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1.0 INTRODUCTION

WasteServ Malta Limited (WasteServ) has prepared this Hydrogeological Risk Assessment in the support of an application for the development of an interim non-hazardous landfill facility at Ta' Zwejra. The proposed facility is located in the vicinity of closed Maghtab landfill, on the north/east coast of Malta. The proposed development is subject to the IPPC Regulations.

The system of Integrated Pollution Prevention and Control (IPPC) applies an integrated environmental approach to the regulation of waste management activities in operation of the landfill. This means that emissions to air, water (including discharges to sewer) and land, plus a range of other environmental effects, must be considered together. It also means that WasteServ Malta Ltd. as the operator must apply conditions so as to achieve a high level of protection for the environment as a whole. This IPPC application is based on the use of the 'Best Available Techniques' (BAT), which balances the costs to the operator against the benefits to the environment. This application aims to prevent emissions of potential pollutants and where that is not practicable, reduce them to acceptable levels. This application also takes the integrated approach beyond the initial task of permitting, through to the restoration of site when waste management activities cease with proper consideration of specific site conditions around the Maghtab area.

Malta as a small island has a fragile ecosystem with very limited water and other resources, and great care of environment is required to support the inhabitants. The ground water is a principal resource and a natural major supply of fresh potable water. With a very small surface recharge capacity and limited ground water storage capacity combined with the fact that the aquifer is surrounded by saltwater makes its protection a top priority.

In assessing the engineering proposals for construction of the Ta' Zwejra non-hazardous waste landfill facility three basic rules were applied in preparation of this Hydrological Risk Assessment:

- There must be no likelihood of unacceptable discharge/emission over the entire lifecycle of the landfill (i.e. Landfill Regulations and Groundwater Regulations compliant);
- There must be structural/physical stability over the entire lifecycle of the landfill;
- A key output from the conceptual model should be whether the landfilled waste would lie below the groundwater at any stage of its lifecycle and, therefore, whether there is the potential for a direct discharge.

2.0 PROPOSED DEVELOPMENT

The proposed development involves the infilling with the non-hazardous municipal solid waste and restoration of a artificially produced cavity in the natural ground in three phases surrounded by land that is predominantly on the western side natural habitat, although some of the land to the west and east of the site is under cultivation and to the north with marine environment. The application covers an area of approximately 4.5 hectares.

WasteServ proposes to develop the Ta' Zwejra waste management facility as an engineered containment landfill. The Landfill site will be restored to a sloping landform, which ties back in to the surrounding land.

Key components of the proposed scheme are summarised below:

- The landfill site is to be developed through the cleaning of already deposited mainly inert waste material which was identified as stable and having low temperature in the site investigation performed by Messers Scott Wilson. To improve the efficient use of this surface area and to achieve the necessary formation level, excavation of in-situ coralline limestone from Ta' Zwejra site, in the vicinity of the Maghtab Landfill, shall be expectant.

- Following the creation of the void which is in total for 2nd and 3rd phase 200,000 cubic metres and the lining of the whole surface together with the construction of an access ramp, landfilling in the Ta' Zwejra waste facility will be divided into Phases 1, 2 and 3.

- Phase 1 or Zwejra Cell 1 at the time of preparation of this Report was already in operation and had reached 70 % of its capacity. Phase 2 infilling will take place in 2-3m horizontal layers over the whole of the Phase. Once phase 2 reaches the height level of Zwejra phase 1, the two cells will be joined to form a common landform. Phase 3 will be a continuation of Zwejra phase 1 and Zwejra phase 2 cells with infilling taking place in line with that of Phase 2. All phases will be developed in such a way to form a natural landrise which will blend in surrounding environment.

- Following the creation of the formation levels and construction of the new access ramp, infilling of the Zwejra 1 will finish in early 2005 with non-hazardous waste. Zwejra Cell 2 has an estimated capacity to take the total throughput of waste received in a period of 3 months and is expected to start receiving a fraction of the incoming waste by mid-October 2004. The lifetime of this cell should extend till February 2005. Landfilling in the Zwejra 3 will continue upon the closure of Zwejra 2 and should last roughly 9 months till the end of 2005.

- The base of the landfill is to be formed by cut and fill at existing site location of Ta' Zwejra in closed proximity of the Maghtab Landfill. The general fill materials placed will comprise of compacted crushed limestone derived from excavation. The general fill will be placed upon in-situ rocks of the Lower Coralline Limestone Formation.

- The side slopes of the landfill are to be formed by placement of general fill against the existing Lower Coralline Limestone Rock to achieve formation levels. The lower side slopes (up to 3 m above the base of the landfill) will be constructed at an inclination of 1V:2H. The upper side slopes will be constructed in 3m lifts, in line with waste placement, at an inclination of 1V:1H to a maximum height of 20m above the base of the landfill.

- The underlying formation is formed in Lower Coralline Limestone. The excavation side slopes are to be formed in the solid limestone rock.

- The groundwater table elevations below the base of the proposed landfill site range between 0.5 and 1.25m above sea level. The lowest elevation of the landfill floor will lie at 18 m above sea level. As such, the unsaturated zone thickness below the floor of both phases is at least 15 m.

- The base and side-slopes of the landfill will be lined with a composite lining system comprising of an artificially installed geological barrier and an artificial sealing liner.

- Waste placement will occur in 3m lifts across the width of the individual phases.

- Following the completion of infilling in each phase to pre-settlement levels, the waste slopes will be capped with a composite capping system that will inhibit the infiltration of rain water into the waste and contain the generated gases within the landfill.

- 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 2 meters above the basal liner.

3.0 SITE DESCRIPTION

The main hydrogeological conditions of the site are:

- the site is located outside groundwater protection zone
- the relatively dry meteorological conditions
- Water table beneath the site never to reach the base of landfill
- proximity to the sea
- the lining and other engineering elements in line with local and European regulation
- permanent operational and aftercare management
- extensive monitoring program
- low hydraulic gradient
- minor oscillation in water table level

Considering global hydrological and geological conditions within the site and attenuation properties of in situ limestone a distance to the near by receptors is considered safe. Consideration was given for the active phase and the post-closure/passive phase to encompass the whole lifecycle of the landfill up to surrender of the permit. Consideration was also given to failure and degradation of the active controls (e.g. artificial sealing liner and leachate management systems, and operational/management controls including groundwater pumping) in the future as well as the likely contaminant concentrations in the landfill when failure/degradation occurs.

The geological barrier at the Ta' Zwejra landfill site is a combination of natural and artificial materials. Since the natural geological barrier made from Lower Coralline limestone beneath the site does not provide sufficient environmental protection naturally, it was artificially enhanced. In low sensitivity locations it may be possible to use a wholly artificially established geological barrier. In such cases the artificial barrier must be at least 0.5m thick; this thickness is regarded as a reasonable minimum due to the practical difficulties inherent in constructing an engineered barrier and the need for a robust system. It would therefore preclude the sole use of a geosynthetic liner product to enhance the geological barrier.

The sides of the Leachate Collection System (LCS) of the Ta' Zwejra landfill are constructed with relatively shallow gradients lined with an artificial geological barrier. Sidewalls which are situated at an elevated height more than three metres from the landfill basal and which are relatively steep, will be eventually lined similar to the lower partsas the waste level deposited in the landfill rises. The Landfill Regulations require a geological barrier up the landfill sides irrespective of the gradient. Elements that will form part of the sidewall geological barrier include compacted minerals (soft limestone fines), the fill material behind a sealing liner and the natural geology. The designed Leachate Collection System is dimensioned in the way as never to exceed the leachate head of 1 m from the base of landfill.

