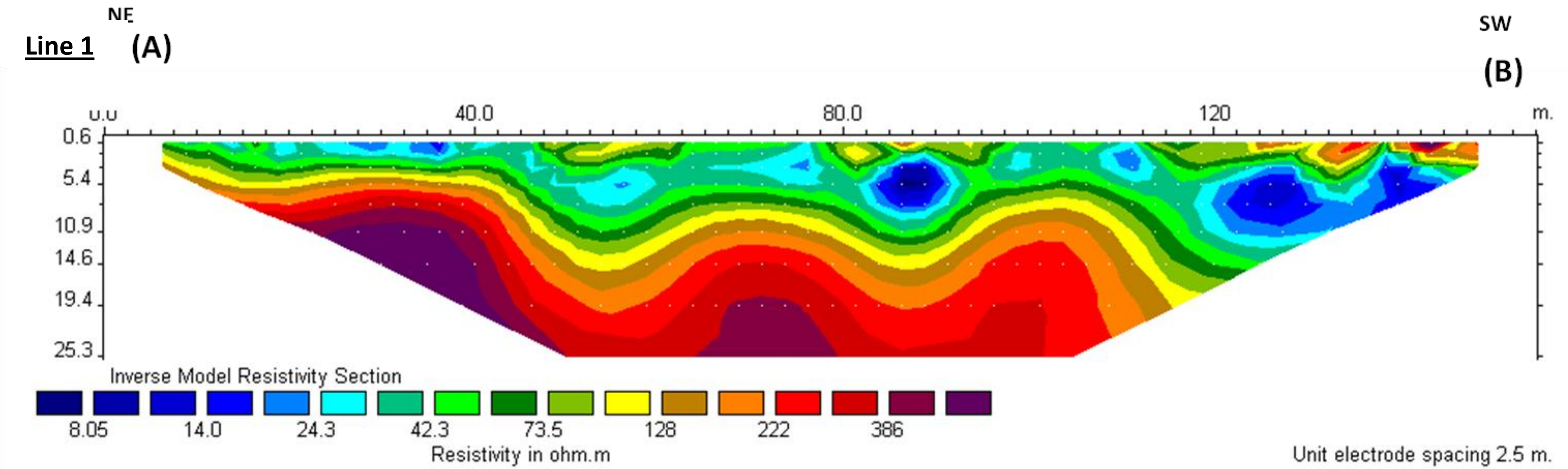
Line 4

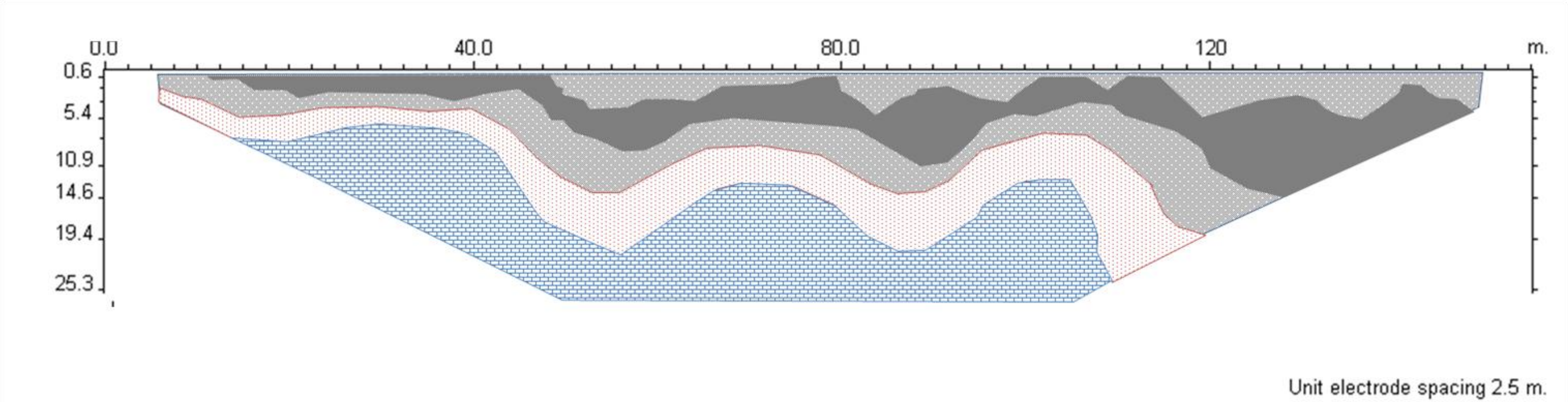

: Line / Spread
Ps.Z
0.0
40.0
80.0
120
160
200
240
280
m.
2.6
7.7
12.8
17.9
23.0
Measured Apparent Resistivity Pseudosection
Calculated Apparent Resistivity Pseudosection
Depth
Iteration 6 RMS error = 24.4 %
0.6
5.4
10.9
14.6
19.4
25.3
Inverse Model Resistivity Section
2.55
9.45
35.1
130
483
1791
6644
24651
Resistivity in ohm.m
Unit electrode spacing 2.5 m.

