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1.0 INTRODUCTION

SLR Consulting Limited (SLR), in association with AIS Environmental Limited, has been appointed by WasteServ Malta Limited (WasteServ) to prepare a Hydrogeological Risk Assessment in support of an application for the development of a non-hazardous landfill facility at Ghallis ta'Gewwa, on the northern coast of Malta. For ease of reference throughout this document the site is referred to as "Ghallis", or the "site".

The proposed development is subject to the EIA Regulations of 2001, which form Article 60 of the Development Planning Act. As the Project is listed under Category 1 of Schedule 1 of the Regulations, it requires a full EIA and the preparation of an Environmental Impact Statement (EIS). This has been submitted.

SLR is one of the UK's leading multi-disciplinary environmental consultancies specializing in waste management. The Company has undertaken over 250 hydrogeological risk assessments for landfill sites and related waste management facilities and has been appointed by the UK Environment Agency to assist in the development of industry guidance relating to groundwater risk assessment methodology.

This report sets out the Hydrogeological Risk Assessment that has been prepared in support of this application.

2.0 SITE SETTING

The following sources of hydrological, geological and hydrogeological information have been utilised to establish the site setting:

- Precipitation data obtained from National Statistics Office, Malta[1],

- Geological Map of the Maltese Islands, Oil Exploration Directorate, Office of the Prime Minister, Malta 1993.

- A mineral feasibility and economic assessment[2] carried out by an island expert (Alex Torpiano), based on the above noted site investigation data completed by SLR Consulting Limited.

- A site visit on the 16th June 2004 to assess the geomorphologic features in the immediate vicinity of the site and a hydrogeological reconnaissance site survey, also completed in June 2004 by a SLR hydrogeologist.

- Published reports and available geological, hydrological and hydrogeological information for the Maghtab Landfill site and surrounding area, together with details regarding estimated evapotranspiration and runoff [3,4].

- A geological investigation undertaken at the proposed site by SLR Consulting Limited on behalf of WasteServ Malta Limited (WasteServ) [5]. Details are summarised below.

The site investigation was undertaken in two phases and the scope was agreed with Malta Environment and Planning Authority (MEPA) and the Malta Resource Authority (MRA) prior to the start of drilling.

- The key objectives of the geological site investigation were to:

  – Provide factual geological information regarding the Ghallis site.

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[1] National Statistics Office, Malta, 2002: *Environment Statistics.*

[2] Prof. Dr. Alex Torpiano, May 2004: *Economic Feasibility of Extracting Mineral Resources from the Site Ghallis Ta' Gewwa New Engineered Landfill Site Proposal*

[3] Scott Wilson: *Development of Rehabilitation Strategies Maghtab, Qortin and Fulija Landfills.* Stage II Final, February 2003, report completed for Ministry of Resources & Infrastructure. This report includes the results of a site investigation completed to assess the geological conditions of the Maghtab Landfill site. This investigation comprised the installation of 6 No. boreholes (MBH1 to MBH6) that were completed as groundwater monitoring installations (wells).
Scott Wilson: *Development of Rehabilitation Strategies Maghtab, Qortin and Fulija Landfills.* Stage III Final, March 2003, report completed for Ministry of Resources & Infrastructure.

[4] Mario Saliba, May 1999: *Environmental Impact Assessment of the Maghtab Landfill on the Marine Environment* Unpublished BSc dissertation at The University of Malta.

[5] SLR Consulting Limited, February 2004: *Proposed Waste Management Facility Site Investigation, Ghallis T Gewwa, Factual Report*

  - Undertake an assessment of the quality of the limestone resource within the footprint of the site.

  - Accurately located geological boundaries.

  - Locate the position of the groundwater table beneath the site.

- The first phase comprised the drilling of 5No boreholes (boreholes BH03/02 to BH04/07) between 27th August 2003 and 2nd January 2004.

- A factual report detailing the site investigation findings was then submitted to MEPA and MRA[5].

- A second series of 6No. boreholes (BH's 04/08 to BH04/13) were installed at the site between 14th April and 3rd May 2004, and the investigation was fully audited by an independent assessor (Harrison Group, UK) approved by MEPA and MRA.

- The borehole locations were agreed with WasteServ following meetings with MEPA and MRA.
- The boreholes were drilled to a depth near sea level in order to intercept the maximum vertical thickness of rock within the footprint of the excavation area required for the proposed Ghallis landfill development, and the groundwater within the Mean Sea Level aquifer. Depths range from 30 to 50m below ground level.

- The drilling operations and logging of core samples was undertaken by AAN Terracore Company Limited of Malta. All the boreholes were continuously cored at a diameter of 80mm, and the core was logged by a professional Maltese geologist.

2.1 Site Location

The site is approximately 2km to the north of Naxaar and 2km east of Qawra along the northern coast of Malta, as shown on Drawing No.1.

The site is located in a semi rural setting. A number of built developments detract from the rural nature of the area. The most notable of these is the Maghtab Landfill, although the Coast Road (Route 1) and several settlements in the general vicinity also form notable features.

In the general vicinity of the site the land rises steadily from the coast to a level of around 30-50 above sea level (mASL) adjacent to the site. Further to the south the land rises up steeply to over 100m ASL along the Victoria Lines, which are located over 1 kilometre from the site. The land also rises steadily to the west, reaching a high point of around 116mASL at Gebel Ghawzara, around 2 kilometres from the site.

The area to the east of the site is occupied by the former Maghtab landfill. This steep sided, and relatively flat topped feature rises to over 90mASL. The steep sideslopes, particularly along the western edge facing the development site, are largely unvegetated. This is partly due to the steepness of some of the slopes, together with the frequent disturbance and the lack of soils. Proposals are being developed by Wasteserv for the restoration of the former Maghtab landfill. To the east of Maghtab the land is mainly in agricultural use.

To the north of the development site the land falls steadily, from around 30-40mASL, down to the coast. The Coast road (Route 1) runs through this area, generally following a route very close to the coastline.

To the west of the development site the land is mainly in active agricultural use, although some of the fields are disused and/or have been given over to trapping or shooting. A number of farms and occasionally occupied properties are located to the west of the site, sometimes clustered into small settlements.

The Coastline Hotel is located a minimum of around 700m to the west of the site with further residential properties beyond it to the west and the south. Qawra, on the far side of Salina Bay is located over 1km from the development site.

To the south much of the land is again agricultural, although there are a far greater number of properties including small settlements such as Ghallis, some 600m from the proposed site.

2.2 Site Description

A site plan is shown in Drawing No.2. The northern half of the site consists predominantly of undisturbed land which either consists of agricultural fields or, in the case of the land adjacent to Maghtab, consists of unused areas of largely natural habitat. The development site also includes the western edge of the former Maghtab landfill where the proposed infilling or engineering works will extend part way up the external slopes of the former landfill.

The northern part of the development site extends from a low point of around 30mASL at the northern and north-eastern edges of the area, up to high point of around 50mASL towards the central part of the site. The northern part of the development site is located on the eastern slopes of a shallow hill and therefore the land predominantly falls to the south-east, east and north east. These slopes disappear beneath the Maghtab Landfill.

The higher ground located in the northern part of the development site is mainly in active agricultural use, although a number of the fields are now used for trapping. The fields are typically separated by dry stone walls. To the east, adjacent to Maghtab the slopes are generally steeper, the soil cover lower and this area retains much of its natural characteristics.

In the central part of the development site the land again slopes to the south east, east and north east. Although much of the central area is divided into fields, separated by dry stone walls, some of these fields are fallow or have been abandoned and have naturally regenerated.

There are two small farms within the northern half of the site, together with a number of smaller buildings that are not believed to be inhabited. Both properties are understood to be small farms and both are located relatively close together, and are close to Maghtab landfill. Both properties are accessed from the track running through the larger farms located to the west of the development site. Both properties would be removed by the proposed development.

The southern part of the development site consists of the existing main access road to the former Maghtab Landfill, which is currently used to provide access to the temporary Zwerja Disposal areas, and will provide access for the reclamation of the Maghtab Landfill. The road also provides access to a private waste management facility.

No significant works are proposed in the southern part of the development site. The weighbridges and office, together with the access road, would continue to be used, to provide access to the proposed waste facilities. The project area has been drawn to include this area in order that all elements of the development from the public highway are included.

2.3 Proposed Development and Landfill Design

The proposed development is for a non-hazardous landfill with a capacity of 1.7Mm^3 (7 years). A hazardous landfill and hazardous waste treatment facility are also proposed.

The project would contain the following elements:

- Continued use of the existing access to the former Maghtab landfill, together with the weighbridge office and twin weighbridges;

- Excavation of 1.2 Mm^3 of limestone in order to create the footprints for the landfills, of which at least half will be utilised on site and up to half will be exported from site;

- Creation of a containment landfill for non-hazardous waste in the void formed by limestone extraction with a capacity of 1.7Mm^3 to be filled at a rate of around 250,000 tonnes per annum over a period of 7 years. The site would be restored to a mixture of agricultural land and nature conservation afteruses;

- Creation of a containment landfill for hazardous waste with a capacity of 100,000m^3 to be infilled at a rate of around 5,000 cubic metres per annum over a period of 20 years;

- Construction of a hazardous waste treatment facility for the storage and treatment of up to 13,000 tonnes per annum of hazardous waste; and

- Construction of central facilities for the management of landfill gas and leachate from the landfill facilities.

All waste to be handled by the facilities would be generated from within the Maltese Islands. Extraction of the stone to prepare the non-hazardous landfill would commence in time for the landfill to receive waste in mid-late 2005. It is envisaged that the hazardous waste facilities would be constructed during 2005 or 2006.

In addition to requiring planning permission for the proposed development, an IPPC Permit for the landfill operations will be required.
This hydrogeological risk assessment considers the non-hazardous landfill development.

The non-hazardous landfill will be developed as an engineered containment facility in a phased manner. The proposed basal lining system will comprise the following (from top to bottom):

- 2mm HDPE textured geomembrane.
- 100mm thick mineral liner with a minimum permeability $5x10^{-11}$ m/s (Trisoplast or similar).
- 400mm thick screen/crushed material with maximum permeability of $1x10^{-7}$m/s.
- Minimum 300mm lining formation layer.