The intention for the geological barrier within the Ta' Zwejra facility is to provide sufficient attenuation capacity for any potential discharge of leachate at the bottom of landfill down to water table. The hydrogeological risk assessment therefore demonstrates that leakage through the landfill sidewalls will not cause an unacceptable discharge at the compliance points.

4.0 SITE SETTING

The following information sources have been consulted in order to establish the site setting:

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

- Restoration of quarries by landfilling at Ix- Xaghra ta' Maghlaq and Qasam il Kbir – Qrendi, SLR 2004;
- Precipitation data, together with details regarding estimated evapotranspiration and runoff, National Statistics Office;
- Scott Wilson, March 2003: Development of Rehabilitation Strategies, Maghtab, Qortin and Wied Fulija Landfills, Stage III Final Report, prepared for Ministry of Resources and Infrastructure, Government of Malta;

- Published reports.

5.0 SITE SURROUNDING CONDITIONS

The engineered Ta' Zwejra landfill is situated in the vicinity of the solid waste disposal sites of Magħtab, developed at a time when the full environmental impacts of waste management operations were not considered. As a result, this has no containment systems in place for the proper control of landfill leachate.

The Scott Wilson Report and groundwater risk assessment prepared for the former Maghtab dump deal with assessing potential long-term impacts on groundwater quality.

The Maghtab site investigation identified evidence for potential impacts on groundwater quality (although the magnitude of the impacts was not considered to be significant at the time of monitoring). A lack of measured impacts on groundwater quality (despite the presence of potentially polluting materials within each landfill) is likely to be related to the finding that free leachate was not observed during the site investigation (although wastes at depth within Magħtab were moist and a condensate sample was collected and analysed). This absence of free leachate is likely to be related to a combination of the following factors (in order of presumed importance):

- High temperatures recorded within the Maghtab landfill may significantly limit free leachate generation;
- Any leachate generation is likely to be sporadic and related to intense rainfall events (the landfills were investigated during a very dry period); and
- Any leachate that is generated within the waste mass at Magħtab is likely to leave the landfill and enter groundwater by migrating rapidly from permeable waste materials into underlying fractured and fissured bedrock.

The implication of the above is that current impacts on groundwater quality by two landfills: the Ta' Zwejra, engineered, fully contained waste facility and the Maghtab uncontrolled waste dump is likely to be complex although significantly different by landfill leachate quality and quantity. In the medium to long-term, as Maghtab landfill combustion processes cease the leachate is likely to be generated transiently in increasing quantities in the wet winter season. Consequently, it is considered that the potential for detrimental impacts on groundwater quality from Maghtab dump are likely to increase with time (particularly as the source of potential chemical contamination within the landfill is unlikely to diminish in intensity for the foreseeable future).

Any cross contamination between the closed Maghtab Landfill and the engineered facility of Zwejra can be detected, monitored and mitigated through the access provided by the inspection chamber separating the two facilities.

6.0 THE GEOLOGICAL BARRIER

The hydraulic performance of mineral liners (both as artificial geological barriers and as artificial sealing liners) is generally assumed to remain unchanged throughout the lifetime of a site. It is important at this stage to identify between direct and indirect discharges.

Direct discharges are:

"the introduction into groundwater of substances in Lists I or II [or pollutants] without percolation through the ground or subsoil".

Indirect discharges are:

"the introduction into groundwater of substances in Lists I or II [or pollutants] after percolation through the ground or subsoil".

The seepage of landfill leachate through a natural geological barrier, such as an unsaturated zone, to the water table is an indirect discharge, whereas seepage directly into groundwater without the benefit of a geological barrier is a direct discharge.

This distinction is important because the direct discharge of List I substances and pollutants to groundwater is, for all practical purposes, prohibited by the Ground Water Directive (GWD) and WFD respectively.

The geological barrier within Ta' Zwejra Landfill extends along the base and all the way up the sides of the landfill site.

The geological barrier is the geological formation between the underside of the artificial sealing liner (2 mm thick geo-membrane) and the compliance point at which the requirements of the Groundwater Regulations (GWR) should be met (i.e. no unacceptable discharge). This compliance point for List II substances (described further on) could be a groundwater monitoring borehole down the hydraulic gradient of the site or another sensitive receptor. This will be a site-specific location based upon the geological/hydrogeological conditions at the site. For List I substances the compliance point will be the top of the saturated zone below the site (i.e. the water table) till the base of Landfill which is in range of 30 m.

The geological barrier of 30 m in lower coralline lime stone reinforced with crushed limestone fines which reaches a permeability rate of k= 1x10-7 m/s in combination with GCL is providing a sufficient attenuation to prevent a potential risk to soil and groundwater. This risk assessment will demonstrate the performance of the proposed geological barrier for Ta' Zwejra site against the requirements of the Groundwater and Landfill Directives. This assessment includes stability considerations, and the management of landfill gas.

7.0 RISK ASSESSMENT METHODOLOGY

The methodology for the groundwater risk assessment consists of:

1. Defining a conceptual model for the Ta' Zwejra landfill including a description of the source of contamination, the receptors at risk and the pathways by which they might be linked;
2. Application of an appropriate modelling results simulating the conceptual model and contaminant transport to the receptor; and
3. Setting targets for water quality against which the results of the modelling can be assessed.

The implementation of the risk assessment methodology is outlined below and discussed in detail for the Ta' Zwejra facility. The conceptual models describe the following process in which a source of contamination in the Ta' Zwejra landfill leachate impacts on a specified groundwater receptor by means of a pathway through the liners, mineral barrier and the limestone aquifer.

Sources

Defining the source potential of the landfills depends on an assessment of:

- The general composition of waste materials deposited in the landfill;
- The ability of the contaminants within the wastes to migrate into groundwater in aqueous solution as leachate.

For the landfill the source is defined using a combination of:

- monitoring of in-situ leachate quality from the Ta' Zwejra landfill;
- knowledge of waste input types at landfill; and available literature data on typical landfill leachate composition; and
- available literature data on typical landfill leachate composition.

At the time of drafting of this Report (October 2004) leachate was not observed at the base of Zwejra landfill. Due to absorption capacity of MSW waste disposed at site, the high temperatures of the summer season and the low precipitation rate (total of 45.5 mm) no free leachate was generated.

Source	**Landfilled Waste** ↓	Contamination mobilised by leaching via infiltrating rainfall
Pathway	**Unsaturated Zone** ↓	Assumed rapture in the geo-membrane. Downward vertical contaminant migration dissolved in infiltrating rainfall moving through the GCL and 0.5 m geological barrier then through the fissures and pores in bedrock above the water table
	Saturated Zone ↓	Horizontal contaminant migration within the limestone aquifer through fissures and pores with attenuation via dilution, dispersion, retardation and biodegradation.
Target	**Receptor**	Attenuated contamination reaches receptor (abstraction or marine environment)

Pathways

The ability of contaminants to impact on water quality depends on the rate at which they can migrate from the landfills via pathways through the unsaturated and saturated zones in bedrock to receptors. The area in which the Ta' Zwejra engineered landfill is situated is outside of Groundwater Protection Zone. The water quality is low with high content of the chloride due to vicinity of the landfill to the coast and sea environment. The magnitude of the impact depends on:

- the quantity and quality of contaminated leachate leaving the landfill (dependant on effective rainfall and waste composition);
- the physical and hydraulic properties of the unsaturated zone in bedrock between the base of the landfill and the groundwater table;
- the physical and hydraulic properties of the saturated aquifer in the bedrock;
- the local groundwater flow regime around each site (groundwater flow velocity and direction);
- the ability of contaminant concentrations to be attenuated by dilution, dispersion, retardation and biodegradation during transport in groundwater; and
- the distance from landfill to sensitive receptors.