Line 5

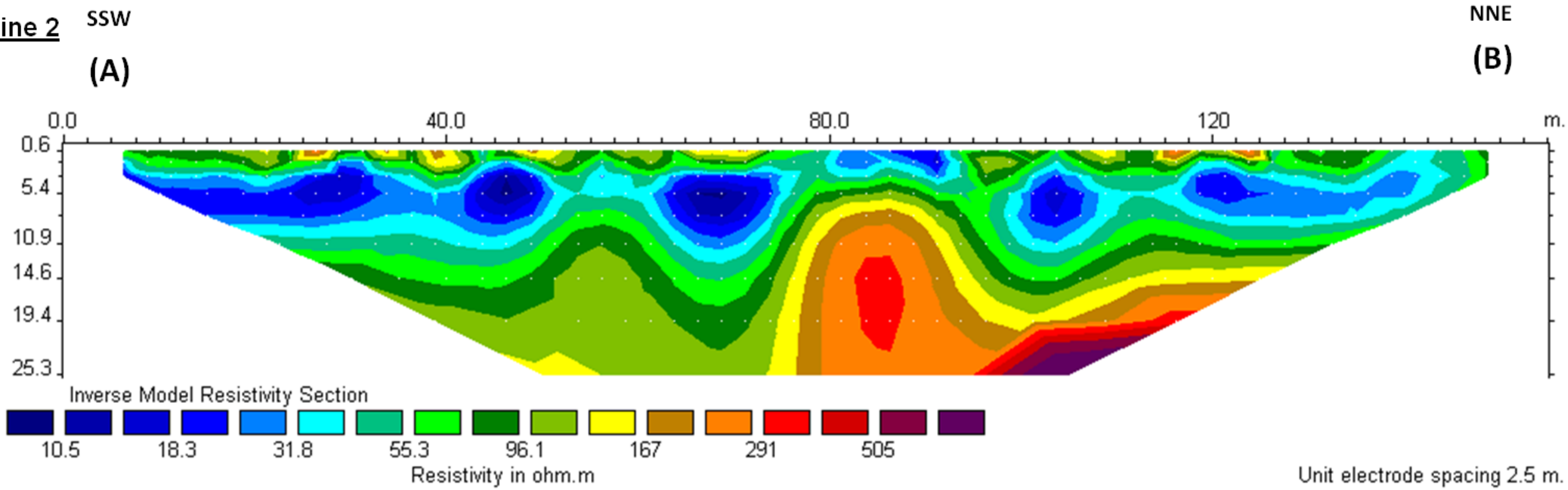

: Line / Spread
Ps.Z
0.0 40.0 80.0 120 160 200 240 280 m.
2.6 7.7 12.8 17.9 23.0
Measured Apparent Resistivity Pseudosection
Ps.Z
0.0 40.0 80.0 120 160 200 240 280 m.
2.6 7.7 12.8 17.9 23.0
Calculated Apparent Resistivity Pseudosection
Depth
Iteration 8 RMS error = 9.5 %
0.0 40.0 80.0 120 160 200 240 280 m.
0.6 5.4 10.9 14.6 19.4 25.3
Inverse Model Resistivity Section
11.8 32.0 86.5 234 632 1709 4620 12489
Resistivity in ohm.m
Unit electrode spacing 2.5 m.

APPENDIX G – GEOPHYSICAL SURVEY - INTERPRETED PROFILE LINES 1-5 (See Legend after Line 5)