The basal lining system will extend 3m vertically around the perimeter of the cells and will be overlain by the leachate collection system as described below.

- The proposed sidewall lining system will comprise the following (from top to bottom):

  - 2mm HDPE textured geomembrane.
  - 2000mm thick screen/crushed material with maximum permeability of $1x10^{-7}$m/s.

- A leachate drainage blanket comprising 500mm of clean aggregate of minimum permeability of $1x10^{-3}$m/s, with nominal 200mm diameter perforated HDPE pipework, will be installed over the basal area of the landfill and a minimum of 3m horizontally up the sideslope. The base of each phase would fall at a gradient of 1:50. A leachate extraction well and two leachate monitoring points will be installed in each phase.

- Upon completion of filling the wastes will be capped. The proposed capping and restoration profile is as follows (from top to bottom):

  - 1000mm thick restoration soils.
  - Geocomposite drainage layer.
  - 1.5mm Very Flexible Polyethylene (VFPE) geomembrane.
  - 300mm thick stabilisation layer.

- During and after landfilling, the leachate head in the landfill will be controlled in accordance with the Landfill Permit conditions that will apply. It is anticipated these will require that the leachate level is maintained a maximum of 1m above the basal liner.

2.4 Hydrology

2.4.1 Rainfall

Published rainfall data for the period 1841 to 2000 are summarised below in Table 1, and presented graphically in Figure 1.

Review of the rainfall data indicates the following:

- Rainfall is highly variable from year to year. The mean rainfall for the period 1841 – 2000 was 501.76mm. The maximum recorded annual rainfall for the period 1841 to 2000 was 1009.4mm, in 1951, while the minimum recorded annual rainfall over this period was 224.3mm in 2000.

- The wettest month is typically December, with an average rainfall of 93.69mm. The driest month is July with an average monthly rainfall of only 0.57mm.

TABLE 1: RAINFALL (1841 - 2000)

	Mean	**Minimum**	**Maximum**	**Standard Deviation**
Jan.	83.56	9.14	225.60	49.24
Feb.	54.58	0.00	187.90	41.00
Mar.	38.90	0.00	172.97	32.98
Apr.	22.88	0.00	107.95	21.59
May	9.64	0.00	82.04	12.62
Jun.	2.30	0.00	34.54	5.07
Jul.	0.57	0.00	28.70	2.71
Aug.	5.20	0.00	155.50	15.78
Sep.	31.78	0.00	235.20	40.57
Oct.	75.62	0.00	586.23	72.46
Nov.	81.17	1.50	292.90	53.43
Dec.	93.69	6.10	353.31	61.92
Total	501.76	224.3	1009.40	141.96

FIGURE 1: MONTHLY RAINFALL (1841 – 2000)

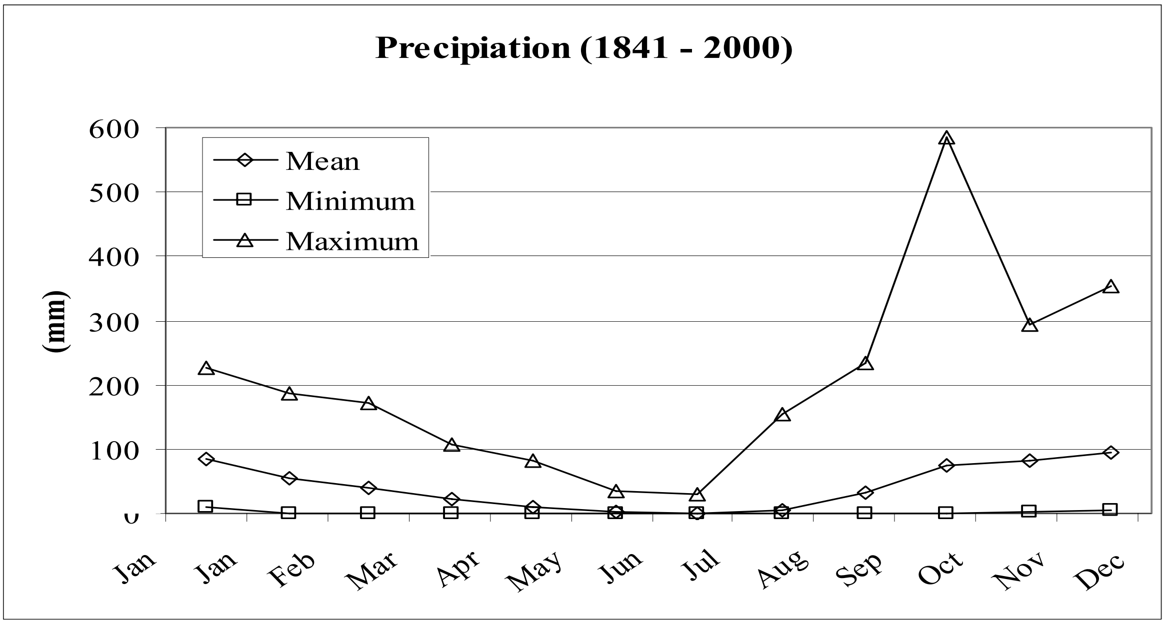
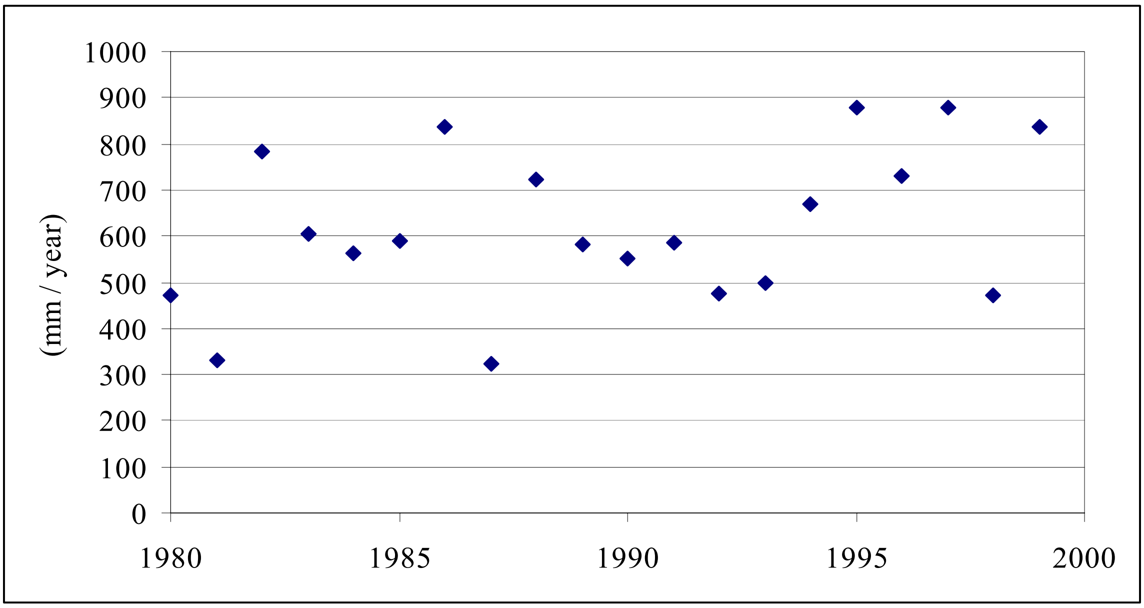


FIGURE 2: ANNUAL RAINFALL (1980 – 1999)



Note: Data Source from Meteorological Office Luqa.

- The majority of rainfall takes place between October and March with c.85% of the average annual precipitation for the period 1841 – 2000 falling during this part of the year.

- Even during the dry season (April to September), rainfall may be significant, with maximum recorded monthly rainfalls total for August and September of 155.5 and 235.2mm respectively.

- Rainfall events are typically characterised by single storms of relatively short duration. This often results in runoff taking place over a short period, during and immediately following the storm event.

Available information regarding the average water balance of the Maltese Islands indicates that approximately 6% of rainfall runs off to the sea, while c.65 to 80% is lost to evapotranspiration. Potential evapotranspiration also greatly exceeds total rainfall.

The significant evapotranspirational losses reflect the relatively high temperatures and windy conditions experienced by Malta. The remaining rainfall will form groundwater recharge after meeting soil moisture deficits. It is noted that the site specific rainfall - runoff characteristics will be dependent on the hydraulic conductivity and thicknesses of the soils and underlying bedrock.

2.4.2 Surface Water Features

There are no permanent surface water features within the site or adjacent surrounding area. This reflects the small catchment size, climatic conditions, and the high hydraulic conductivity of the limestone bedrock that underlies the site and surrounding area.

The Central Malta Local Plan (Local Plans Unit, Planning Authority, 2002) indicates that the proposed site is located at the top of three small surface water drainage catchments. The western half of the site lies within a westerly draining catchment that discharges into Salina Bay. The northern part of the site drains northward to the coast, just to the east of Ghallis Point. The eastern part of the proposed site lies within an easterly draining catchment, which is dominated by the Maghtab Landfill. Drainage from the proposed site eastwards to the sea is therefore effectively prevented by the Maghtab landfill.

The very small and localised extent of the three catchments (the largest of which is approximately 48 hectares in size), together with the fact that the proposed landfill lies in the upper parts of each catchment, results in very limited potential of flooding risk. An approximate estimate of surface water runoff volumes from the largest catchment within which the site is located is summarised below:

- Average Rainfall: 502mm/year
- Area of western catchment including site: c.477,000m^2
- Average Runoff: 6% of annual rainfall
- Estimated average annual run-off = 477,000 x 502/1000 x 0.06

  = c.14,370m^3/year

Given that the site represents 4% of the catchment area, it is considered very unlikely that the site will impact significantly on the surface water runoff or groundwater infiltration volumes within this catchment. In deed, it is proposed that all surface water runoff from the landfill cap and perimeter ditches will be directed, via peripheral drainage ditches to a storm water retention/infiltration pond, to be located at the site. The retention/infiltration pond will be designed and sized so that all the clean surface water is able to recharge through the base and sides of this structure into the unsaturated limestone bedrock underlying the site, thereby ensuring no surface water runoff is able to leave the site. The infiltration of all effective runoff (i.e. precipitation excluding evapotranspirational losses) via this approach will ensure that the hydrogeological regime of the site is not altered significantly from current conditions, and recharge will remain effectively unchanged, if not improved.