These pathways may be modelled using a combination of hydrogeological parameters for Maltese strata available in the published literature supplemented by field observations and measurements undertaken during the site investigation. Any modelling undertaken must also take into account the specific hydrogeological situation in Malta, in particular the presence of an anisotropic karstic (dual porosity) aquifer rather than an isotropic homogenous (single porosity) aquifer.

Receptors

There are three receptors (or groups of receptors) potentially at risk from potential contaminant migration from the landfills to the water environment; these are (in order of decreasing sensitivity):

- groundwater abstractions for potable use (Wied il-Għasel) pumping station near Magħtab
- agricultural groundwater abstractions; and
- the marine environment (via coastal sub-marine discharge of contaminated groundwater).

It is reasonable to identify the receptor(s) most at risk on the basis of proximity to the landfill (impacts being likely to reduce with distance) and sensitivity.

8.0 HYDROLOGY

Rainfall

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

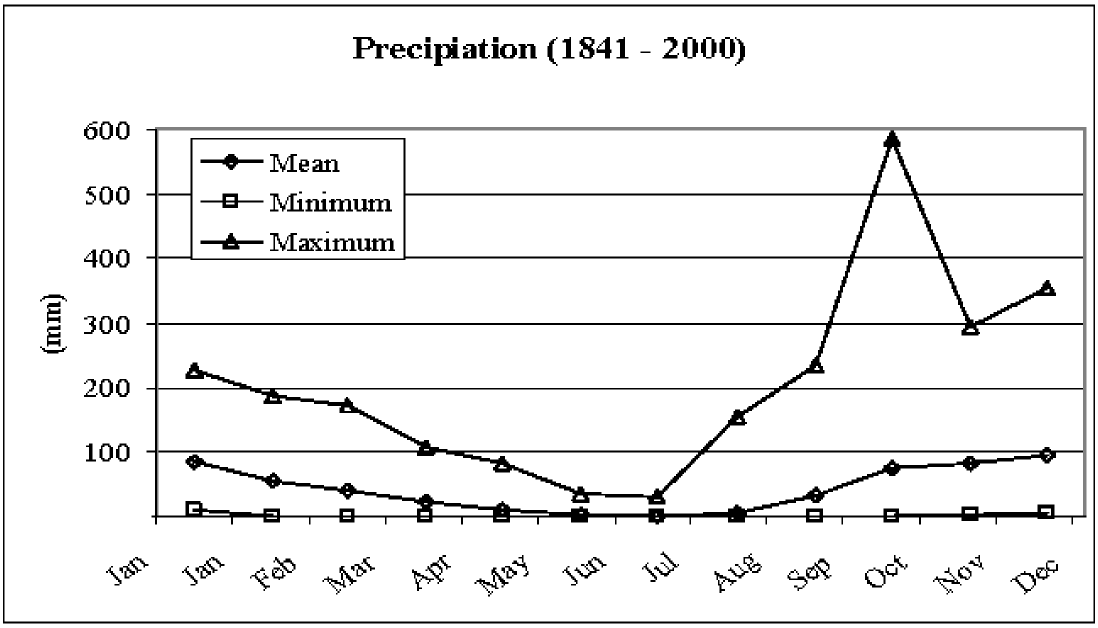
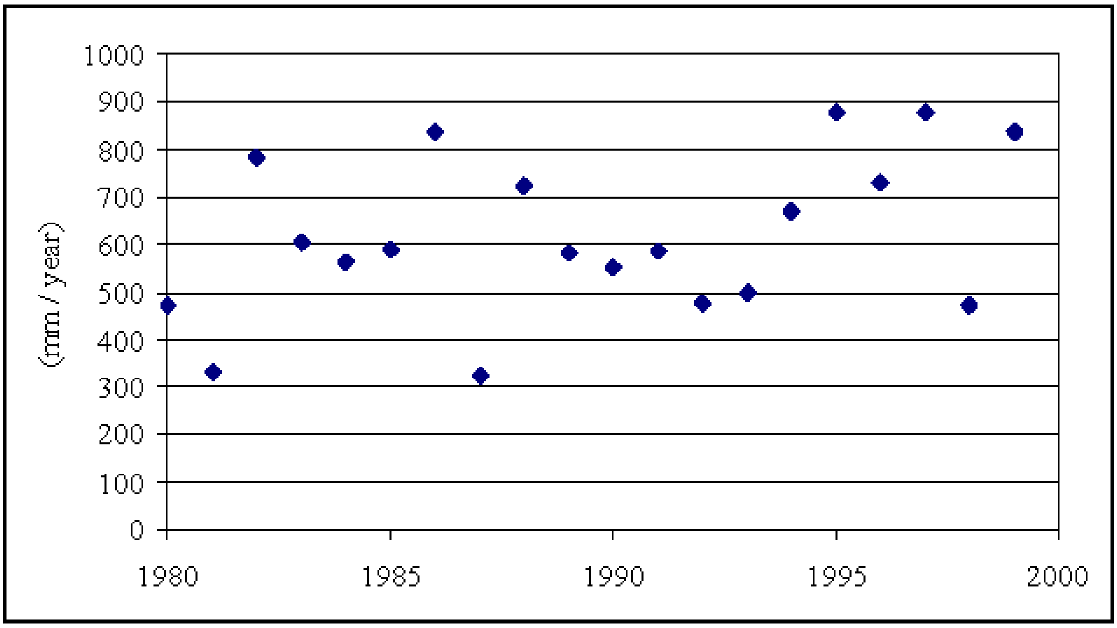


FIGURE 2: ANNUAL RAINFALL (1980 – 1999)



Note: Data Source from Meteorological Office Luqa

- The majority of rainfall takes place between October and March with approximately 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 approximately 65 to 80% is lost by 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.

Surface Water Features

- There are no permanent surface water features within the site or adjacent surrounding area if not considering the marine environment.
- The Zwejra installation lies within the small surface water catchments of Wied Ta' Kieli, covering an area of approximately 60 Hectares, as shown in Drawing No. 3. Under current conditions the surface water drainage system consisting of channels and natural water run-off slopes direct any surface water runoff from the areas towards the sea therefore preventing this surface water runoff from reaching the Landfill ground cavity.
- Surface water runoff from the majority of the catchment upgradient of the site is captured and directed by the coastal road into the sea, thus bypassing all three cells.
- The main feature of Wied Ta' Kieli is a dry water course that only contains surface water runoff during flash floods associated with heavy rainfall events.

Surface Water Abstractions

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

9.0 DRIFT GEOLOGY

There are two distinct soil types present on the site and its vicinity, the Xaghra Series and the L'Inglin Complex.

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 and occurs intermittently among hard limestone outcrops on the karst landscape. This soil series is strongly associated with Lower Coralline Limestone Formation.

The L'Inglin Complex is a strongly terraced man-made soil complex of pale brown to red, shallow to moderately deep, light to heavy textured soil resembling San Biagio, tal-Barrani, Xaghra or tas-Sigra soils. This complex is developed on carbonate raw soils, rock flour, Xerorendzina and Terra Soil mixed by strong terracing. The soil type is associated with the Lower Coralline Limestone and Lower Globigerina Limestone and is located on karst terrain.

10.0 SOLID GEOLOGY

Drawing No. 3 (ZW003/04) shows the distribution of the solid geology units located within the site. The rock section exposed from sea level at Ta' Zwejra is composed of the following rock formations:

- Globigerina Limestone
- Lower Coralline Limestone

Globigerina Limestone

The Globigerina Limestone Formation consists of three members, which are listed below, youngest to oldest.