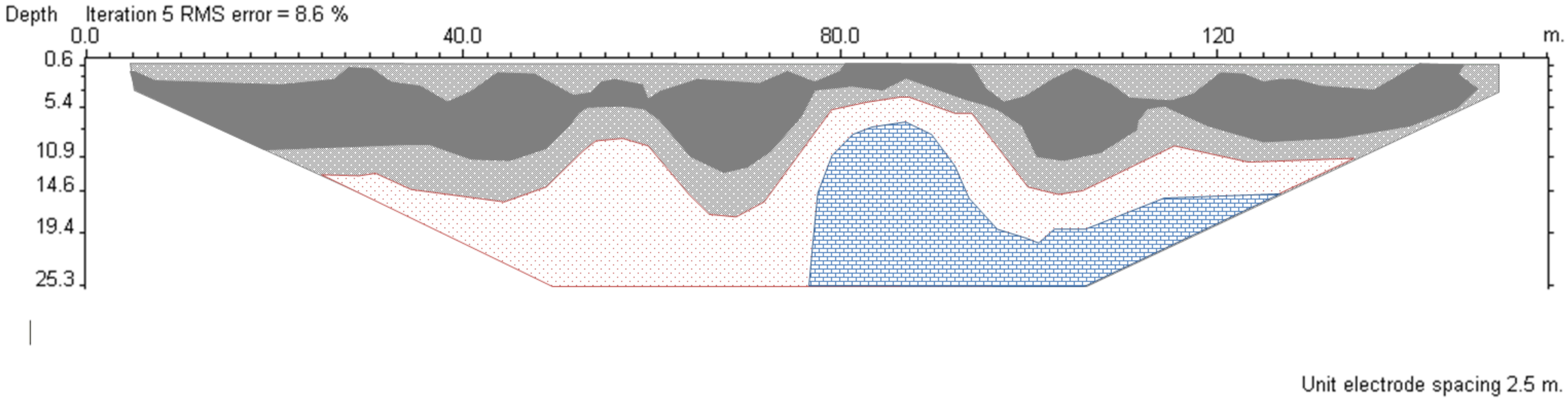




Line 2

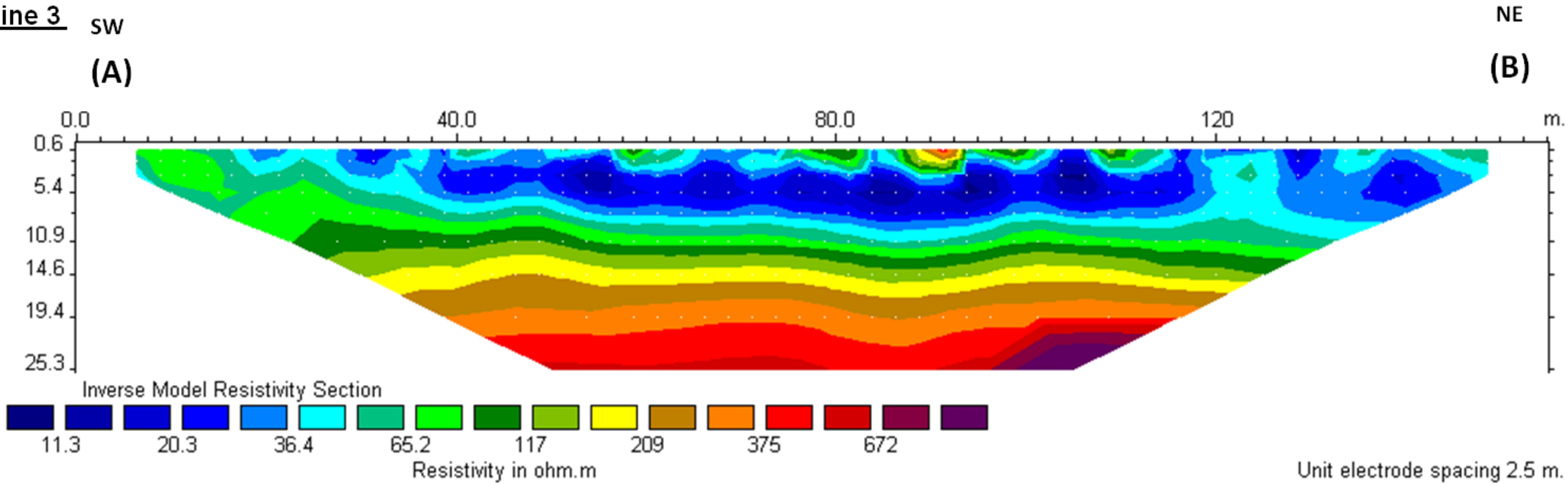


SSW
(A)
NNE
(B)
0.0
40.0
80.0
120
m.
0.6
5.4
10.9
14.6
19.4
25.3
Inverse Model Resistivity Section
10.5
18.3
31.8
55.3
96.1
167
291
505
Resistivity in ohm.m
Unit electrode spacing 2.5 m.

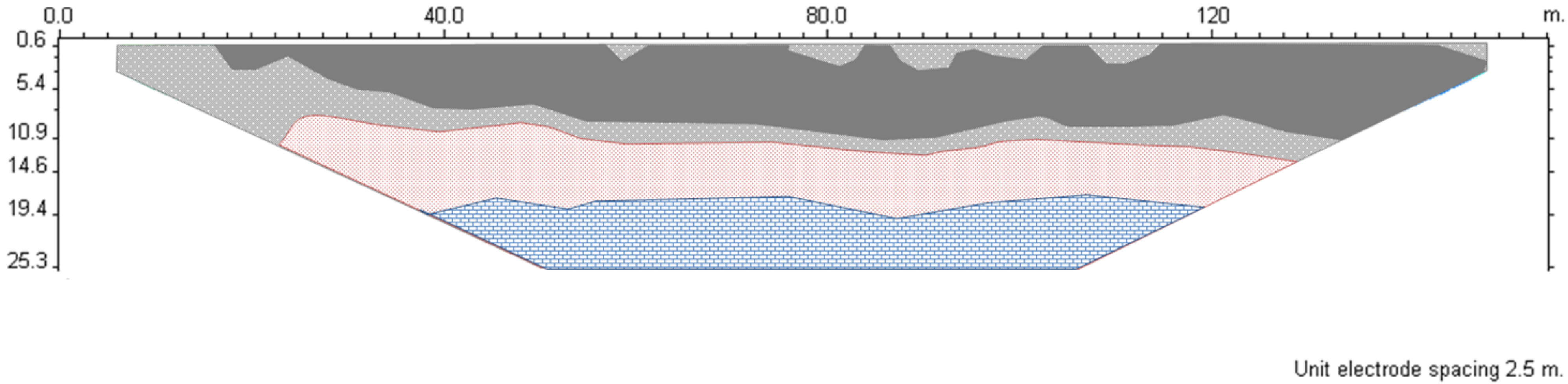


Depth
Iteration 5 RMS error = 8.6 %
0.0
40.0
80.0
120
m.
0.6
5.4
10.9
14.6
19.4
25.3
Unit electrode spacing 2.5 m.