2.4.3 Surface Water Quality

There are no surface water quality data for the site or immediate surrounding area.

2.4.4 Surface Water Abstractions

There are no surface water abstractions in the vicinity of the site.

2.5 Geology

The geological setting of the site and immediate surroundings are described in the following sections.

2.5.1 Stratigraphy

The geological setting of the site and surrounding area is shown in the excerpt of the published geological map for Malta, as presented in Drawing No. 3. A geological cross section is shown in Drawing No. 4. The stratigraphy of the bedrock outcropping at the site and in the surrounding area is summarised in Tables 2a and 2b, below.

The geological site setting can be summarised as follows:

Drift Geology

The development of soils on site is both patchy and limited. This is indicated by the shallow depth of the bedrock, ranging between 0 and 1.7m below ground level within the site investigation boreholes.

Two distinct soil types are present on the site. These can be summarised as follows:

- The Xaghra Soil Series is represented by very shallow, red, heavy textured (clays and clay loam known as Terra Rossa) decalcified soils with a strong subangular to angular blocky structure. This soil type is associated with the Lower Coralline Limestone Formation.

- The L'Inglin Complex are a strongly terraced man-made soil of pale brown to red, shallow to moderately deep, light to heavy textured soil. This soil type is associated with the Lower Coralline Limestone and Lower Globigerina Limestone.

Solid Geology

The stratigraphy of the bedrock at the site and in the surrounding area is summarised in Tables 2a and 2b, below.

TABLE 2a: GEOLOGICAL SETTING

	Formation	Member	Proven Thickness at Site[6] (m)	Geological Description (based on Borehole Logs from Site Investigation completed by SLR in 2004)
Recent	Made Ground, Soils & Overburden	-	0 – 7.7	Brown top soil and fill, including loose stone material (Globigerina Limestone).
Miocene	Globigerina Limestone	Lower Globigerina Limestone	0.4 – 9.8	Pale cream to yellow LIMESTONE (packstones and wackestones). Moderately strong with a fine to medium grain size. Although of limited exposure at the site there is some outcrop to the north-east of the site near the Ghallis Tower. Identified in boreholes BH03/3, BH04/9, BH04/12 and BH04/13. Depth at top of bed ranges from approximately 40m to 30masl and the depth of the base of bed ranges from approximately 37m and 24masl. Also identified in borehole MBH3, with thickness of 2m, and possibly down-faulted against Lower Coralline Limestone.
Oligocene	Lower Coralline Limestone	Il-Mara Member	0.8 - 1.2m	Brown or grey recrystallised LIMESTONE. At the site the member is moderately strong, weathered and moderately fissured and has poor rock quality designation values (RQD). Identified in boreholes BH03/2 and BH03/3. Depth at top of bed ranges from approximately 30m and 29.5m and base of bed at 28.8masl in both holes.
		Xlendi Member	6 - 11.5m	Light brown LIMESTONE (massive to laminated fossiliferous calcarenite). Moderately strong with a very coarse grain size. Slightly fissured and has excellent RQD values (frequently 100%). Found in all boreholes except BH1A. Depth at top of bed ranges from approximately 47.5m to 24.2masl and depth of base of bed ranges from approximately 37.9 to 16masl.
		Attard Member	16 – 35.7m	White to light yellow LIMESTONE. Very coarse grain size and classed as weak to moderately strong. Composed predominantly of white algal fragments and algal rhodoliths. Poorly fissured with excellent RQD values (frequently 100%). Found in all boreholes. Depth at top of bed ranges from approximately 37.9m to 16masl and depth of base of bed ranges from approximately 37.9 to 16m asl and base of bed reached in one hole only (BH04/8) at 28.2masl.
		Maghlaq Member	5.8 – 6.8m	White to light yellow LIMESTONE. Massive bedding, very fine grained and weak to moderately weak, recrystallised in places. Solid core recovery and recovery figures range from poor to moderate. Found only in boreholes BH04/10 and BH04/8. Depth at top of bed ranges from 8m to 2.8masl and the base was not penetrated.

[6] As shown in the boreholes constructed during specific site investigations, detailed in Section 2.

The geology within the boreholes installed around the perimeter of the Maghtab landfill during the site investigation in 2002, is provided below in Table 2b.

TABLE 2b: GEOLOGICAL SUMMARY

Borehole No.	Depth (mbgl)	Strata
MBH1	GL to 3 3 to 40	Fill / Construction Material Coralline Limestone
MBH2	GL to 71	Coralline LIMESTONE
MBH3	GL to 5 5 to 8.5 8.5 to 10.5 10.5 to 50	Fill / Construction Material Coralline LIMESTONE Globigerina LIMESTONE Coralline LIMESTONE
MBH4	GL to 1.5 1.5 to 15	Overburden – Sand Coralline LIMESTONE
MBH5	GL to 0.5 0.5 to 20	Overburden – Sand Coralline LIMESTONE
MBH6	GL to 57	Coralline LIMESTONE

2.5.2 Structure

The 1:25,000 published geological map (Drawing No. 3), and site specific borehole logs and geological mapping, indicate the following with regard to structural geology:

- An E-W trending fault with a substantial down throw to the north may be present entering the western side of the proposed site.

- Minor faults are known to be common in this area of Malta and often comprise a conjugate set with a general north-south and east-west orientation.

- The geological strata are approximately horizontally bedded with a gentle regional dip to the north at between 2 and 3^{o}. This shallow geological dip is indicated by the cross section, as shown in Drawing 4.

- The borehole logs and observations during drilling indicate that discontinuities (fractures and joints) and solution type (karst) features are present within the limestone bedrock below the site, based on the following:

- The partial or complete loss of drilling fluid returns at various depths during drilling of the site boreholes. A summary of drilling fluid returns in relation to approximate depths in the boreholes, which were installed during the SLR site investigation, are summarised below:

BH No.	Full Returns (metres below ground level)	Partial Returns (metres below ground level)	Lost Returns (metres below ground level)
1A	0.0 - 15.75 (full depth)	-	-
03/2	21.5 – 30.0 (full depth)	20.0 – 21.5	0.0 – 15.5 18.5 – 20.0
03/3	0.0 – 24.5	-	24.5 – 29.7 (full depth)
03/4	0.0 – 30.88 (full depth)	-	-
03/5	8.5 – 27.0 30.0 – 33.0	-	27.0 – 30.0 33.0 – 50.2 (full depth)
03/7	0.0 – 35.0	-	35.0 – 40.0 (full depth)
04/8	0.0 – 22.5	-	22.5 – 35.0 (full depth)
04/9	0.0 – 10.0	-	10.0 – 39.55 (full depth)
04/10	0.0 – 21.0	-	21.0 – 40.8 (full depth)
04/11	0.0 – 25.0	-	25.0 – 35.9 (full depth)
04/12	0.0 – 10.0	-	10.0 – 39.0 (full depth)
04/14	0.0 – 2.0	-	2.0 – 36.0 (full depth)

- An indurated breccia, representing a palaeosol or cavern fill, was noted in BH03/7 between 35 and 37m below ground level.

- Visual observations of the rock core recovered from the site investigations, thereby allowing quantification of fracture frequency and Rock Quality Designation (RQD). These indicate fracture frequency typically ranging between 0 and 2 fractures per metre of core.

2.6 Hydrogeology

2.6.1 Recharge Mechanisms

The conceptualised model for groundwater recharge in the vicinity of the site and surrounding area is as follows:

- Precipitation is the only source of groundwater recharge (i.e. there are no other significant sources such as leaking municipal drainage or water supply pipes that could potentially recharge the underlying aquifer with desalination waters or irrigation water derived from outside the catchment).

- Average effective groundwater recharge for the Maltese Islands is estimated to be c.25% of annual rainfall (Debono, 1988). Given an average annual rainfall for the period 1841 to 2000 of 502mm, this indicates an average effective groundwater recharge of c.125mm per year.

- In the vicinity of the proposed site and surrounding areas to the west, north and south, the limestone bedrock is located at or just below surface under a relatively thin mantle of soil and overburden. Effective recharge rates (rainfall – evapotranspiration – soil moisture deficit – surface water runoff) are expected to be similar or higher than the average. This is because of the shallow topographic gradient across the site, and the soil moisture deficits will be smaller than other areas of the island where soil and overburden thickness are greater. Infiltrating rainfall will move downwards through the unsaturated zone of the Limestone bedrock, ultimately joining the groundwater in the underlying aquifer, as described below.

- Effective recharge rates in the majority of the existing Maghtab Landfill footprint are expected to be negligible, given the substantial adsorptive capacity of the waste deposited at the landfill site. Also, any rainfall infiltrating into the waste mass is unlikely to be form groundwater recharge, given the combustion that is taking place across large parts of the landfill site, as confirmed by the thermal investigations completed by others[7].

2.6.2 Aquifer Characteristics

The available information indicates the following with regard to aquifer characteristics:

- The primary aquifer below Malta is principally developed within the Lower Coralline Limestone Formation or the Globigerina Limestone Formation.

[7] Scott Wilson, February 2003: *Development of Rehabilitation Strategies Maghtab, Qortin and Wied Fulija Landfills.* Stage II Final Report completed for Ministry of Resources & Infrastructure.

- The aquifer is represented by a thin freshwater lens that overlies brackish/saline groundwater. This is locally known as the 'Mean Sea Level Aquifer', given that the groundwater elevations lie just above sea level.

- The limited saturated thickness of the aquifer, and the low groundwater elevation relative to sea level reflect the following factors:

- The relatively small size of the island of Malta;

- The relatively low effective groundwater recharge;

- The relatively high secondary permeability of the limestone bedrock.