- Upper Globigerina Limestone Member
- Middle Globigerina Limestone Member
- Lower Globigerina Limestone Member

The Lower Globigerina Limestone Member is a pale cream colour that is enriched in foraminifera. The Middle Globigerina Limestone Member is white and massive in nature. The Upper Globigerina Limestone Member is cream to pale grey mudstones to marly mudstones. The overall thickness of this formation is between 100 and 150m. Only the Lower Globigerina Limestone is present on site and constitutes only a minor geological feature that has limited exposure. The rock is described as packstones at the base grading into wackestones above the base. The member is up to 2m thick where present in vicinity of the site.

Lower Coralline Limestone

This formation is widely exposed in the environs of the site including the coastline from Salina Bay to Bahar ic-Caghaq and the slopes from Ghallis ta' Gewwa to Maghtab. The maximum thickness of this rock formation at the site is about 40m but the formation is known to subcrop below sea level. Its maximum exposed thickness within the Maltese Islands is 8km to the north-west of the site at Ta'Cenc Gozo where it is 140m. The Lower Coralline Limestone Formation is subdivided into the following rock units, some or all of which maybe present at any one location:

- Il-Mara Member (Youngest)
- Xlendi Member
- Attard Member
- Maghlaq Member (Oldest)

The rock member's summary

On site, the geology is represented by the following rock types:

- **Lower Globigerina Limestone Member**: Up to 2 m thick yellow LIMESTONE with a medium to fine grain size and is classed as moderately strong. Depth at top of bed ranges from approximately 45m to 35m asl and the depth at base of bed ranges from approximately 42m to 40 m.

- **Il-Mara Member:** Approximately 1.2m thick brown or grey recrystallised LIMESTONE classed as moderately strong and weathered. Rock is moderately fissured and has poor rock quality designation values (RQD). Depth at top of bed ranges from approximately 30m and 29.5m and base of bed at 28.8m asl.

- **Xlendi Member:** Approximately 10m thick light brown LIMESTONE with a very coarse grain size and is moderately strong. It is a massive to laminated fossiliferous calcarenite. The rock is slightly fissured and has excellent RQD values (frequently 100%). Depth at top of bed ranges from approximately 47.5m to 24.4m asl and depth of base of bed ranges from approximately 37.9m to 16m asl.

- **Attard Member:** Over 30m thick white to light yellow LIMESTONE with a very coarse grain size and classed as weak to moderately strong. It is composed predominantly of white algal fragments and algal rhodoliths. The rock is very poorly fissured with excellent RQD values (frequently 100%). This type of rock is found in all boreholes. Depth at top of bed ranges from approximately 37.9m to 16m asl and depth of base of bed at 28.2m.

- **Maglaq Member:** Over 7m thick white to light yellow, very fine grained limestone classed as weak to moderately weak. It is massive and chalky in nature and is recrystallised in places. Solid core recovery and recovery figures range from poor to moderate.

- A geological cross section is shown on Drawing No. 3 with ground levels based upon a topographical survey.

11.0 STRUCTURAL GEOLOGY

According to the 1:25,000 published geological map and geological mapping exercise, no major faults are recognized in the vicinity of the site although geological map evidence indicates that an E – W fault with substantial down throw to the north may be present running east-west and entering the proposed site. Clear evidence of this fault was not found during site excavation. Minor faults are known to be common in this area of Malta and often comprise a conjugate set with a general orientation north-south and east-west. A more detailed field mapping survey would be required to locate such minor features accurately and confirm their presence.

The geological mapping and the published geological map shows that the rocks in the vicinity are approximately horizontally bedded gently dipping north to north west in the north of the site and between south west to south east to the south of the map.

12.0 HYDROGEOLOGY

The only freshwater aquifer existing beneath the site is the mean sea level aquifer. Given the proximity of the site to the sea, and the known characteristics of groundwater within Malta, it is assumed that the freshwater lens lying above brackish water would be at most 1-2m thick with equal portions of this lying above and below sea level. From monitoring data of boreholes in vicinity of site it is expected that the groundwater will be at or close to mean sea level with slight seasonal variations.

This lead to conclusion that water table is never to reach the level of the base of landfill.

13.0 RISK ASSESSMENT TOOLS

Risks to the water environment are assessed in this report using the UK Environment Agency software package ConSim (*Contamination Impact on Groundwater: Simulation by Monte Carlo Method,* Version 1.06, February 2002). The software simulates the transport of contaminants from a source in the unsaturated zone to a receptor within groundwater. The functionality of the model is described in detail in its manual and critically evaluated in the UK Environment Agency document *Benchmarking and Guidance on the Comparison of Selected Groundwater Risk-Assessment Models* (EA NGWCLC report NC/00/14, 2000).

ConSim is designed for undertaking risk assessments using probabilistic Monte Carlo techniques in which individual values for input parameters are replaced with user specified distributions. The output produced by the model is also in the form of a probability distribution and the result is expressed in the form of the probability of a particular concentration at the receptor exceeding the target concentration (the 95th percentile of the distribution is usually adopted). This approach is very useful in minimizing the risk of producing over conservative models when modeling systems where there is significant uncertainty in the input parameters (as is often the case when simulating groundwater flow and contaminant transport).

The ConSim software uses a tiered approach to risk assessment. The three tiers within ConSim allow assessment of impacts at points along the transport pathway located progressively further away from the source. In summary:

Level 1: allows comparison of contaminant source concentration with target concentrations in groundwater;
Level 2: allows assessment of concentrations at the water table by consideration of Level 1 processes together with attenuation processes (dispersion, retardation, degradation) in the unsaturated zone and dilution in the saturated zone; and
Level 3: allows assessment of concentrations at a receptor (at some distance from the site) including consideration of Level 1 and 2 processes, together with advection and attenuation processes (dispersion, retardation, degradation) in the saturated zone.

The results of the assessment become progressively less conservative from Level 1 to Level 3. Modelling the impact of the landfill sites requires a Level 3 analysis.

The ConSim model can simulate either single or dual porosity systems; the latter being more appropriate for the karstic nature of the Mean Sea Level and Perched aquifers on Malta and Gozo. However, the dual porosity module in ConSim is designed specifically for modelling groundwater flow in the UK Chalk aquifer, which is likely to differ in detail from the behavior of groundwater in Maltese aquifers. Instead, the implementation of the conceptual contaminant transport model has assumed a single porosity system but, where necessary, it considers the implications of dual porosity flow in the aquifer when selecting input parameters and interpreting the results of the modelling.

The ConSim model requires the conceptual model to be defined in the form of inputs to the following subject areas:

- infiltration
- source term
- unsaturated pathway
- aquifer pathway
- receptor location

The translation of the conceptual model for Magħtab into inputs to ConSim is described in general below and in detail on the worksheets in Annex 1.

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 approximately 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 approximately 125mm per year.
- In the vicinity of the proposed site and surrounding areas, where the limestone bedrock is located 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 higher than the average. This is because soil moisture deficits will be smaller than other areas of the island where soil and overburden thickness are greater.
- Under existing baseline conditions a greater proportion of precipitation falling within the landfill footprint is expected to infiltrate into the underlying bedrock of the Lower Coralline Limestone Formation, due to the removal of soil and overburden. However, given the small footprint of the waste facility compared to the overall Wied Ta' Kieli catchment area, any additional component of groundwater recharge is expected to be negligible.
- Infiltrating rainwater will move downwards through the unsaturated zone of the Lower Coralline Limestone bedrock, ultimately joining the groundwater in the underlying aquifer, as described below.