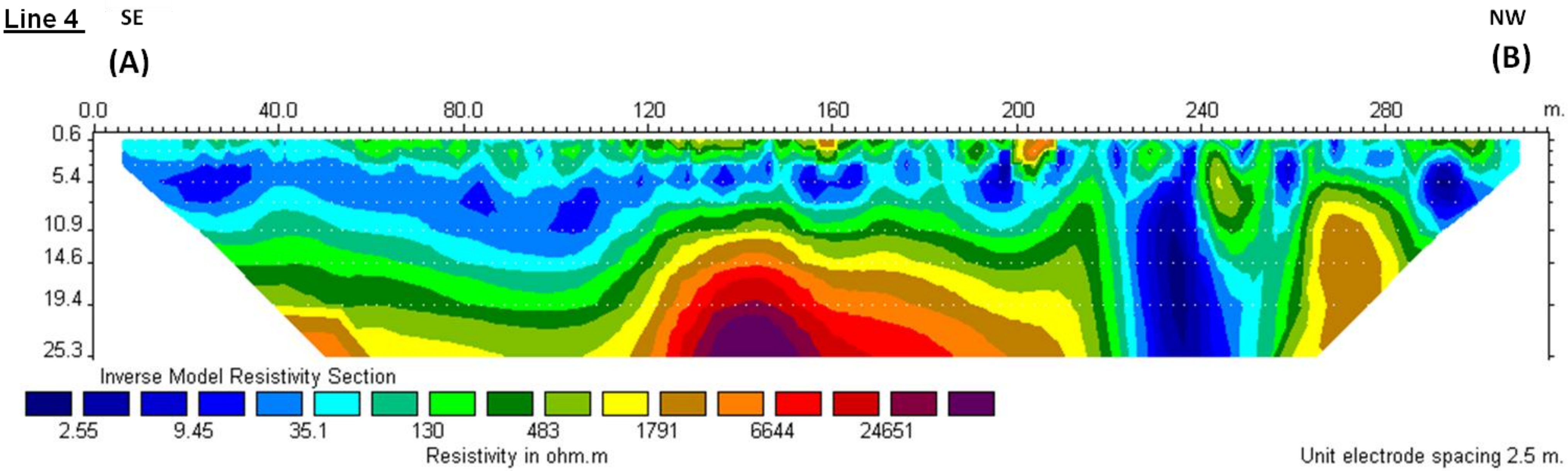
Line 3



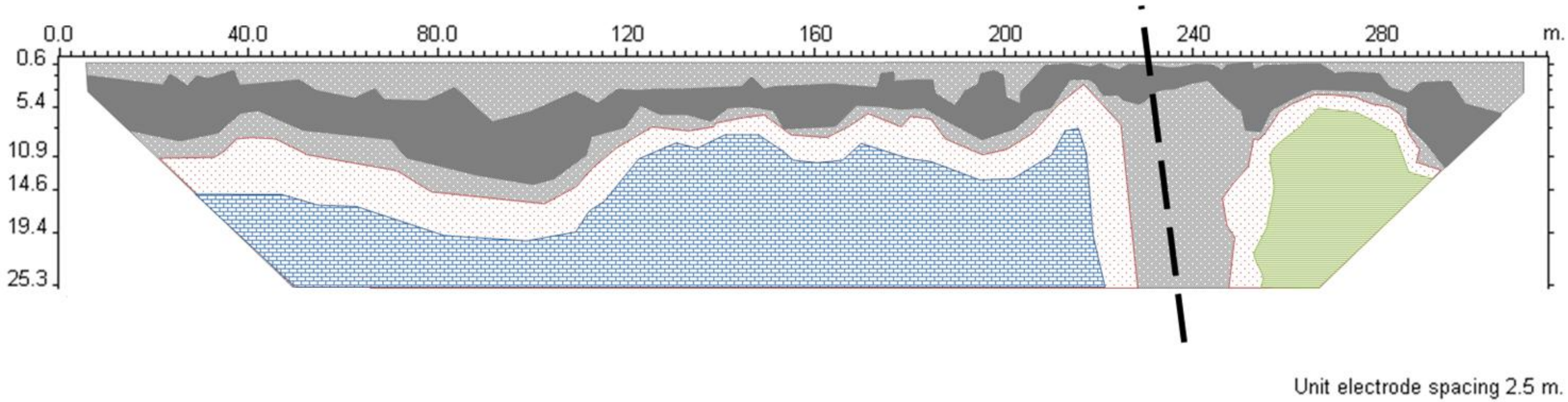
SW
NE
(A)
(B)
0.0
40.0
80.0
120
m.
0.6
5.4
10.9
14.6
19.4
25.3
Inverse Model Resistivity Section
11.3
20.3
36.4
65.2
117
209
375
672
Resistivity in ohm.m
Unit electrode spacing 2.5 m.



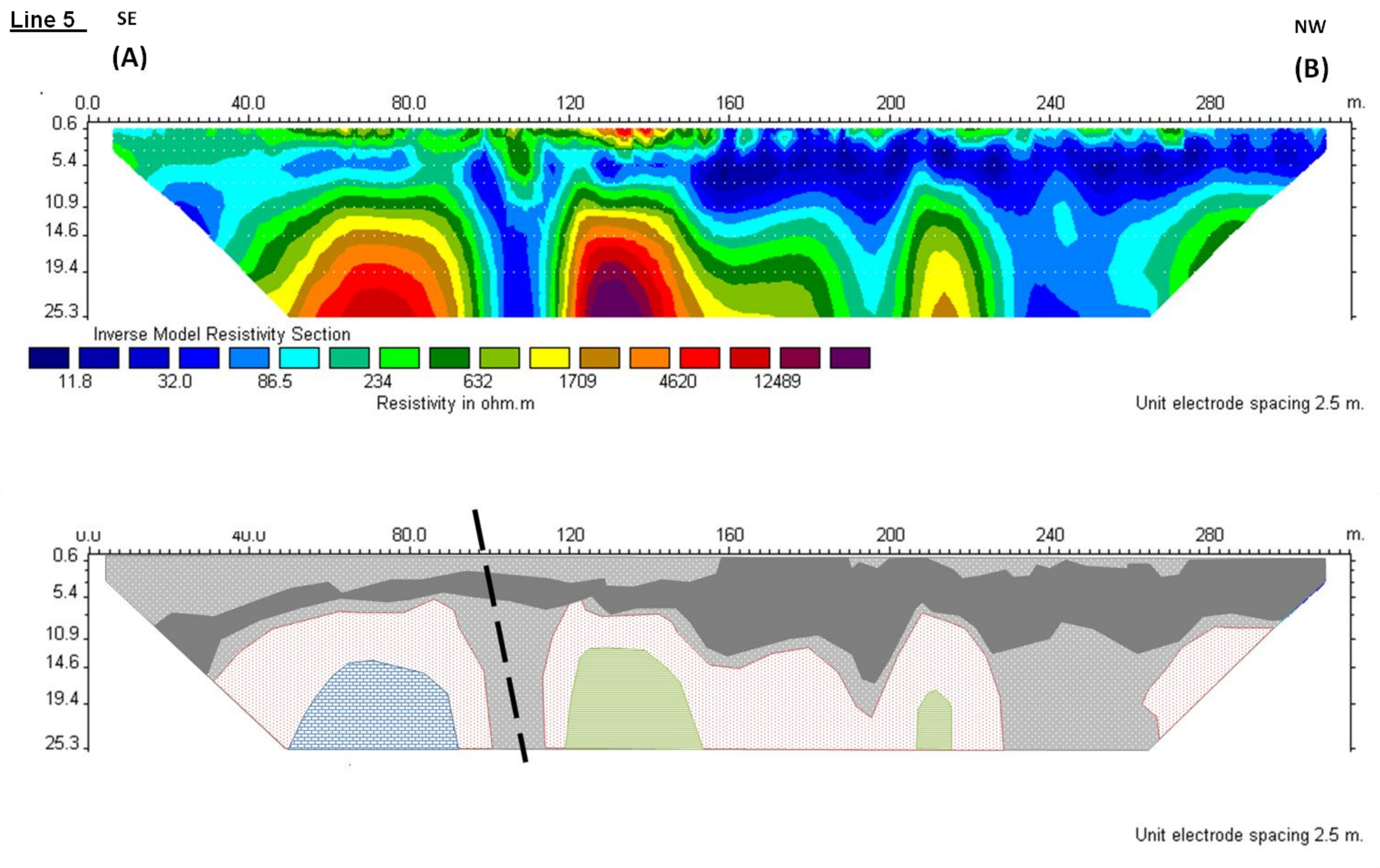
0.0
40.0
80.0
120
m.
0.6
5.4
10.9
14.6
19.4
25.3
Unit electrode spacing 2.5 m.