- The freshwater "floats" on the more saline waters by virtue of its lower density and owes its existence to precipitation that percolates through the ground, adding more freshwater (recharge) to this underground storage system that can be dissipated by direct discharge to the sea at the coastline or by abstraction.

- As a general rule, the saturated thickness of the freshwater lens is greatest below the central portions of the island, while thinning towards the coast as a result of the freshwater-seawater transition zone (or interface) extending at depth below the coastal areas. Localised variation in orientation, location and depth of the freshwater/seawater interface will be controlled by a number of site specific conditions including aquifer hydraulic conductivity, degree of faulting and karst development, pumping rates and depths of abstraction boreholes and wells, as well as the effective groundwater recharge rates from precipitation throughout the catchment.

- Heavy abstraction from this aquifer has deteriorated its quality, due to upcoming of more saline waters and/or seawater intrusion. For this reason, a considerable part of the abstraction (over 50%) has gradually been replaced by supplies from reverse osmosis desalination plants.

- In the vicinity of the site, the Mean Sea Level Aquifer is developed within the Lower Coralline Limestone Formation. The hydraulic characteristics (i.e. the ability of the bedrock to transmit and store groundwater) are principally controlled by the secondary hydraulic conductivity of the limestone strata. This is associated with discontinuities (faults, fractures, joints and bedding planes), in addition to karstic solution features where present within the limestone strata.

- The hydraulic characteristics of the Lower Coralline Limestone Formation bedrock in the vicinity of the site are summarised in Table 3, below.

TABLE 3: HYDRAULIC CHARACTERISTICS OF THE LOWER CORALLINE LIMESTONE FORMATION

Formation	Primary Hydraulic Conductivity (m/s)	Secondary Hydraulic Conductivity (m/s)	Effective Porosity (%)
Lower Coralline	2.4×10^{-10} to 2.27×10^{-6}	2.0×10^{-4} to 1.5×10^{-3}	10 to 15

Note:
1. Primary hydraulic conductivity and effective porosity values are taken from Martin (1970)[8]
2. Secondary hydraulic conductivity values based on predicted effective field scale hydraulic conductivity values after an assessment of transmissivity measurements (i.e. flow rate transmitted through a unit width of aquifer under a unit hydraulic gradient) within the Maghtab area[9].

2.6.3 Groundwater Levels and Flow

A potentiometric map of the Mean Sea Level Aquifer produced by BRGM (1991) and reproduced in Axiak and Sammut (2002)[10], has previously been used to assess groundwater level and flow conditions in the vicinity of the Maghtab Landfill site[11]. Given the proximity of the proposed Ghallis Landfill, this information has therefore been utilised to assess conditions below the proposed site. This information indicates the following:

- Groundwater levels in the vicinity of the Ghallis site range between 0m above datum at the coast, and 0.75m above datum to the immediate south of the proposed site boundary.
- Given that the minimum basal elevation of the proposed landfill (Phases 2, 3 and 4) will lie at about 16m above sea level, this indicates a minimum unsaturated zone thickness of approximately 14 to 15m.
- Groundwater flow direction below the site and adjacent area is north towards the coast.
- The hydraulic gradient ranges between 0.0006 and 0.00083.

The groundwater levels and flow direction are considered to reflect the slightly higher groundwater elevations below the middle of the island, where the freshwater lens is at its thickest, compared to the elevations adjacent to the coastline.

It is noted that on a local scale the groundwater flow direction could be effected by groundwater abstractions in the immediate vicinity of the site. However, it is considered that

[8] Martin, 1970: *Interim Report on the Hydrology of Malta,* Attiga Consortium
[9] Guttierez, 1994: *Evaluation des Resources en Eau Souterraine de l'Ille de Malta, BRGM, Orleans, France*
[10] Axiak V. and Sammut, A. 2002: *The Coast and Freshwater Resources.* In: *State of the Environment Report for Malta , 2002.* Ministry of Home Affairs and the Environment, August 2002
[11] Scott Wilson, March 2003: *Development of Rehabilitation Strategies Maghtab, Qortin and Wied Fulija Landfills.* Stage III Final Report completed for Ministry of Resources & Infrastructure.

these will not have any significant impacts on the general groundwater flow direction due to the likely low yields of these private wells. It is also noted that large abstraction rates from these private wells are extremely unlikely given that high pumping rates and drawdown levels are likely to cause upcoming of the freshwater-seawater interface, thereby resulting in a significant increase in groundwater salinity of the pumped water making it unsuitable for water supply requirements.

Groundwater levels recorded on 27th October 2004 in the monitoring boreholes installed by SLR ranged between 1.32mASL (BH03/2) and 0.73mASL (BH03/4).

2.6.4 Groundwater and Marine Quality

A review of available groundwater and marine water quality data, collected during previous assessments of the Maghtab Landfill site[12], has been undertaken in order to provide an assessment of groundwater and marine water quality in the vicinity of the proposed site. This information is summarised below:

- Six groundwater samples were collected from the monitoring boreholes (MBH1 to MBH6, inclusive) that were installed during the site investigation completed in 2002 by Scott Wilson[3]. During this investigation, groundwater samples were also taken from three nearby agricultural abstractions (Water Services Corporation Registration Nos 2026, 2027 and 3308) and the nearest public water supply pumping station to the proposed site, located at Wied il-Ghasel. All monitoring locations are shown on Drawing No. 5.

- The groundwater samples from the monitoring boreholes were taken using a submersible pump, after purging of three well volumes before sampling, in order to ensure that the sample was representative of that within the Mean Sea Level Aquifer. Samples from the agricultural abstractions were collected, where possible, using existing pumping equipment. Alternatively a stainless steel bucket was used. The groundwater from Wied il-Ghasel was sampled using the dedicated sampling point within the pumping station. The samples were stored in dedicated sample bottles, and the samples for metals analysis were filtered on-site before preservation.

- The marine water sample (MMW1) was taken from accessible coastline location with a maximum water depth of 0.5m at Qalet Marku Bay, and the sample was stored and preserved as necessary. The sample location is shown in Drawing No. 5.

- All water samples were analysed in the UK by Alcontrol Geochem in Chester, a UKAS accredited laboratory. Bacteriological analyses were analysed by Malta National Laboratories in Valetta. The storage, transportation and preservation of all samples was as per standard protocols, including the use of cool boxes containing frozen ice packs and storage in a refrigerator in Malta prior to dispatch.

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[12] Scott Wilson, February 2003: *Development of Rehabilitation Strategies Maghtab, Qortin and Wied Fulija Landfills.* Stage II Final Report completed for Ministry of Resources & Infrastructure.

- Groundwater quality data collected during an earlier investigation of the Maghtab Landfill site[13] from agricultural abstractions (Water Services Corporation Registration Nos 2026, 2027, 2130, 2041 and 2604) have also been used to assess hydrogeological conditions for this Environmental Impact Assessment. The locations of these agricultural abstractions are shown on Drawing No. 5.

All the above noted monitoring data are included within Table 4a, below.

[13] Mario Saliba, May 1999: *Environmental Impact Assessment of the Maghtab Landfill on the Marine Environment* Unpublished BSc dissertation at The University of Malta.

TABLE 4a: GROUNDWATER AND MARINE WATER QUALITY IN THE VICINITY OF GHALLIS

Sample Type	Location	Arsenic Low Level by AA (ug/l)	Calcium (mg /l)	Cadmium by ICP-US4(ug/l)	Chromium by ICP-USN (ug/l)	Copper by ICP-USN (ug/l)	Mercury Low Dutch Target AA (ug/l)	Iron by ICP-USN (ug/l)	Manganese by ICP-USN (ug/l)	Nickel by ICP-USN (ug/l)	Lead (ug /l)	Selenium (ug/l)	Zinc by ICP-USN (ug/l)	Magnesium (mg/l)	Chloride (mg/l)	COD On Unfiltered Sample (mg/l)	Kjeldahl Nitrogen on Water (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)	Sulphide In Water (mg/l)	Sulphate (soluble) (mg/l)	Ammoniacal Nitrogen as NH4-N (mg/l)	Potassium (mg/l)	Sodium (mg/l)	Total Suspended Solids (mg/l)	Total Phenols HPLC (mg/l)
	EU DWS	10	-	5	50	2000	1	200	50	20	10	10	-	-	250	-	-	50	-	-	250	0.39	12	200	-	-
BH's	MBH1	<0.05	200	0.05	0.77	12.70	<0.05	<100	4.90	3.30	1.10	1	47.50	170	2360	55	<20	2.80	<0.08	<0.1	422	<0.2	74.3	1200	18	0.01
	MBH2	<2	118.8	<0.4	11	<5	<0.05	350	<1	<10	<50	<50	<5	56.61	899	15	<20	7.50	<0.08	<0.1	109	<0.2	26.4	382.5	<10	<0.01
	MBH3	<0.05	237	<0.05	0.73	25.10	<0.05	<100	6	3.40	1.50	<0.5	42.20	401	5860	106	<20	1.10	<0.08	<0.1	891	0.2	148.5	2400	156	<0.01
	MBH4	<0.05	342	0.07	<0.05	66.9	<0.05	<100	5.90	6.40	1.70	<0.5	25.10	1030	16235	214	<20	<0.3	<0.08	<0.1	2227	0.2	472.5	6825	112	<0.01
	MBH5	<0.05	394	<0.05	<0.05	97.10	<0.05	<100	84.5	12.50	2.50	<0.5	25.40	1380	22251	322	<20	<0.3	<0.08	<0.1	3040	0.7	652.5	9300	178	<0.01
	MBH6	<0.05	132	<0.05	0.16	11.80	<0.05	<100	2.2	1.20	0.60	<0.5	10.80	160	2713	48	<20	1.10	<0.08	<0.1	395	<0.2	76.5	1200	22	<0.01
Agric. BH's	2026	<0.05	155	0.16	0.08	8.56	<0.05	<100	0.70	4	1.46	<0.5	60.80	169	3068	84	<20	4.30	<0.08	<0.1	448	0.3	81	1440	<10	-
	2027	<0.05	116	0.11	<0.05	3.04	<0.05	<100	3.10	1	0.48	<0.5	608?	96.62	1723	21	<20	7.90	<0.08	<0.1	245	0.2	51	870	<10	-
	3308	<0.05	159	0.06	<0.05	2.94	<0.05	<100	0.50	1.70	0.57	<0.5	20.80	168	3007	23	<20	5.10	<0.08	<0.1	452	0.2	72	1470	<10	-
PWS	WIED IL-GHASEL PS	<2	84.7	<0.4	12	<5	0.10	<1	<1	<10	<50	<50	160	32.63	532	228	<20	22.30	<0.08	<0.1	95	0.2	12.9	270	<10	-
Sea Water	MMW1	<0.05	329	<0.05	<0.05	97	<0.05	<100	0.70	5.80	0.40	<0.5	24	1480	22673	389	<20	<0.3	<0.08	<0.1	3036	1.1	630	9600	160	<0.01