Risk Reduction Goals

Risk reduction goals represent targets against which potential impacts can be assessed. The most appropriate risk reduction goals for the chosen receptor are standards for drinking water quality. It is a very conservative and strict approach considering the groundwater beneath the facility is not actually potable. There are no appropriate Maltese standards and in their absence the standards set out in EC Council Directive 98/83/EC on the Quality Of Water Intented For Human Consumption have been used.

14.0 INFILTRATION

The detailed water balance is presented in Appendix 1. The parameters adopted represent the worst-case scenario and it is doubled as per mean annual rainfall data. The maximum quantity of rainwater infiltrating into the landfill is unlikely to exceed the effective rainfall falling on Malta. This is the total rainfall less losses due to:

- evapotranspiration (combined transpiration by vegetation planted during aftercare period and direct evaporation due to the effect of temperature, solar radiation and wind); and
- waste absorption and chemical breakdown

Actual evapotranspiration in Malta has been calculated by Gutierrez (1994) to be between 64% and 74% of the total precipitation (measured using rainfall records from Luqa). The calculation of the infiltration term is detailed in the Annex 1.

It is not expected to have the run-off water entering the Ta' Zwejra landfill facility since the surface drainage system is already in place. The infiltration rate was calculated as per lined area for leachate collection and removal system. This system was constructed under independent quality assurance program that confirms the adequate specification requirements of the lining material through the whole life of the landfill.

Construction Quality Assurance Report prepared by SLR (4C/585/001) is available on request. It confirms that all installed engineered materials for efficient collection and leachate extraction system was built as per highest environmental standards in the EU. The installation of the lining engineering works for the Ta' Zwejra non-hazardous landfill incorporate the following elements:

- Excavation to achieve formation level;
- Trimming and shaping of engineered fill to create formation surfaces;
- Installation of a 500mm thick foundation layer of maximum permeability of 1×10^{-7} m/s (soft lime stone fines – ramel tal-franka)
- Laying the geo-synthetic liners (GCL with natural sodium bentonite , 2 mm thick textured geo-membrane and protective geo-textile)
- Construction of containment bunds and slopes
- Supply and installation of a leachate management system and collection point
- Laying 500 mm thick drainage layer of hard lime stone aggregate

15.0 SOURCE TERM

The source term (i.e. extent of contamination within the landfill that can impact on groundwater quality) is very poorly defined. The type and concentrations of leachate will depend on the type and location of active waste (i.e. non-inert) within the landfill, these are known to include:

- municipal solid waste (including hotel and restaurant waste, non-contaminated waste from hospitals, commercial waste and rejects from Sant Antnin Composting plant);
- industrial wastes (principally inorganic wastes from thermal processes and non-hazardous residues from waste water treatment);
- slaughterhouse and abattoir wastes;
- agricultural wastes (excluding pesticides);
- wastes from ships ;
- grit blasting wastes (non-hazardous);
- airport wastes.

Typical contaminants associated with disposal of these wastes are:

- inorganic compounds;
- heavy metals;
- acids/alkalis;
- hydrocarbons;
- asbestos;
- volatile organic compounds (including solvents);
- semi-volatile organic compounds (including tars);
- organotin compounds; and
- PCDDs/PCDFs (dioxins and furans from combustion).

Since no leachate was detected during this study the chemical analysis of condensate from well within the waste at Magħtab was used as to provide potential leachate quality in the landfill. This analysis identified elevated concentrations of the following contaminants or indicators of contamination:

- metals (arsenic, chromium, iron, manganese, nickel, lead, selenium);
- chloride;
- COD;
- ammoniacal nitrogen;
- phenols and alkyl phenols;
- chlorobenzenes; and
- PAHs.

However, the likely variability of possible leachate composition was illustrated by monitoring of groundwater quality in monitoring wells and agricultural abstractions near Magħtab. These identified the presence of a number of chemical species likely to originate within the landfill, in particular:

- cadmium and lead;
- organic solvents; and
- organotin.

Of these, only lead was observed in elevated concentrations in borehole MW3.

In the absence of definitive data on landfill leachate composition, an alternative approach to assessing the likely sources of contamination within the landfill was adopted. This depends on identifying:

- contaminants associated with the range of likely waste types deposited (listed above) for which risk reduction goals exist;
- the assumed leachability of contamination in surface waste materials sampled during the site investigation;
- contaminants in the analysis of condensate from MW3; and
- supplementing the above with literature data on landfill leachate composition.

The contaminants considered in the assessment are:

Arsenic	Nitrate	Bromoform
Benzene	Nitrite	Dibromochloromethane
Benzo(a)pyrene	Benzo(b)fluoranthene	Bromodichloromethane
Cadmium	Benzo(k)fluoranthene	Vinyl chloride
Chromium	Benzo(ghi)perylene	Ammonium
Copper	Indeno(1,2,3-cd)pyrene	Chloride
Cyanide	Naphthalene	Iron
1,2-dichloroethane	Selenium	Manganese
Lead	Tetrachloroethene	Sulphate
Mercury	Trichloroethene	Sodium
Nickel	chloroform (trichloromethane)	

The parameters are those for which a drinking water quality stand exists in European legislation (EC Council Directive 98/83/EC of 3 November 1998 on the Quality Of Water Intented For Human Consumption). Napthalene is included as an additional parameter to represent a highly mobile polycyclic aromatic hydrocarbon (PAH). (A number of the above chemical species were not identified in the analyses of either solid waste or condensate and were entered in the model at concentrations equivalent to the limit of detectio).

A number of parameters included in the Drinking Water Directive (listed below) have not been included in the model, either because there was no evidence that these are likely to be present within leachate or because site specific monitoring data is unable to distingish between the presence of the substance due to the landfill and its presence as a result of other background sources of contamination:

Acrylamide	Bromate	Pesticides (individual and total)
Antimony	Epichlorohydrin	Aluminium
Boron	Fluoride	Tritium.

Finally groundwater transport of a number of other properties of drinking water that could potentially be impacted by landfill leachate and which are specified in the Directive cannot simulated using the ConSim model. These include:

- bacteriological parameters; and
- water quality indicators (pH, electrical conductivity, taste etc.).

When calculating the leachate source term for the modelling, ConSim also requires the following inputs relating to the waste:

- its dry bulk density; and
- the dimensions of the waste source (i.e. length, width and thickness).

These are detailed in the Annex 1 and are based on measurements of the geometry of the landfill and assumptions regarding waste inputs.

16.0 UNSATURATED PATHWAY

ConSim models the migration of aqueous phase contamination mobilised by infiltrating rainfall through the unsaturated zone in bedrock beneath the landfill. The model describes this pathway by:

- its thickness;
- porosity and hydraulic conductivity; and
- vertical dispersive.

Depths to groundwater have been measured in monitoring boreholes MBH1-MBH6 around the landfill where groundwater levels were within 0.3 m or less of mean sea level. This agrees with regional mapping of the elevation of the top of the mean sea level aquifer (e.g. BRGM, 1991). The range in thickness of the unsaturated zone can therefore be taken to be the maximum and minimum elevation of the base of the waste above sea level (i.e. the range in elevation of the original ground surface beneath the landfill footprint).

The water filled porosity of the unsaturated zone is unknown but is reasonably (and conservatively) assumed to be very low. The unsaturated hydraulic conductivity of the Maltese rocks is unknown but conservatively is assumed to be the same as the saturated hydraulic conductivity (see below) - although in reality it is likely to be significantly lower. Following conventional practice, the vertical dispersivity of the unsaturated pathway is assumed to be to be 10% of the unsaturated zone thickness.