Line 4
SE
NW
(A)
(B)
0.0
40.0
80.0
120
160
200
240
280
m.
0.6
5.4
10.9
14.6
19.4
25.3
Inverse Model Resistivity Section
2.55
9.45
35.1
130
483
1791
6644
24651
Resistivity in ohm.m
Unit electrode spacing 2.5 m.



0.0
40.0
80.0
120
160
200
240
280
m.
0.6
5.4
10.9
14.6
19.4
25.3
Unit electrode spacing 2.5 m.


Line 5
SE
(A)
NW
(B)
0.0 40.0 80.0 120 160 200 240 280 m.
0.6
5.4
10.9
14.6
19.4
25.3
Inverse Model Resistivity Section
11.8 32.0 86.5 234 632 1709 4620 12489
Resistivity in ohm.m
Unit electrode spacing 2.5 m.
0.0 40.0 80.0 120 160 200 240 280 m.
0.6
5.4
10.9
14.6
19.4
25.3
Unit electrode spacing 2.5 m.

Legend for Profile lines 1-5

Limestone Bedrock (WA)

Gravel and Fractured Bedrock

Siltstone/ Sandstone (Cuskinny Member)

Clayey Gravel or Gravely Clay

Clay or Peat

Faulted Contact

PRIORITY GEOTECHNICAL

Priority Geotechnical Ltd.
Tel: 021 4631600
Fax: 021 4638690
www.prioritygeotechnical.ie

Drilled By	Logged By	Borehole No
GW	SC	NR01 (Sheet 1 of 2)

Project Name: Kinsale Road Landfill	**Project No.** P11028	**Co-ords:** -	**Hole Type** RO
Client: Cork County Council	**Dates:** 29/04/2011	**Level:** -	**Scale** 1:50

Sample Depth (m)	Type	Results	Casing / Flush	Level (m AOD)	Depth (m)	Stratum Description
0.00-1.20	B					Topsoil: Brown, slightly gravelly slightly gravelly CLAY with occasional cobbles. Sand is fine to coarse. Gravel is fine, subangular to subrounded. Cobbles are subangular, flat, limestone.
1.50-3.00	B				1.50	Dark brown, slightly gravelly plastic amorphous PEAT. Gravel is fine to medium, subangular.
3.00-4.50	B					
6.00-7.50	B				5.70	Purple/ brown, slightly sandy slightly gravelly CLAY. Sand is fine to coarse. Gravel is fine to medium, angular to subrounded. (Water strike ▽)
7.50-9.00	B				7.50	Purple/ brown, slightly sandy clayey GRAVEL. Sand is fine to coarse. Gravel is fine to medium, subangular to subrounded.
	B					

Continued next sheet

Groundwater:

Struck	Rose to	After	Sealed	Comment
5.80m	-	-	-	

Hole Information:

Hole Depth	Casing Diameter	Casing Depth
17.80m	131mm	17.80m

Chiselling:

Depths (m)	Time (hhmm)	Tool
to		

Remarks: Inspection pit dug to 1.2m. Borehole terminated at required depth. 50mm dia standpipe installed, response zone from 17.3m to 12.3m.

Shift Data:

Groundwater	Shift (dd/mm/yyyy)	Casing depth	Remarks
-	29/04/2011	0.00m	Start of Borehole
-	29/04/2011	17.80m	End of Borehole

Equipment & Methods: Soil Mech PSM 8G

PRIORITY GEOTECHNICAL

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Fax: 021 4638690
www.prioritygeotechnical.ie

Drilled By	Borehole No
GW	**NR01**
Logged By	Sheet 2 of 2
SC	

Project Name:	Project No.	Co-ords:	Hole Type
Kinsale Road Landfill	P11028	-	RO
Client: Cork County Council	**Dates:** 29/04/2011	**Level:** -	**Scale** 1:50

Well / Backfill	Water Strikes	Samples & In Situ Testing Depth (m)	Type	Results	Casing / Flush	Level (m AOD)	Depth (m)	Stratum Description	Legend
		9.00-10.50						Purple/ brown, slightly sandy clayey GRAVEL. Sand is fine to coarse. Gravel is fine to medium, subangular to subrounded.	
		10.50-12.00	B				11.50	Rock recovered as: Light grey, GRAVEL. Gravel is coarse, angular, limestone.	
							12.00	Open hole boring. Driller described: Rock.	
					17.80		17.80	End of Borehole at 17.80 m	
	Water	Depth (m)	Type	Results	Casing	Level	Depth		

Groundwater:

Struck	Rose to	After	Sealed	Comment
5.80m	-	-	-	

Hole Information:

Hole Depth	Casing Diameter	Casing Depth
17.80m	131mm	17.80m

Chiselling:

Depths (m)	Time (hhmm)	Tool
to		

Remarks: Inspection pit dug to 1.2m. Borehole terminated at required depth. 50mm dia standpipe installed, response zone from 17.3m to 12.3m.