1. Data Source: Scott Wilson, March 2003
2. Sample Locations are shown on Drawing No.5.

TABLE 4a (CONTD.): GROUNDWATER AND MARINE WATER QUALITY IN THE VICINITY OF GHALLIS

Sample Type	Location	Electrical Conductivity (mS/cm)	Dissolved Oxygen (mg/l)	pH Value In Water	Total Dissolved Solids (mg/l)	Alkalinity Total as CaC03 (mg/l)	Phenol (ug/l)	2-Methylphenol	4-Methylphenol	2,4-dimethyl phenol	1,4-dichlorobenzene	2-Methyl Naphthalene (ug/l)	Diethyl phthalate	Bis (2-ethylhexyl)phthalate (ug/l)	Naphthalene (ug/l)	cis-1,2-Dichloroethene (ug/l)	Chloroform (ug/l)	Trichloroethene (ug/l)	1,1,1-Trichloroethane (ug/l)	Total Coliforms (counts/100 ml)	E.coli (counts/100 ml)	Candida albicans (detection)	Bacillus stearothermophilus (detection)	Listeria monocytogenes (detection)	BOD (mg/l)	TBT (ng/l)	DBT (ng/l)
	EU DWS	2.5	-	6.5 - 9.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	-	-	-	-
Peripheral BH's	MBH1	8.2	7.7	8.35	5215	312						2							1	150	<3	x	x	x	28.2	<50	<50
	MBH2	2.97	10.30	8.37	1558	264														23	<3	x	√	x	13.6	<50	<50
	MBH3	15.84	8.5	8.36	10050	244													2	23	<3	x	√	x	14.7	<50	<50
	MBH4	38.5	8.4	8.36	24250	192								9						240	240	x	x	x	11.3	<50	<50
	MBH5	51.4	6.6	8.22	33175	176								9	3											<50	<50
	MBH6	7.73	10.3	8.50	4723	176								7						64	<3	x	x	x	13.3	<50	<50
Agric. BH's	2026	8.39	4.6	8.42	4550	232														>1100	<3	x	√	x	<1	76	<50
	2027	5.43	9.3	8.44	2735	204														>1100	23	x	x	x	<1	52	<50
	3308	8.46	8.6	8.44	3535	224														15	<3	x	x	x	3.7	<50	<50
PWS	WIED IL-GHASEL PS	49.1	8.90	8.49	1263	168														-	-						
Sea Water	MMW1	51.3	9.6	8.23	33725	148								9						-	-						

1. Data Source: Scott Wilson, March 2003
2. Sample Locations are shown on Drawing No. 5

TABLE 4a (CONTD.): GROUNDWATER AND MARINE WATER QUALITY IN THE VICINITY OF GHALLIS

Monitoring Location	*Lead (ug/l)*	*Nickel (ug/l)*	*Copper (ug/l)*	*Chromium (ug/l)*	*Cadmium (ug/l)*	*Arsenic (ug/l)*
2026	*9.56*	*165*	*19.02*	*BDL*	*0.424*	*1.73*
2027	*BDL*	*4.56*	*BDL*	*0.3*	*0.219*	*0.51*
2041	*5.72*	*7.62*	*BDL*	*BDL*	*0.032*	*0.13*
2604	*BDL*	*BDL*	*BDL*	*0.1*	*0.019*	*BDL*
2130	*BDL*	*BDL*	*BDL*	*BDL*	*0.003*	*BDL*

1. Data Source – Mario Saliba, May 1999: *Environmental Impact Assessment of the Maghtab Landfill on the Marine Environment* Unpublished BSc dissertation at The University of Malta.
2. BDL = Below Detection Limit
3. Monitoring locations are shown on Drawing No. 5.

Review of these water quality data indicates the following:

- The groundwater salinity, as indicated by chloride, sodium and electrical conductivity monitoring results, increases towards the coast. A chloride concentration of 22,251 mg/l was recorded in MBH5. This concentration is just below a chloride concentration of 22,673mg/l recorded for the seawater sample collected at MMW1. The sodium concentrations in MBH5 groundwater and the MMW1 seawater sample are also very similar, at 9,300 and 9,600mg/l, respectively. This reflects the influence of saline intrusion and/or the possible penetration of the monitoring boreholes below the base of the freshwater lens, which is likely to be thin in this area given proximity to the coast.

- Groundwater quality improves in MBH3 and MBH6, although remaining brackish. This is likely to reflect the greater distance of these monitoring locations from the coastline (400m and 600m, respectively) and/or the greater thickness of the freshwater lens. This decrease in salinity with distance from the coast is also indicated by lower sodium concentrations and electrical conductivity.

- Further away from the coast at MBH2, located approximately 800m from the coast, groundwater quality is significantly better as reflected by lower chloride concentration of 899mg/l. Sodium and electrical conductivity values are also significantly lower than at the other monitoring borehole locations.

- MBH1 is located furthest from the coast, at approximately 950m. However, groundwater quality at this location is significantly more saline, and reflects that within MBH6, located 600m away from the coastline. Review of the published geological map indicates that MBH1 is located very close to a large north-south trending fault that extends to the sea, meeting the coastline to the immediate north-east of the site. A second fault, extending north-east to south-west is also identified lying to the immediate south of MBH6. Given the above, it is considered very likely that the poorer groundwater quality in MBH6 reflects it close proximity to these two faults, which are allowing more saline water to extend further inland due to their likely higher transmissivity.

- Groundwater quality in the agricultural boreholes is brackish, as indicated by chloride concentrations ranging between 1,723mg/l and 3,068mg/l for Well 2027 and 2026, respectively. These concentrations reflect the general variation of groundwater quality with distance from the coast and proximity to faults, as discussed above.

- Groundwater quality from the Wied il-Ghasel Pumping Station is significantly better than at all other monitored locations, as indicated by a chloride concentration of 532mg/l. This reflects the location of the pumping station beyond the influence of the coast, located approximately 2.2km to the north-east.

- The bacteriological analytical results indicate the presence of bacteria in the sampled boreholes as follows:

  – Total coliforms in all groundwater samples except Wied il-Ghasel.

  – E.coli in MBH4 and 2027.

  – Bacillus stearothermophilus in MBH4 and 2027.

- It is considered very likely that the elevated concentrations reflect the limited ability of the limestone aquifer and very thin overburden/soils to attenuate bacteriological sources associated with farming activities (e.g. animal slurry) in the vicinity and up-gradient of the site.

- The presence of the organic compound bis(2-ethylhexyl)phthalate in a number of samples including the seawater sample would suggest possible sample contamination, and therefore it is considered that these specific results are unlikely to be representative.

- The presence of the organic substance 2-Methyl Naphthalene at 2ug/l, and 1,1,1-Trichloroethane at 1ug/l in MBH1, located upgradient of the Maghtab Landfill site, also suggests either possible contamination following sampling or another source other than the existing landfill.

- The presence of Naphthalene at a concentration at 3ug/l in MBH5 may reflect contaminated runoff from the adjacent coastal highway.

- With regard to metal analytical results, the general increase in concentrations towards the coast suggests that these reflect the marine influence on the aquifer.

- The marine water quality, as indicated by the sample taken from Qalet Marku (MMW1) by Scott Wilson[14], is very similar to that taken near Qortin on Gozo during the same

[14] Scott Wilson, February 2003: *Development of Rehabilitation Strategies Maghtab, Qortin and Wied Fulija Landfills.* Stage II Final Report completed for Ministry of Resources & Infrastructure.

investigation by Scott Wilson. The Gozo sample is expected to be relatively clean and representative of Maltese background conditions, given its remote location. However, both the Qalet Marku and Gozo samples contained slightly elevated ammoniacal nitrogen concentrations, and Scott Wilson conclude that sewage discharges to the marine environment or fish farms may be a likely source. Another possible source is the Maghtab Landfill, although this is less likely given that ammoniacal nitrogen concentrations in the groundwater between the landfill and the coast are lower than detected in the marine environment.

Available information from previous investigations undertaken to assess concentrations of heavy metals in marine sediments adjacent to the coastline near the proposed Ghallis Landfill site, has been reviewed. Analytical results are summarised in Table 4b, and are discussed below.

TABLE 4b: SUMMARY OF METAL CONCENTRATIONS IN MARINE SEDIMENT NEAR GHALLIS

Parameter	Mediterranean Background[15] (mg/kg dry weight)	Bahar ic-Caghaq		Qalet Marku			Ghallis Rocks (south)	Ghallis Rocks		Ghallis Rocks (north)	Ramla L-Hamra
		Scott Wilson[16] (MMS3) (mg/kg dry weight)	Pace [17] (mg/kg dry weight)	Saliba [18](Station 1) (mg/kg dry weight)	Scott Wilson (MMS2) (mg/kg dry weight)	MEPA PCCU[19] (mg/kg dry weight)	Saliba (Station 2) (mg/kg dry weight)	Scott Wilson (MMS1) (mg/kg dry weight)	Saliba (Station 3) (mg/kg dry weight)	Saliba (Stations 4&5) (mg/kg dry weight)	Saliba (mg/kg dry weight)
Lead	20	9	41.19	77	9	18.4	12	4	37	10	5
Nickel		<1		9	1		5	<1	5	3	7
Copper	5	2	44.42	11	1	8.6	3	<1	5	5	4
Chromium		5		14	5		12	9	11	10	14
Manganese				23			20		16	14	43
Zinc	50	9	75.9		14	65		25			
Cadmium	0.25	<0.5	7.53	0.018	<0.5	0.4	BDL	<0.5	0.011	0.016	BDL
Arsenic		<1		3	<1		1	<1	3	5	9

Notes:
1. BDL - below detection limit.
2. Sample locations are shown on Drawing 5
3. Saliba data for stations 1 to 5 are averaged results for sampling events on 06/09/98, 20/01/99 & 26/01/99. Data for Ramla L-Hamra are for sampling event on 12/01/99.