17.0 AQUIFER PATHWAY

The simulation of groundwater flow through the aquifer requires knowledge of the velocity of groundwater flow, which in turn requires information on the following properties of the aquifer:

- hydraulic conductivity and porosity;
- hydraulic gradient;
- dispersivity; and
- aquifer geometry.

17.1 Hydraulic Conductivity

The hydraulic conductivity (or permeability) is one of the principal parameters that characterise the behavior of an aquifer. The primary (intrinsic) permeability of the Lower Coralline Limestone is low: However, on the field scale the hydraulic conductivity of the Mean Sea Level aquifer is likely to be considerably higher and very heterogeneous with its value varying considerably in space.

The reasons for the heterogeneity and enhancement of field scale hydraulic conductivity relate to the well-developed secondary permeability of the limestone sequence. This is the result of tectonic fracturing (faulting and jointing) enhanced as a result of partial karstification by the development of local solution cavities on a range of scales including localised cavern formation (Martin 1970). These solution cavities tend to be strongly oriented along the lines of pre-existing fractures.

Obtaining meaningful field measurements of hydraulic conductivity in a karstic limestone aquifer is difficult. It is more praticable to take measurements of the related parameter transmissivity (flow rate per unit depth of the aquifer, units m^3/d/m or m^2/d). Gutierrez (1994) collated the results of numerous transmissivity measurements from boreholes across Malta. By combining these results with the modelled thickness of the Ghyben-Herzberg freshwater lens (i.e. the thickness of the Mean Sea Level aquifer) a number of effective hydraulic conductivity measurements were produced. By then studying the variation in the spatial distribution of the calculated hydraulic conductivity together with the specific yield of the tested wells (using the geostatistical technique co-kriging) Gutierrez produced a map of the variation in hydraulic conductivity across most of Malta. In the Magħtab area predicted effective field scale hydraulic conductivity values varied between $2x10^{-4}$ m/s to $1.5x10^{-3}$ m/s.

Determination of the bulk porosity of limestones is subject to similar difficulties to that presented by assessment of the bulk hydraulic conductivity of the rock. Laboratory porosity measurements for the Lower Coralline Limestone by ATIGA and reported by Martin (1970) were highly variable between 9% and 20 %. However, not all porespace within the limestones is interconnected and Martin estimated the effective field porosity of the Lower Coralline Limestone as probably being within the range of 10% -15% (0.10 – 0.15).

17.2 Hydraulic Gradient

The hydraulic gradient in the Mean Sea Level aquifer is low as a consequence of the very limited change in potentiometric level across the island (between 0 and 4 m above mean sea level). A potentiometric map for the Mean Sea Level aquifer produced by BRGM (1991) and reproduced in Axiak and Sammut (2002) shows that in the vicinity of Magħtab landfill, groundwater levels fall from 1m above mean sea level to 0 m at the coast over a distance of 1.3 km south of the site to 1.8 km north of the site. This implies that there is a very low hydraulic gradient of between 5.7×10^{-4} and 7.6×10^{-4} with groundwater flow in a north-east to north-north easterly direction perpendicular to the shoreline.

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

- The primary freshwater aquifer below Malta is developed within the Lower Coralline Limestone Formation. It is represented by a thin freshwater lens that overlies brackish/saline groundwater. This is known locally as the mean sea level aquifer, given that the groundwater elevations lie just above sea level. The freshwater “floats” on saline waters by virtue of its lower density and owes its existence to rainwater that every winter, percolates through the ground, adding more freshwater (recharge) to this underground storage system than can be dissipated by direct discharge to the sea at the coastline or by extraction. Heavy extraction from this aquifer has deteriorated its water quality. For this reason, a considerable part of the extraction (over 50%) has gradually been replaced by reverse osmosis desalination plants.

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

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

TABLE 3:

HYDRAULIC CHARACTERISTICS OF THE LOWER CORALLINE LIMESTONE FORMATION

Formation	Lower Coralline
Primary Hydraulic Conductivity (m/s)	2.4 x 10-^{10} to 2.27 x 10^{-6}
Secondary Hydraulic Conductivity (m/s)	3.8 x 10^{-4} to 7 x 10^{-4}
Effective Porosity (%)	10 to 15

Note:

- Primary hydraulic conductivity and effective porosity values are taken from Martin (1970).
- An assessment of transmissivity measurements (i.e. flow rate per unit depth of the aquifer) throughout Malta has indicated that secondary hydraulic conductivity values in the Ta' Zwejra area, range from <6 x 10-5 m/s to 1 x 10-4 m/s.

The aquifer has a limited saturated thickness, with groundwater elevations close to sea level. This reflects the following factors:

- The relatively small catchment size of the island of Malta;
- The relatively low effective groundwater recharge;

17.3 Geometry

The width of the aquifer is taken to be the width of the aquifer affected by (i.e. overlain by) the aquifer in the direction of presumed groundwater flow (i.e. toward the receptor –see below) (see Annex 1). The thickness of the aquifer is assumed to be equivalent to the thickness of the freshwater lens beneath Ta' Zwejra. The mixing zone thickness is assumed equivalent in thickness to the aquifer thickness – a reasonable assumption for a fractured aquifer.

17.4 Dispersivity

Dispersivity measures the degree to which groundwater contamination plumes spread in horizontal directions during transport in groundwater. In the absence of field values (which are very difficult to determine), it is conventional to assign values of 10 % and 1% of the distance between the source and receptor to the longitudinal (x-direction) and transverse (y-direction) dispersivity respectively.

18.0 ATTENUATION

In addition to dilution and dispersion in the aquifer contaminants entering groundwater may be attenuated during transport by a number of natural mechanisms, the most important of which are:

- retardation; and
- biodegradation.

Retardation slows down the movement of contaminants by sorption on mineral and organic matter within the aquifer. In particular, the clay mineral content of the aquifer is important for retarding inorganic species such as metals whilst elevated organic matter content will retard movement of organic contaminants in groundwater. Biodegradation involves oxidation of organic compounds in groundwater usually (but not always) into less harmful species mediated by naturally occurring micro-organisms.

Although, both processes can be simulated within ConSim, neither has been implemented in the model. This is because:

- the clay mineral and organic matter content of the limestone bedrock is likely to be low (thus limiting retardation); and
- the extent to which bioremediation processes are operative is unknown.

Also, modelling retardation and biodegradation may not give a conservative estimate of the impacts of contaminants on groundwater given that the presence of preferential flow paths within fissures may enhance the contaminant migration above that predicted in the model.

19.0 LOCATIONS OF RECEPTORS

The closest sensitive receptors to Ta' Zwejra are the agricultural abstractions. This is because these wells are used for irrigation of crops, watering of animals and also may provide farms with drinking water.

The risk assessment will therefore use the closest of the wells (2026) in which species likely to have originated on the landfill were detected in water as the receptor for modelling purposes.

The location of agricultural abstraction 2026 in relation to Zwejra landfill is shown in Annex 1.

20.0 HYDROGEOLOGICAL RISK ASSESSMENT

The Nature of the Hydrogeological Risk Assessment

As set out within Section 2, the proposed 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 license 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, 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. Given the nature of interim 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.

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.

Given the non-hazardous waste stream of the proposed interim 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 List I and II chemical species have been modelled, principally due to their presence within the leachate/condensate sample from Maghtab Landfill.

List I Substances:

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

Mecoprop: commonly found within leachate generated by non-hazardous (domestic) waste streams in the United Kingdom. It is also an acid herbicide, and a semi-volatile organic substance.

Naphthalene: 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.

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.