Equipment & Methods: Soil Mech PSM 8G

Shift Data:

Groundwater	Shift (dd/mm/yyyy)	Casing depth	Remarks
-	29/04/2011	0.00m	Start of Borehole
-	29/04/2011	17.80m	End of Borehole

PRIORITY GEOTECHNICAL

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Fax: 021 4638690
www.prioritygeotechnical.ie

Drilled By	Logged By	Borehole No
GW	SC	**NR02** Sheet 1 of 1

Project Name:	Project No.	Co-ords:	Hole Type
Kinsale Road Landfill	P11028	-	RO
Client: Cork County Council	**Dates:** 29/04/2011	**Level:** -	**Scale** 1:50

Well / Backfill	Water Strikes	Depth (m)	Type	Results	Casing / Flush	Level (m AOD)	Depth (m)	Stratum Description
		0.00-1.20	B					Fill: Brown, slightly sandy slightly gravelly CLAY with occasional cobbles and a shoe. Sand is fine to coarse. Gravel is fine to coarse, subangular to subrounded. Cobbles are subangular, tabular.
		1.50-3.00	B				1.50	Black/ dark brown, slightly gravelly slightly clayey plastic pseudofibrous PEAT. Gravel is fine to medium, subangular.
		3.00-4.50	B					
							5.80	Open hole boring. Driller described: Sandy gravelly CLAY.
	▽						6.10	Open hole boring. Driller described: CLAY.
					6.70			End of Borehole at 6.70 m

Groundwater:

Struck	Rose to	After	Sealed	Comment
6.10m	-	-	-	

Hole Information:

Hole Depth	Casing Diameter	Casing Depth
6.70m	131mm	6.70m

Chiselling:

Depths (m)	Time (hhmm)	Tool
to		

Remarks: Inspection pit dug to 1.2m. Borehole terminated at required depth. 50mm dia standpipe installed, response zone from 6.2m to 3.2m.

Equipment & Methods: Soil Mech PSM 8G

Shift Data:

Groundwater	Shift (dd/mm/yyyy)	Casing depth	Remarks
-	29/04/2011	0.00m	Start of Borehole
-	29/04/2011	6.70m	End of Borehole

APPENDIX I – NEMO RANGERS ANALYSIS AT NON POTABLE GROUNDWATER EXTRACTION POINT

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Fax: +353 21 453 6149
Web: www.elsltd.com
email:info@elsltd.com

ISO 17025 INAB ACCREDITED TESTING
DETAILED IN SCOPE REG NO.111T

Contact Name	Brendan Goggin	**Report Number**	**120688 - 1**
Address	Cork City Council (Lee Rd) Laboratory, Waterworks,	**Sample Number**	120688/001
		Date of Receipt	29/11/2017
		Date Started	29/11/2017
Tel No		**Received or Collected**	Hand
Customer PO	507440 OG	**Date of Report**	14/12/2017
Quotation No	QN006611	**Sample Type**	Drinking Water
Customer Ref	P3		

CERTIFICATE OF ANALYSIS

TEST	ANALYTE	SUB	METHOD	LOQ	SPEC	RESULT	UNITS	ACCRED.	OOS
Coliforms									
	Total Coliforms		MIC133	0	0	0	MPN/100ml	INAB	
	Analyst Micro Comment: The start date for this micro test is 29.11.2017								
	E. Coli		MIC133	0	0	0	MPN/100ml	INAB	
Cyanide-Free									
	Cyanide-Free		EW154M-1	1.2	50	<1.2	ug/L	INAB	
	Tested by accredited method EW175								
Gallery Plus-Suite A									
	Ammonia as N		EW175	0.005		<0.005	mg/l N	INAB	
	Ammonium as NH4 (calc)		EW175	0.006	0.3	<0.006	mg/l NH4	INAB	
	Colour-Apparent		EW175	2.0		<2.0	PtCo	INAB	
	Nitrate as N		EW175	0.15		5.0	mg/l N	INAB	
	Nitrate as NO3 (Calc)		EW175	0.66	50	22	mg/l NO3	INAB	
	Nitrite as N		EW175	0.005		<0.005	mg/l N	INAB	
	Nitrite as NO2 (Calc)		EW175	0.016	0.5	<0.016	mg/l NO2	INAB	
	Chloride mg/L		EW175	1.0	250	19	mg/L	INAB	
	Sulphate mg/L		EW175	1.0	250	27	mg/L	INAB	
GCMSMS-Pesticides & PAH									
	Cyperemethrin-(IH)		EO181	0.003	0.1	<0.003	µg/L	INAB	
	Dichlobenil (IH)		EO181	0.003	0.1	<0.003	µg/L	INAB	
	Pendimethalin (IH)		EO181	0.003	0.1	<0.003	µg/L	INAB	
	Acenaphthene		EO181	0.003		<0.003	µg/L	INAB	
	Benzo (a) Pyrene		EO181	0.003	0.01	<0.003	µg/L	INAB	
	Benzo (b) Fluoranthene		EO181	0.010		<0.010	µg/L	INAB	
	Benzo (ghi) Perylene		EO181	0.010		<0.010	µg/L	INAB	
	Benzo (k) Fluoranthene		EO181	0.010		<0.010	µg/L	INAB	
	Benzo (a) Anthracene		EO181	0.005		<0.005	µg/L	INAB	
	Chrysene		EO181	0.003		<0.003	µg/L	INAB	
	Dibenzo (ah) Anthracene		EO181	0.005		<0.005	µg/L	INAB	
	Fluoranthene		EO181	0.010		<0.010	µg/L	INAB	
	Fluorene		EO181	0.010		<0.010	µg/L	INAB	
	Indeno (123-cd) Pyrene		EO181	0.005		<0.005	µg/L	INAB	
	Phenanthrene		EO181	0.010		<0.010	µg/L	INAB	
	Pyrene		EO181	0.010		<0.010	µg/L	INAB	
	Drinking Water PAH Sum		EO181	0.010	0.1	<0.010	µg/L	INAB	