[15] Axiak V. and Sammut, A. 2002: *The Coast and Freshwater Resources.* In: *State of the Environment Report for Malta, 2002.* Ministry of Home Affairs and the Environment, August 2002
[16] Scott Wilson, February 2003: *Development of Rehabilitation Strategies Maghtab, Qortin and Wied Fulija Landfills.* Stage II Final Report completed for Ministry of Resources & Infrastructure.
[17] Pace L, 1998 *Biomonitoring of Heavy Metal Pollution in Malta,* Unpublished MSc Dissertation. Faculty of Science University of Malta
[18] Mario Saliba, May 1999: *Environmental Impact Assessment of the Maghtab Landfill on the Marine Environment* Unpublished BSc dissertation at The University of Malta
[19] Pollution Coordination and Control Unit, MEPA

Metal concentrations at these sampling locations can be compared with typical values recorded for the Mediterranean in general, and from Ramla L-Hamra, Gozo, where the sample was collected during the winter months when there is less anthropogenic influence on the marine environment.

There is no indication of any significant and consistently elevated metals concentrations around the coastline in the immediate vicinity of the proposed site, with all results typically lying relatively close to the background concentrations for Mediterranean and Ramla L-Hamra sea water.

The exception to this is the analyses for lead which are, on occasion, significantly elevated above both the Mediterranean and Ramla L-Hamra lead concentrations (e.g. Saliba sample at Qalet Marku (Station 1) is 15 times higher than that for Ramla L-Hamra). It is considered very likely that elevated lead concentrations may reflect close proximity and associated runoff from coast road, which is located in the vicinity of the sampling locations. This source is also identified by Scott Wilson, who concluded that there was 'no conclusive evidence of any significant impact of landfill-derived contamination on sediment quality'.

2.6.5 Abstractions and Source Protection Zones

Available information[20,21] indicates that there are at least six agricultural abstractions within 1km of the proposed site (Water Services Corporation Registration Nos 2026, 2027, 2130, 2041, 2604 and 3308). Their locations are shown on Drawing No. 5. It is understood that these abstractions are utilised to meet agricultural water requirements. No information could be obtained with regard to groundwater quantities abstracted from these wells over the past five years.

The site lies outside the Aquifer Protection Zone which has been established in order to help protect the islands groundwater resources within the Mean Sea Level Aquifer[22]. At its closest point, the southern boundary of the proposed landfill site lies approximately1.5km to the north of the Aquifer Protection Zone associated with the Wied il-Ghasel pumping station.

[20] Scott Wilson, February 2003: *Development of Rehabilitation Strategies Maghtab, Qortin and Wied Fulija Landfills.* Stage II Final Report completed for Ministry of Resources & Infrastructure.
[21] Mario Saliba, May 1999: *Environmental Impact Assessment of the Maghtab Landfill on the Marine Environment* Unpublished BSc dissertation at The University of Malta.
[22] Local Plans Unit, Planning Authority, 2002: *The Central Malta Local Plan*

2.7 Conceptual Hydrogeological Site Model

The conceptual hydrogeological site model is presented in Table 6.

The receptors that have been used within this assessment are as follows:

- For **List I Substances**, the potential receptor has been assumed to be the groundwater within the Mean Sea Level aquifer of the Lower Coralline Limestone, directly below the landfill site (prior to any dilution occurring); while

- For **List II Substances**, the potential receptor has been assumed to be the groundwater within the Mean Sea Level aquifer of the Lower Coralline Limestone, at down gradient (northern) boundary of the site.

TABLE 5: SUMMARY OF CONCEPTUAL HYDROGEOLOGICAL MODEL

Hazard	Source	Potential Primary Pathway	Potential Secondary Pathways	Potential Receptors	Compliance Point
• Leachate generated within the Ghallis Non-Hazardous landfill. • The site represents a potential hazard to ground and surface water resources in that it is likely to contain List I and List II Substances. • The development falls, therefore, within the scope of the EU Groundwater Directive.	• The landfill will be developed following the principal of containment. • An artificial sealing liner comprising 2mm HDPE Geomembrane will extend across the landfill base and up the landfill sides. • The artificial geological barrier will comprise a 0.1m thick mineral liner (Trisoplast or similar) with a maximum permeability of $5x10^{-11}$m/s, overlying a 0.4m thick (base) to 2.0m thick (side walls) layer of screened/crushed material, with a maximum permeability of $1x10^{-7}$m/s. • Leachate levels will be maintained a maximum of 1m above the basal liner.	• Leachate migration will potentially take place through the artificial sealing liner and geological barrier. • It has been assumed that contaminant degradation and retardation occurs within the artificially installed geological barrier/attenuation layers. • This will be underlain by a substantial thickness (14 to 26m) of *in situ* unsaturated Lower Coralline Limestone bedrock.	• Groundwater flow within the Mean Sea Level aquifer of the Lower Coralline Limestone. • Flow in a north-north-easterly direction.	• For List I Substances: Groundwater within the Mean Sea Level aquifer of the Lower Coralline Limestone below the site, prior to dilution. • For List II Substances: Groundwater within the Mean Sea Level aquifer of the Lower Coralline Limestone, at the northern (downgradient) boundary. • Seawater along the coastline to the north of the site.	• For List I & List II Substances: Groundwater within the Mean Sea Level aquifer of the Lower Coralline Limestone, at the northern (downgradient) boundary.

3.0 HYDROGEOLOGICAL RISK ASSESSMENT

3.1 The Nature of the Hydrogeological Risk Assessment

As set out within Section 2, the proposed Ghallis landfill site represents a potential hazard to groundwater and marine water resources. Consequently, this development has to comply with the requirements of the EC Groundwater Directive, 1980, and additional risk assessment work is required. In the UK, the EC Groundwater Directive has been implemented by the Groundwater Regulations, 1998. These regulations include a requirement for 'prior investigation' (i.e. risk assessment) of potential impacts on groundwater to be carried out before the granting of a licence or a permit allowing waste disposal to land, where the wastes may contain certain polluting substances (referred to List I and List II Substances).

As set out within the UK Environment Agency's technical guidance[23], the appropriate complexity of assessment for a site should be determined from the potential risks presented by the site, which are linked to the nature of potential hazards, the sensitivity of the surrounding environment, degree of uncertainty and likelihood of a risk being realised. There are essential two levels of complexity:

- ***Simple risk assessments*** should be carried out where feasible source-pathway-receptor linkages are identified, or in preparation for conducting a more complex assessment, and where either:

  - It is clear from the conceptual model and the risk screening that the hazards are relatively low and the environmental setting is sufficiently insensitive to negate the possibility of significant impacts (e.g. sites on low permeability strata remote from abstractions and surface waters); or

  - The potential source, pathway and receptor terms can all be defined with sufficient certainty so as to be confidently represented by conservative inputs, models and assumptions, e.g. a single homogenous source of in-house waste, well-defined flow characteristics and directions etc.

- ***Complex risk assessments*** should be carried out where complete source-pathway-receptor terms are present and where either:

  - The site setting is sufficiently sensitive to warrant detailed assessment e.g. on permeable strata; or

  - There is uncertainty relating to any of the source, pathway or receptor terms e.g. variable leachate quality, or an undefined groundwater flow pattern that can not be overcome by the adoption of conservative inputs or assumptions.

[23] UK Environment Agency, March 2003, Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater Control and Trigger Levels.

Given the nature of landfill site and the site's environmental setting, it is considered appropriate to carry out a complex risk assessment in support of the development proposals.

3.2 The Proposed Assessment Scenario

It is recognised that the hydrogeological risk assessment must assess the compliance of the proposed development with the requirements of the Groundwater Directive, 1980, throughout the lifecycle of the landfill i.e. from the start of the operational phases until the point at which the landfill no longer is capable of posing an unacceptable environmental risk.

Details of the assessment scenario are presented within Table 6, along with the conceptualisation of how different aspects of the technical precautions will perform during the lifecycle of the landfill. An indication of how the different technical precautions are modelled is also provided.

3.3 The Priority Contaminants to be Modelled

Given the non-hazardous waste stream of the proposed landfill site, there is the potential for the leachate generated by the site to contain both List I and II Substances. UK Environment Agency guidance (UK Environment Agency, 1999) recognises that attempting to model the entire range of substances that could potentially exist in leachate would be extremely time consuming and difficult to do. Consequently, for the purposes of this risk assessment, a limited number of representative general, List I and II chemical species have been modelled, principally due to their presence within the leachate/condensate sample from Maghtab Landfill[24].

List I Substances:

Cadmium: A heavy metal that is present within the leachate/condensate sample from Maghtab Landfill (0.00027mg/l).

Naphthalene: Selected because it has been commonly found within leachate generated by non-hazardous (domestic) waste streams in the United Kingdom. Present within the leachate/condensate sample from Maghtab Landfill (0.055mg/l). It is also a poly-aromatic hydrocarbon (PAH) and a volatile organic substance.

Toluene: Selected because it has been commonly found within leachate generated by non-hazardous (domestic) waste streams in the United Kingdom, and it is a volatile organic substance.

[24] Scott Wilson: *Development of Rehabilitation Strategies Maghtab, Qortin and Fulija Landfills.* Stage III Final, March 2003, report completed for Ministry of Resources & Infrastructure.