Determination of Environmental Assessment Limits (EALS)

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:

- 0.1 µg/l is considered to be appropriate for cadmium
- 4 µg/l is considered to be appropriate for toluene
- 0.04 µg/l is considered to be appropriate for mecoprop
- 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 interim 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 interim 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 Interim Landfill were the UK Drinking Water Standards (DWSs). The UK Environmental Quality Standards (EQSs) were not considered appropriate, given the lack of surface water in the immediate vicinity of the site

Numerical Modelling

The hydrogeological risk assessment has been carried out using conservative assumptions regarding the pathways and receptors. The risk assessment has therefore focused 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 2m 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 LandSim2.5 software was 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.
- 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 groundwater flow, the bulk hydraulic conductivity of the Lower Coralline aquifer has been assumed to range between 5x10-3 and 1x10-4 m/s, with a 'most likely' value of 5x10-4m/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 significantly 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.

21.0 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.

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.

Under the considered worst-case assumptions, the resultant concentrations are significantly lower than the concentrations that are considered to be discernible. Consequently, for the worst 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 seawater along the coast.

List II Substances

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 south-south-west 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.

22.0 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.

Lining Design

The engineered basal and sidewall lining design should incorporate a low permeability geological barrier that can attenuate potential pollutants. The risk assessment has demonstrated that the proposed geological barrier, comprising a GCL mineral liner with a maximum permeability of 5x10-11m/s, underlain by a layer of screened/crusher material with a minimum thickness of 500mm thick and a maximum permeability of 1x10-7m/s, should be sufficient. The liner should be installed using third party construction quality assurance.

Leachate Drainage System

The leachate drainage system should incorporate a leachate drainage blanket comprising gravel with a hydraulic conductivity of not less than 1x10-4 ms^{-1}, which could incorporate carrier pipework. The leachate drainage layer should extend across the landfill base.

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 2.0m 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.

Groundwater Management

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

Leak Detection System

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

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.

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;
- 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 Zwejra 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 behavior) 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.

Leachate, Groundwater and Surface Water Monitoring Schedule

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

23.0 CONCLUSIONS

The conceptual model must explicitly identify whether there is potential for a direct discharge of any polluting substances, including listed substances under GWD, or pollutants under WFD.

A key output from the conceptual model should be whether the landfilled waste would lie below the groundwater at any stage of its lifecycle and, therefore, whether there is the potential for a direct discharge as described previously. This will have a bearing on the level of detail required in the risk assessment as well as the nature of the landfill development.

The location of landfill sites should be as such where they do not have the potential to cause direct discharges of pollutants into groundwater, or for ingress of groundwater to the wastes. From the perspective of groundwater protection, sites on low-permeability strata that are also remote from any groundwater resource or surface water body are preferred. Sub-water table sites in permeable strata are likely to be viewed least favorably in this context. The passage of leachate through a substantial and intact mineral barrier (that is, an artificially established geological barrier) can be regarded as analogous to percolation through the ground. As such, any discharge should be viewed as indirect. It also follows that if there was a substantial breach of this barrier, the hydraulic discontinuity would be removed and the discharge may become direct. Hydraulic containment works on the principle of maintaining a hydraulic gradient into the landfill site. Under these conditions, operators typically seek to reduce hydraulic gradients into the site to minimize inward seepage that will add to leachate production.

Compliance with the Waste Management (Landfill) Regulations, 2002

The results of this risk assessment have established the following:

- The proposed development has a potential hazard to ground and surface water quality.
- Consequently, arrangements have been made to collect the contaminated water and leachate that may bs 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 side slopes. 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 Waste Management (Landfill) Regulations, 2002.

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.

ANNEX 1

MODEL PARAMETERS FOR TA' ZWEJRA **LANDFILL SOURCE**

Parameter Value Derivation
Infiltration in to Open Waste during Operational Period (mm/year)
Min: 224
Mode: 500
Max: 1009
Triangular
As a worst case this assumes that all rainfall is able to enter the waste mass during the operational phase of the landfill. Between 1841 and 2000 the average annual rainfall is reported as 502mm.
Cap Design Infiltration
Rate for Post Closure Period(mm/year) 20.0 ± 5.0
Normal Typical accepted values for restored landfill cap.
Effective Infiltration during Long Term Post Closure Period (Scenario 3) (mm/year)
125 ± 50.0
Normal (Debono, 1988). Between 1841 and 2000 the average annual rainfall is reported as 502mm.

LEACHATE QUALITY DATA

Parameter Value Derivation
Ammoniacal-N (mg/l)
Min: 32.1
Mode: 267
Max: 1,100
Log Triangular
LandSim 2.5 defaults values for Operational Period (Scenario1). the maximum concentration is significantly higher than The measured contaminant concentration of 643mg/l that was
detected in the leachate/condensate sample from the Maghtab Landfill1, and so represents worst case conditions.
Chloride (mg/l)
Min: 227
Mode: 997
Max: 5,554
Log Triangular
The maximum concentration is based on the measured contaminant concentration of 5,554mg/l that was detected in the leachate/condensate sample from the Maghtab Landfill1, and is significantly higher than the LandSim 2.5 maximum default value of 2,650mg/l. The Mode and Minimum are based on LandSim 2.5 defaults values, as a worst case.
Parameter Value Derivation
Arsenic (mg/l)
Min: 0.00371
Mode: 0.00485
Max: 0.0107

Log Triangular
Chromium (mg/l)
Min: 0.0231
Mode: 0.0981
Max: 0.416
Log Triangular
Copper (mg/l)
Min: 0.0129
Mode: 0.0509
Max: 0.191
Log Triangular
Lead (mg/l)
Min: 0.0337
Mode: 0.111
Max: 0.340
Log Triangular
Nickel (mg/l)
Min: 0.0345
Mode: 0.126
Max: 0.627
Log Triangular
Based on LandSim 2.5 defaults values, as a worst case. All parameters present within the leachate/condensate sample from Maghtab Landfill
Cadmium (mg/l)
Min: 0.0001
Mode: 0.00027
Max: 0.027
Log Triangular
The modal concentration is based on the measured contaminant concentration of 0.00027mg/l that was detected in the leachate/condensate sample from the Maghtab Landfill1, The maximum value has been increased by 2 orders of magnitude in order to represent worst case conditions.
Mecoprop (mg/l)
Min: 0.0001
Mode: 0.022
Max: 0.140
Log Triangular
Napthalene (mg/l)
Min: 0.0001
Mode: 0.003
Max: 0.055
Log Triangular
Toluene (mg/l)
Min: 0.010
Mode: 0.087
Max: 1.287
Log Triangular
Values are based on Knox, *et.al.* (Oct 2000) The maximum concentration for Naphthalene is based on the
measured concentration of 0.055mg/l that was detected in the leachate/condensate

sample from the Maghtab Landfill1
Note: Kappa value constants of m (slope) and c (intercept) are taken from LandSim V2.5 defaults.
2 Knox, K *et.al.* (Oct 2000)2 : *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.

BASAL LINING SYSTEM

Parameter Value Derivation
Artificial Sealing Liner (Composite Basal Lining System comprising HDPE underlain by Miner Liner).
2mm HDPE Membrane
Defects (per Ha) Pin Holes (0-5mm2)
Min: 0
Mode: 13
Max: 13
Holes
(5-100mm2)
Min: 0
Mode: 3
Max: 3
Tears (100-
10,000mm2)
Min: 0
Mode: 0.1
Max: 1
Triangular
Assuming CQA, leak detection survey and any necessary repairs are undertaken prior to waste deposition, as per LandSim V2.5 defaults.
Onset of HDPE Liner Degradation (years since filling commenced) 150 Single LandSim 2.5 default.
Time for Area of Defects to Double (years) 100 Single LandSim 2.5 default.
Mineral Liner GCL Bentofix or similar approved (m) 0.1
Single Value Proposed design.
Liner Permeability (m/s)
Min: 1x10-12
Mode: 1x10-11
Max: 5x10-11
Log Triangular
Range is based on manufacturer's specifications for Bentofix.
Retardation Coefficient -
Cadmium
(Kd) (l/kg)
Min: 0.9
Max: 4,500
Uniform
LandSim default values have been for cadmium. As a worst case no retardation has been assumed for the other considered leachate parameters.