Signed : Domenico Giliberti 14/12/2017

Domenico Giliberti-Technical Manager

NOTES
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2.SPEC= Allowable limit or parametric value
3.OOS=Result which is outside specification highlighted as OOS-A
4.LOQ=Limit of Quantification or lowest value that can be reported
5.ACCRED=Indicates matrix accreditation for the test,a blank field indicates not accredited
6."*" Indicates sub-contract test

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email:info@elsltd.com

ISO 17025 INAB ACCREDITED TESTING
DETAILED IN SCOPE REG NO.111T

Contact Name	Brendan Goggin	**Report Number**	**120688 - 1**
Address	Cork City Council (Lee Rd) Laboratory, Waterworks,	**Sample Number**	120688/001
		Date of Receipt	29/11/2017
		Date Started	29/11/2017
Tel No		**Received or Collected**	Hand
Customer PO	507440 OG	**Date of Report**	14/12/2017
Quotation No	QN006611	**Sample Type**	Drinking Water
Customer Ref	P3		

CERTIFICATE OF ANALYSIS

TEST	ANALYTE	SUB	METHOD	LOQ	SPEC	RESULT	UNITS	ACCRED.	OOS
Ion Chromatography									
	Bromate		EW137	1.0	10	<1.0	ug/L	INAB	
LCMSMS-Acid Herbicides									
	236-Trichlorobenzoic Acid (TBA)		EO162	0.005	0.1	<0.005	ug/L	INAB	
	2,4 D		EO162	0.005	0.1	<0.005	ug/L	INAB	
	Bentazone		EO162	0.005	0.1	<0.005	ug/L	INAB	
	Bromacil		EO162	0.005	0.1	<0.005	ug/L	INAB	
	Clopyralid		EO162	0.005	0.1	<0.005	ug/L	INAB	
	Dichloroprop (24DP)		EO162	0.005	0.1	<0.005	ug/L	INAB	
	MCPA		EO162	0.005	0.1	<0.005	ug/L	INAB	
	Mecoprop (MCPP)		EO162	0.005	0.1	<0.005	ug/L	INAB	
	Trichlopyr		EO162	0.005	0.1	<0.005	ug/L	INAB	
LCMSMS-Glyphosate & AMPA									
	Glyphosate-LC		EO164	0.005	0.1	<0.005	ug/L	INAB	
LCMSMS-Pesticide Suite A									
	Chlorfenvinphos-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Atrazine-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Simazine-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Diflufenican-Triaz-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Pendimethalin-LC		EO 165	0.005	0.1	<0.005	ug/L		
	Propyzamide-Triaz-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Diuron-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Isoproturon-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Linuron-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
	Metaldehyde-LC		EO 165	0.005	0.1	<0.005	ug/L	INAB	
Metals-Trace									
	Aluminium		EW188	5.0	200	<5.0	ug/L	INAB	
	Arsenic		EW188	0.2	10	<0.2	ug/L	INAB	
	Cadmium		EW188	0.1	5	<0.1	ug/L	INAB	
	Chromium		EW188	1.0	50	<1.0	ug/L	INAB	
	Iron		EW188	20	200	<20	ug/L	INAB	
	Mercury		EW188	0.02	1	<0.02	ug/L	INAB	
	Manganese		EW188	1.0	50	<1.0	ug/L	INAB	
	Nickel		EW188	0.5	20	<0.5	ug/L	INAB	
	Lead		EW188	0.3	10	0.4	ug/L	INAB	
	Antimony		EW188	0.1	5	<0.1	ug/L	INAB	

Signed : ______________________________ 14/12/2017

Domenico Giliberti-Technical Manager

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ISO 17025 INAB ACCREDITED TESTING DETAILED IN SCOPE REG NO.111T

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Address	Cork City Council (Lee Rd) Laboratory, Waterworks,	Sample Number	120688/001
		Date of Receipt	29/11/2017
		Date Started	29/11/2017
Tel No		Received or Collected	Hand
Customer PO	507440 OG	Date of Report	14/12/2017
Quotation No	QN006611	Sample Type	Drinking Water
Customer Ref	P3		