List II Substances:

Ammoniacal Nitrogen:	Typically present at high concentrations within non hazardous leachate. Very low UK Drinking Water Standard of 0.5mg/l. Present within the leachate/condensate sample from Maghtab Landfill (643mg/l ammonium).
Arsenic:	Present within the leachate/condensate sample from Maghtab Landfill (0.431mg/l). Can be present within non hazardous leachate.
Chromium:	Present within the leachate/condensate sample from Maghtab Landfill (0.22mg/l). Typically present within non hazardous leachate.
Copper:	Present within the leachate/condensate sample from Maghtab Landfill (0.026mg/l). Typically present within non hazardous leachate.
Lead:	Present within the leachate/condensate sample from Maghtab Landfill (0.0895mg/l). Typically present within non hazardous leachate.
Nickel:	Present within the leachate/condensate sample from Maghtab Landfill (0.219mg/l). Typically present within non hazardous leachate.

General Substances:

Chloride:	Even though it has a low risk factor, and it is not a List II Substance, it is commonly associated with landfill leachate. It is also a useful contaminant to model as it acts in a conservative manner.

TABLE 6: HYDROGEOLOGICAL RISK ASSESSMENT SCENARIO

Conditions	Landfill Source		Landfill Cap[25]		Leachate Drainage System		Artificial Sealing Liner		Geological Barrier/ Attenuation Layer	
	Assumed Function	**Assumed Parameter**	**Assumed Operation**	**Assumed Parameter**	**Assumed Operation**	**Assumed Parameter**	**Assumed Operation**	**Assumed Parameter**	**Assumed Operation**	**Assumed Parameter**
Operational (outward gradients)	Leachate quality at full strength	LandSim V2.5 defaults, site specific quality and Knox *et.al* (2000)[26] (Log Triangular)	Cap not present	Infiltration in to Open Waste 224 to 1009mm/ year (Triangular)	Operates as designed	Leachate head maintained between 0.0 and 1.0m above the basal liner (Uniform)	HDPE geo-membrane defects as per LandSim 2.5 defaults, assuming CQA, leak detection and repair	LandSim V2.5 defaults (Triangular)	Operates as designed	Trisoplast $5x10^{-11}$ $1x10^{-11}$ $1x10^{-12}$ m/s (Log Triangular Screened/ crushed material $1x10^{-7}$ m/s
Post Closure (outward gradients)	Leachate strength declined due to declining source and degradation		Engineered geo-membrane cap operates as designed	50mm +/- 10mm (Normal)		Leachate head maintained between 0.0 and 1.0m above the basal liner (Uniform)	HDPE geo-membrane defects increasing	Onset of HDPE liner degradation after 150 years and defects double every 100 years (Triangular)		
Long-term Post Closure (c.1000 years) (outward gradients)	Leachate strength declined due to declining source and degradation		Engineered geo-membrane cap eventually degrades completely	Infiltration equivalent to effective precipitation, 125mm +/- 50mm (Normal)	Non-functional	Leachate head reflects net inputs through landfill cap and leachate leakage through landfill basal liner	HDPE geo-membrane eventually degrades completely	Not present		

[25] Assumed that landfill cap will function as designed up until c.250 years. Following that period it has been assumed that it degrades completely after c.1000 years, so that final infiltration is equal to effective rainfall.
[26] Knox, K *et. al.* (Oct 2000)[26] : *The Occurrence of Trace Organic Components in Landfill Leachates and their removal during Onsite Treatment.* From the Proceedings of Waste 2000 Conference, Stratford upon Avon, 2-4 October 2000, p263-272.

3.3.1 Determination of Environmental Assessment Limits (EALS)[27]

Compliance with the EC Groundwater Directive, 1980, requires that the landfill will not result in discernible discharges of List I Substances entering the groundwater and will not cause pollution of groundwater by List II Substances. With regards to List I Substances, the appropriate EALs are the levels at which they become "discernible". With regards to the priority List I Substances that are considered within this assessment[28]:

- 0.1 µg/l is considered to be appropriate for cadmium
- 4 µg/l is considered to be appropriate for toluene
- 0.01 µg/l is considered to be appropriate for naphthalene, given that there is no published Minimum Reporting Values (MRV) for this substance.

With regards to List II Substances, in order to determine both the sensitivity of the groundwater within the vicinity of the proposed landfill and an indication of what could be regarded as "pollution", it was considered necessary to identify the most appropriate groundwater Environmental Assessment Limits (EALs) for the contaminants that are present within the leachate. EALs are important as they provide both an indication of groundwater sensitivity as well as target values for the risk estimation process associated with the risk assessment phase of the project. Determination of an EAL was not considered to be appropriate for chloride, given the coastal location of the site, and the likelihood that the groundwater quality underlying the site would be significantly influenced by saline intrusion effects.

The EAL for ammoniacal nitrogen that is considered appropriate for the landfill site is derived within Table 7, presented below. In order to provide the greatest level of protection, the appropriate EAL for was determined to be the most stringent applicable standard, except where background groundwater quality exceeds the specified standards. The standards that were considered to be appropriate for Landfill were the UK Drinking Water Standards (DWSs) given the distance from the coast (>200m) and the possibility (although unlikely given the natural brackish water quality) for groundwater to be utilised immediately downstream of the site. The UK Environmental Quality Standards (EQSs)[29] were not considered appropriate, given the lack of surface water in the immediate vicinity of the site.

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[27] An EAL can be defined as a water quality standard that is defined by either UK Regulations (e.g. Water Supply (Water Quality) Regulations 1989), EU Directives (e.g. Drinking Water Directive (80/778/EEC)) or another relevant source (e.g. non-statutory UK Environmental Quality Standards).

[28] These values are derived from Appendix 7 "Minimum Reporting Values for selected List I Substances in clean water" of the UK Environment Agency's March 2003, Hydrogeological Risk Assessments for Landfills and the Derivation of Groundwater Control and Trigger Levels.

[29] These were determined to be appropriate after considering Figure 3.1, Determination of Target Concentrations in UK Environment Agency, October 1999, Methodology for the Derivation of Remedial Targets for Soil and Groundwater to Protect Water Resources, R&D P20.

TABLE 7: DERIVATION OF ENVIRONMENTAL ASSESSMENT LIMITS

Determinand	UK Drinking Water Standard (mg/l)	Maximum Concentrations in Background Groundwater (After monitoring data for MBH1, MBH2, Agricultural wells 2026, 2027 & 2130) (mg/l)	Resultant EAL (mg/l)
Ammoniacal-N	0.39	0.30	0.39
Arsenic	0.01	0.0017	0.01
Chromium	0.05	0.011	0.05
Copper	2.0	0.019	2.0
Lead	0.01	0.010	0.01
Nickel	0.02	0.005	0.02

3.4 Numerical Modelling

3.4.1 Justification for Modelling Approach and Software

The hydrogeological risk assessment has been carried out using conservative assumptions regarding the pathways and receptors. The risk assessment has therefore focussed on the functioning of the containment system for the landfill.

During the operational and post closure phases of the site, active leachate management will ensure that leachate levels are held within 1m of the basal liner. Given the site setting, outward potential leachate migration by advective flow will be possible through the lining system and substantial thickness of Lower Coralline Limestone in the unsaturated zone above the Mean Sea Level aquifer.

Under the long term post closure scenario, when active leachate management measures are not required, outward hydraulic gradients are likely to increase, while the HDPE geocomposite liner will also be subject to degradation.

The Environment Agency's LandSim v2.5.16 software has therefore been used to provide an estimate of the potential risks associated with the proposed development under these conditions. This software was used for the following reasons:

- It uses Monte Carlo (stochastic) techniques and so allows a probabalistic appreciation of the landfill's performance.
- It provides a consistent approach to the estimation of hydrogeological risks in respect to landfills and groundwater.
- It provides an audited and verified code that is widely accessible.

- It aids comprehensive reporting of input values, assumptions and results.
- The model provides a good indication of the potential leakage rates associated with the proposed development. This is important as the installation's compliance with the requirements of the EC Groundwater Directive, 1980, depends significantly upon the functioning of the containment system.

- It allows the estimation of the potential attenuation via retardation and degradation effects within the liner, vertical and aquifer pathways.

3.4.2 Model Parameterisation

The nature of all of the input parameters used, together with the appropriate probability distributions used to describe them are presented in the following:

- Table 5: which outlines how certain management systems would operate with time;

- Appendix 1: contains details regarding the LandSim v.2.5.16 model parameterisation;

- Appendices 2 & 3: contain hard copies of the LandSim v.2.5.16 models and results;

Parameter values were determined from information from authoritative sources or previous SLR experience. Unless certain alternative distributions were apparent (such as uniform or normal), triangular distributions were used throughout the modelling process. Log triangular distributions were used to parameterise leachate concentrations.

With regards to the potential leakage of leachate from the proposed development and the potential dilution of this leachate within the aquifer, there are two key elements: the permeability of the mineral element of the lining system and groundwater flow.

- With regards to the ***permeability of the geological barrier / attenuation layer***, the input probability distribution: log-triangular, $1x10^{-12}$, $1x10^{-11}$, $5x10^{-11}$ m/s, has been utilised for the Trisoplast (or similar) lining system, based on liner specifications provided by the manufacturer. It is noted that the maximum permeability is expected to be lower than $5x10^{-11}$m/s once the compressive forces of the overlying waste are taken into account. This range is therefore considered to represent worst case conditions. It is also noted that the basal lining system, including the HDPE geomembrane and the Trisoplast liner (or similar), will be installed under a stringent CQA programme/procedure.

- With regards to ***groundwater flow***, the bulk hydraulic conductivity of the Lower Coralline aquifer has been assumed to range between 1.5×10^{-3} and 2×10^{-4}m/s, with a 'most likely' value of 8.5×10^{-4}m/s. This range is considered reasonable, given that the site is located in an area of the island where the Lower Coralline Limestone has been influenced by faulting and karst (solution features).

The above noted two elements of the risk assessment are particularly critical to the compliance of the proposed development with the requirements of the EC Groundwater Directive, 1980.

3.5 Emissions to Groundwater

This section of the assessment considers whether the predicted discharge from the proposed development complies with the requirements of the EC Groundwater Directive, 1980.