Density (kg/l)
Min: 1.5
Max: 1.6
Uniform Based on GCL specifications, as provided by manufacturer. Moisture Content (fraction)
Min: 0.01
Max: 0.20
Uniform
Artificial Geological Barrier (m)
Thickness (m) 0.5
Single Proposed design of screened/crushed material.
Longitudinal Dispersion 0.04
Single Value LandSim approach (10% of pathway length).
Hydraulic Conductivity (m/s)
Min: 5x10-8
Mode: 8x10-8
Max: 1x10-7
Log Triangular
Proposed design will have a maximum value of 1x10-7m/s.
Parameter Value Derivation
Moisture Content / Effective Porosity (fraction)
Min: 0.10
Max: 0.40
Uniform
Representative range based on proposed screened/crushed material to be used.
Density (kg/l)
Min: 1.5
Max: 1.8
Uniform Representative range.
Organic Carbon Content (%)
Min: 0.0017
Max: 0.017
Uniform
Maximum value is based on Fraction of Organic Carbon (foc) analysis, undertaken by ***TES*** Bretby Laboratory, UK, on two samples of material likely to be used as the artificial geological barrier. Minimum value reduced by 1 order of magnitude in order to represent worst case conditions.

Retardation Coefficient - Ammonical-N (Kd) (l/kg)
Min: 0
Max: 10
Uniform
LandSim default values. Minimum Value represents worst case condition.
Retardation Coefficient – Chloride (Kd) (l/kg)
0
Single Value
Retardation Coefficient – Arsenic (Kd) (l/kg)
Min: 25
Max: 250
Uniform

Retardation Coefficient – Chromium (Kd) (l/kg)
Min: 0
Max: 4,400
Uniform
Retardation Coefficient – Copper (Kd) (l/kg)
Min: 40
Max: 30,000
Uniform
Retardation Coefficient – Lead (Kd) (l/kg)
Min: 20
Max: 270,000
Uniform
Retardation Coefficient – Nickel (Kd) (l/kg)
Min: 0.1
Max: 8,100
Uniform
Retardation Coefficient – Cadmium (Kd) (l/kg)
Min: 0.9
Max: 4,500
Uniform
LandSim default database.
Retardation Coefficient – Mecoprop (Koc) (l/kg)
20
Single Value
Value sourced from web page
http://www.ext.nodak.edu/extpubs/h2oqual/watgrnd/er18-1.htm
Retardation Coefficient – Naphthalene (Koc) (l/kg)
Min: 1288
Max: 2000
Uniform
RBCA Tool Kit for Chemical Releases, Version 1.0a and Soil Screening Guidance: User's Guide, US EPA
Document Number: EPA540/R-96/018, July 1996
Retardation Coefficient – Toluene (Koc) (l/kg)
Min: 131
Max: 242
Uniform
ConSim default value.
Degradation Half Life - Ammonical-N (years)
Min: 3.5
Max: 4.5
Uniform
Minimum value is based on ammoniacal nitrogen degradation for unsaturated conditions Erskine (2000)3. Maximum value assumes worst case conditions.
Degradation Half Life – Chloride (years) 0
Single Value No degradation assumed.
3 Erskine A.D. (2000): *Transport of ammonium in aquifers: retardation and degradation.*
Parameter Value Derivation
Degradation Half Life – Cadmium (years) 0

Single Value No degradation assumed.
Degradation Half Life – Mecoprop (years)
Min: 0.07 Max: 0.5 Uniform
Degradation Half Life – Naphthalene (years)
Min: 0.07
Max: 0.7
Uniform
Degradation Half Life – Toluene (years)
Min: 0.15
Max: 0.57
Uniform
Degradation half lives are taken from Howard *et. al.* (1991) Handbook of Environmental Degradation Rates, and reflect range for aqueous anaerobic biodegradation.

UNSATURATED VERTICAL PATHWAY IN LOWER CORALLINE LIMESTONE

Parameter Value Derivation
Thickness below landfill (m)
Min: 15
Max: 50
Uniform
Vertical thickness of the in situ limestone above the 'Mean Sea Level' Aquifer. Minimum value represents distance from the floor of the landfill to the Mean Sea Level Aquifer. Maximum value represents proposed basal elevation of landfill above inert fill.
Thickness below Site (m)
50
Single Value
Vertical thickness of the *in situ* limestone between the base of the landfill and the 'Mean Sea Level' Aquifer.
Effective Porosity (fraction)
Min: 0.01
Uniform
Minimum value takes into account fissure flow.
Longitudinal Dispersion (m) 0.1
Single Value Minimal dispersion assumed as a worst case.
Degradation Half Life - Ammonical-N
(years)
Min: 3.5
Max: 4.5
Uniform
Minimum value is based on ammoniacal nitrogen degradation for unsaturated conditions Erskine (2000)3. Maximum value assumes worst case conditions.
Degradation Half Life – Chloride (years)
0
Single Value No degradation assumed.
Degradation Half Life – Cadmium (years)

0
Single Value No degradation assumed.
Degradation Half Life – Mecoprop (years)
Min: 0.07
Max: 0.5
Uniform
Degradation Half Life – Naphthalene (years)
Min: 0.07
Max: 0.7
Uniform
Degradation Half Life – Toluene (years)
Min: 0.15
Max: 0.57
Uniform
Degradation half lives are taken from Howard et. al. (1991) Handbook of Environmental Degradation Rates, and reflect range for aqueous anaerobic biodegradation rates as a worst case, given that aerobic degradation rates will be dominant within the significant thickness of the unsaturated zone. Aerobic half life degradation rates are smaller than anaerobic half life degradation rates.
FLOW WITHIN LOWER CORALLINE LIMESTONE AQUIFER
Parameter Value Derivation
Hydraulic Conductivity (m/s)
Min: 1x10-4
Mode: 5x10-4
Max: 5x10-3
Log Triangular
Based on range presented for the Lower Coralline Limestone aquifer by (Martin 1970)4 and including faulted/karsified bedrock in the vicinity of the large fault zone to the immediate south of the site.
Pathway Length for Site (m)
Min: 25
Max: 275
Uniform
After site plans and assuming compliance point is downgradient site boundary.
Mixing Zone Thickness (m)
Min: 2
Max: 20
Uniform
Based on groundwater table elevation below the site, including the Ghyben-Herzberg effect at the coast line.
Minimum thickness represents worst case conditions.
Degradation Half Life - Ammonical-N (years)
Min: 6
Max: 10
Uniform
Minimum value is based on ammoniacal nitrogen degradation for saturated aquifer conditions Erskine (2000)3. Maximum value assumes worst case conditions.
Pathway Porosity
(fraction)
Min: 0.10

Max: 0.15
Uniform
Estimated range by Martin (1970)4.
Longitudinal Dispersivity
Min: 2
Max: 27
Uniform
LandSim approach (10% of pathway length).
Transverse Dispersivity
Min: 0.6
Max: 8
Uniform
LandSim approach (3% of pathway length).
Note: No retardation assumed within the Lower Coralline Limestone aquifer pathway for any of the considered leachate parameters. Degradation effects only considered for ammoniacal nitrogen.

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- List I Substances 0.00
- Fixed Value Assumed zero as a worst case condition.
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