CERTIFICATE OF ANALYSIS

TEST	ANALYTE	SUB	METHOD	LOQ	SPEC	RESULT	UNITS	ACCRED.	OOS
Metals-Trace									
	Selenium		EW188	0.2	10	1.4	ug/L	INAB	
	Boron		EW188	0.02	1	0.04	mg/L	INAB	
	Copper		EW188	0.003	2.0	<0.003	mg/L	INAB	
	Sodium		EW188	0.5	200	122.9	mg/L		
Micro-Colony Count @22DegC (Sub 5)									
	Colony Count @22DegC	*	Default	0		300	No/ml	YES	
Micro-Enterococci (Sub 5)									
	Enterococci	*	Default	0	0	0	No/100ml	YES	
Radioactivity-Alpha & Beta (Sub)									
	Gross Alpha	*	Default	0.050	0.1	<0.026	Bq/l	YES	
	Gross Beta	*	Default	0.5	1.0	<0.024	Bq/l	YES	
Titralab									
	pH		EW153	0.0	6.5-9.5	7.4	pH Units	INAB	
	Conductivity @20 DegC		EW153	25	2500	510	uscm-1@20	INAB	
Total Pesticides									
	Total Pesticides		Default	0.01	0.5	<0.010	ug/L		
Tritium (Sub)									
	Tritium (Sub)	*	Default	5	100	<5	Bq/l	YES	
VOC-DW-VOC									
	Benzene		EO025	0.1	1	<0.1	ug/L	INAB	
	1,2-dichloroethane		EO025	0.1	3	<0.1	ug/L	INAB	
	Tetrachloroethene		EO025	0.1		<0.1	ug/L	INAB	
	Trichloroethene		EO025	0.1		<0.1	ug/L	INAB	
VOC-THMs									
	Bromoform		EO025	1		<1.0	ug/L	INAB	
	Bromodichloromethane		EO025	2		<2.0	ug/L	INAB	
	Chloroform		EO025	1		<1.0	ug/L	INAB	
	Dibromochloromethane		EO025	1		<1.0	ug/L	INAB	
	Total THM (Calc)		EO025	5	100	<5	ug/L	INAB	

Signed : ______________________ 14/12/2017

Domenico Giliberti-Technical Manager

NOTES
1.This Report shall not be Reproduced except in full, without the permission of the laboratory and only relates to the items tested.
2.SPEC= Allowable limit or parametric value
3.OOS=Result which is outside specification highlighted as OOS-A
4.LOQ=Limit of Quantification or lowest value that can be reported
5.ACCRED=Indicates matrix accreditation for the test,a blank field indicates not accredited
6."*" Indicates sub-contract test

APPENDIX J – CONCEPTUAL BLOCK MODEL FOR GREENHILLS ESTATE AND NEMO RANGERS COMPLEX

Figure: Position of the Conceptual Block Model to the east of Kinsale Road Landfill Site/Tramore Valley Park

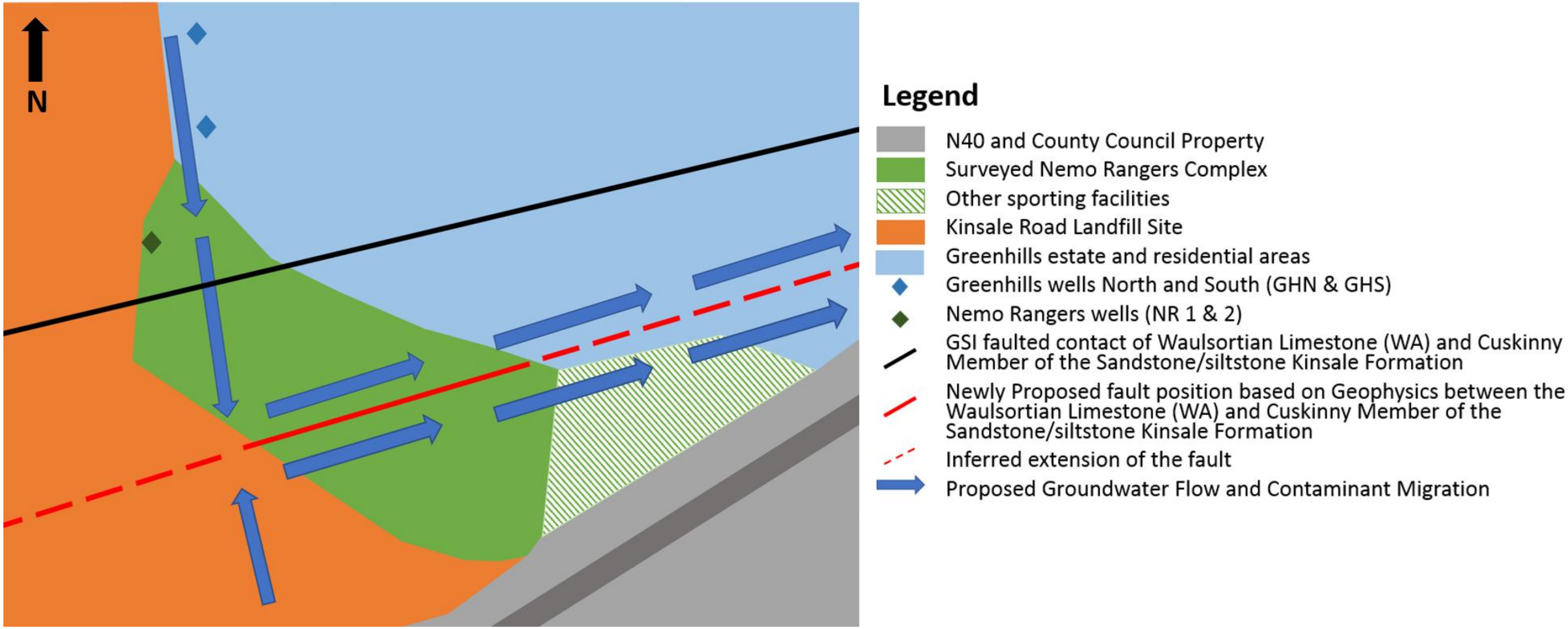

Figure: Conceptual Block Model - Enlarged