3.5.1 List I Substances

The hydrogeological risk assessment must demonstrate that the technical precautions would "*prevent substances in List I from entering groundwater*". Consequently, it must consider whether there is likely to be a discernible discharge of List I Substances to groundwater. Table 8 presents the resultant concentrations of each List I Substances at the base of unsaturated zone within the Lower Coralline Limestone (i.e. immediately before entering the groundwater within the Mean Sea Level Aquifer).

Table 8 demonstrates that, under the considered worst case assumptions, the resultant concentrations are lower than the concentrations that are considered by the UK Environment Agency to be discernible. Consequently, for the considered scenario, it is considered that the modelling has demonstrated that there would be no discernible discharges of List I Substances into the groundwater, or into the adjacent sea water along the coast.

TABLE 8: RESULTS FOR LIST I SUBSTANCES (PRIOR TO DILUTION)

Determinand	95%ile Resultant Peak Concentrations at the base of the 400mm Crushed Limestone Geological Barrier (mg/l)	Discernible Conc. (mg/l)
Cadmium	$<1x10^{-4}$	$1x10^{-4}$
Naphthalene	$<1x10^{-10}$	$1x10^{-5}$
Toluene	$1x10^{-7}$	$4x10^{-3}$

Note: Cadmium concentrations remain below the discernible level for at least 2,000 years below Phases 2, 3 and 4. Given this extended time frame, and taking into account the extreme worst-case assumptions adopted by the hydrogeological risk assessment (e.g. the maximum modelled cadmium concentration is two orders of magnitude higher than the maximum concentration measured in the Maghtab leachate), it is considered that Cadmium will not exceed the discernible concentration (MRV).

3.5.2 List II Substances

Table 9 presents a summary of the simulated resultant concentrations of List II Substances at the downstream compliance point.

Table 9 demonstrates that the resultant concentrations are lower than the appropriate EALs. Consequently, for the modelled scenario, it is considered that the modelling results have demonstrated that the discharge of List II Substances would be sufficiently limited so as to avoid pollution.

The modelling results have also demonstrated that there will be no impacts in terms of pollution of the seawater along the coastline to the immediate north and north-east of the site, given the negligible impacts of the landfill on the groundwater that ultimately discharges to the sea, and the significant dilution effects as the groundwater mixes with the seawater.

TABLE 9: RESULTS FOR LIST II SUBSTANCES AT THE DOWNSTREAM BOUNDARY (COMPLIANCE POINT)

Determinand	95%ile Resultant Peak Concentrations (mg/l)	EAL (mg/l)
Ammoniacal-N	0.365	0.39
Chloride	3,020	See note
Arsenic	0.0019	0.01
Chromium	0.0105	0.05
Copper	0.018	2.0
Lead	0.0096	0.01
Nickel	0.0048	0.02

Notes:
1. Chloride results fall within the assumed background range of 1,700 to 3,100mg/l.

2. The resultant concentration for ammoniacal nitrogen reflects a theoretical duration of management control of 800 years. It is considered likely that the necessary duration of management control will be significantly less than this given the following:
- the ammoniacal nitrogen half life is expected to be smaller than that used within the LandSim model, given site specific conditions in Malta (e.g. higher ambient temperature compared to the UK).
- the model is considered to be very conservative e.g. the leachate strength for ammoniacal nitrogen is significantly higher than that recorded at the adjacent Maghtab Landfill site, and retardation has not been included within the unsaturated or saturated pathways within the Lower Coralline Limestone.

Additionally, there will be a requirement that active leachate management control should continue until leachate strength is sufficiently weak not to cause a risk to the adjacent water environment.

3.6 Essential and Technical Precautions

The hydrogeological risk assessment has demonstrated that the proposed development complies with the requirements of the EC Groundwater Directive, 1980. A series of essential and technical precautions have been identified as part of the hydrogeological risk assessment and are detailed below.

3.6.1 Capping

The site should be capped with a low permeability geomembrane to reduce infiltration and to control leachate generation.

3.6.2 Lining Design

The engineered basal and side wall lining design should incorporate a geological barrier that can attenuate potential pollutants. The risk assessment has demonstrated that the proposed basal geological barrier, comprising a 100mm thick mineral liner with a maximum permeability of $5x10^{-11}$m/s (Trisoplast or similar), underlain by a layer of screened/crusher material with a minimum thickness of 400mm thick and a maximum permeability of $1x10^{-7}$m/s, should be sufficient. The liner should be installed using third party construction quality assurance.

3.6.3 Leachate Drainage System

The leachate drainage system should incorporate a leachate drainage blanket comprising gravel with a minimum hydraulic conductivity of $1x10^{-3}$m/s which should incorporate carrier pipework. The leachate drainage layer should extend across the landfill base.

3.6.4 Leachate Control

It is essential that leachate elevations within all cells are maintained within the heads assumed for this assessment, i.e. leachate elevations no greater than 1.0m above the basal liner.

The leachate inventory needs to be maintained within the distribution used in this assessment. Accordingly control and trigger levels need to be set with the trigger levels representing the maximum concentrations used in the assessment. A loading rate protocol should be used to maintain the leachate inventory within these bounds.

3.6.5 Groundwater Management

Groundwater management will be required in order to allow landfill construction.

3.6.6 Leak Detection System

The site design does not need to incorporate a leak detection system.

3.7 Hydrogeological Completion Criteria

It is considered that the completion criteria for the landfills should be established as the point when the landfills no longer have the potential to cause damage to or deterioration of the environment and risk to human health i.e. they no longer pose a potential risk to the environment or human health.

With regards to potential impact on ground and surface water, this means that the site needs to comply with the requirements of the EC Groundwater Directive, 1980, following the cessation of active leachate management, as represented by the Long Term Post Closure conditions.

The modelling results therefore suggest that the site could potentially comply with the requirements of the EC Groundwater Directive, 1980, following the cessation of active leachate management and the saturation of the waste. Consequently, this suggests that this element of landfill management and control will not be the limiting factor in determining the site's ultimate time to completion.

4.0 REQUISITE SURVEILLANCE

4.1 The Risk Based Monitoring Scheme

Environmental monitoring of leachate, groundwater and surface water is a crucial element of the risk assessment process as it:

- Allows for validation of the risk assessment;

- Can confirm whether risk management options are meeting their desired aims; and

- Provides a warning mechanism if adverse impacts are found.

Control and trigger levels typically form the basis for assessing groundwater monitoring data at landfill sites, and it is proposed that this is also the case for the Ghallis Non-Hazardous Landfill site. Given that there are no permanent surface water features in the immediate vicinity of the site, it will not be possible to include surface water within the risk based monitoring scheme.

Control levels are specific assessment criteria relating to groundwater or other relevant parameters and are used to determine whether a landfill is performing as designed. They are levels that are intended to draw attention of site management and the Regulatory Authorities to the development of adverse, or unexpected, trends in the monitoring data. Such trends may results from failure of site engineering or management, or from variations between actual conditions and those assumed within the conceptual model. Control levels should be treated primarily as an early warning system to enable appropriate investigative or corrective measures to be implemented, particularly where there is potential for a trigger level to be breached.

A well-planned method of assessment, agreed between the operator and the Regulatory Authorities, will help to both protect the environment and thereby avoid breaches of trigger levels, and provide clarity and avoid ambiguity when trigger level conditions are breached.

Control levels should therefore:

- Highlight variations between the conceptual model (i.e. assumed behaviour) and observed conditions;
- Identify unambiguous adverse trends which are indicative of leachate impacts;
- Allow for variation in natural water quality from baseline conditions; and
- Give sufficient time to take corrective or remedial action **before** trigger levels are breached.

Trigger levels are specific compliance levels, or regulatory standards. They are defined as criteria at which significant adverse environmental effects and/or breaches of legislation have occurred. Such effects would be consistent with the groundwater having been polluted.

Both Control and Trigger Levels should be set within the Landfill Permit/Licence. These will be based on data collected during the proposed environmental monitoring programme for the site.

4.2 Leachate, Groundwater and Surface Water Monitoring Schedule

Full details regarding the proposed leachate and groundwater monitoring schedule will be provided once Planning Permission has been granted for the Landfill site.

5.0 CONCLUSIONS

5.1 Compliance with the Landfill Regulations, 2002

The results of this risk assessment have established the following:

- The proposed development poses a potential hazard to ground and surface water quality. Consequently, arrangements must be made to collect the contaminated water and leachate that is generated by the site.

- The proposed development will comply with the minimum specified engineering standards as required by the Landfill Regulations, 2002, i.e. an artificial sealing liner (HDPE geomembrane) underlain be an artificially established geological barrier/attenuation layer across the base and up the landfill sideslopes. This design has been shown to be appropriate based on the findings of this risk assessment.

- Control and trigger levels will be determined in order to ensure the adequate protection of groundwater resources.

The site will therefore comply with the relevant requirements of the Landfill Regulations, 2002.

5.2 Compliance with the EC Groundwater Directive, 1980

The results of this risk assessment have established the following:

- The proposed development poses a potential hazard to ground and surface water quality. Consequently, it falls within the scope of the EC Groundwater Directive, 1980.

- The proposed technical precautions prevent the discernible discharge of List I Substances in groundwater throughout the site's lifecycle.

- The proposed technical precautions also limit the introduction of List II Substances into groundwater so as to avoid pollution throughout the site's lifecycle.

- The following essential and technical precautions have been identified as part of the hydrogeological risk assessment:

  - Maintenance of leachate elevations within all of the proposed cells, to within the heads assumed for this assessment.

  - Maintenance of the leachate inventory within the parameters assumed in this assessment by use of control and trigger levels and a loading rate protocol;

- The mineral lining system is critical for the compliance of this site with the requirements of the EC Groundwater Directive, 1980. It is therefore important to ensure the levels of site engineering and construction quality assurance that have been assumed by this risk assessment.

The establishment of a risk-based programme of leachate and groundwater monitoring, together with the identification of and implementation of control and trigger levels should be included as part of the licensing/permitting of the site.

Based on the above, it is considered that the site should comply with these relevant requirements of the EC Groundwater Directive, 1980.