Magħtab Landfill Site - Steepwall Disposal Cell

Hydrogeological Risk Assessment Report

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1. Introduction

1.1 Report context

This report describes the hydrogeological risk assessment for the new landfill at the Magħtab waste management complex in Malta. The new landfill will receive municipal waste as part of the integrated waste management system in Malta. It is required as the nearby Magħtab and Ta'Żwejra Landfill Sites are full and already closed, and the remaining areas for disposal are limited on the operational Għallis Landfill Site.

The hydrogeological risk from a landfill site results from the potential infiltration of contaminated water (leachate) into groundwater, with subsequent potential impacts on resources and ecological systems. The risk is assessed in this report by:

- Description of the natural environment in the vicinity of the new landfill
- Description of the design of the landfill
- Quantification of the environment and design parameters
- Numerical modelling of potential infiltration and risks

The new landfill will utilise an innovative vertical steepwall lining system which will maximise capacity of the void in comparison to the size of the land footprint. This will also reduce the generation and infiltration of leachate in proportion to the quantity of waste. The design and ground conditions have been described in other documents, which are listed in the references section of this report.

This report was prepared by environmental engineering consultancy, CQA International Ltd, on behalf of the operator of the waste management complex, Wasteserv Malta Ltd.

A hydrogeological risk assessment report was previously prepared by SLR Ltd for Wasteserv Malta Ltd, in relation to the hazardous waste landfill that was planned to be constructed on part of the current site. Some factual information presented in this report is referred to herein, under the terms of use specified in the SLR document.

1.2 Factors affecting the assessed risks

The new landfill site will be compliant with the requirements of the EU Landfill Directive and, as a result, infiltration of leachate into the environment during the operational and managed after-care periods will be extremely low.

Factors which affect the potential for generation of leachate and its subsequent infiltration are:

Waste characteristics

Climate

Dimensions of the site

Lining system

Leachate management

Long-term degradation of components

These factors are described in subsequent sections of this risk assessment report.

2. Conceptual site model

2.1 Natural environment

2.1.1 Topography and land use

The natural ground level in the vicinity of the new landfill is approximately 40-50m above mean sea level, with a gentle slope towards the north west. The landscape to the north and east has been substantially modified by the construction and operation of the adjacent landfill sites, where ground levels now rise to a maximum of approximately 100m. The land to the south and west has a similar level to the site and is divided into fields and small settlements.

The distance to the coastline from the new landfill is 750m in a north-easterly direction and 950m in a north-westerly direction. The distance is greater to the north, where the adjacent landfills are located.

A sketch plan of the area is presented in Figure 1. A sketch cross section, illustrating some of the elements described in this report, is presented in Figure 2.

2.1.2 Climate

The climate of Malta is semi-arid Mediterranean, with hot dry summers and mild wet winters. Rainfall often occurs as intense storms.

The SLR hydrogeological risk assessment summarised the rainfall records, including the following statistics, taken from data for the years 1841 to 2000.

Mean annual rainfall	501.76mm
Maximum annual rainfall	1009.40mm (in 1951)

Minimum annual rainfall	224.30mm (in 2000)

These data are summarised in Figure 3.

The wettest month was observed to be December, with an average rainfall of 93.69mm, and the driest month was July, with an average rainfall in this period of 0.57mm. Data taken from a chart of total rainfall quantities for the period 1980 to 1999 indicates a higher average annual rainfall of 618.40mm in this period.

To augment these data, CQA International Ltd has reviewed rainfall records from the years 2007 to 2017. Some key statistics are:

Mean annual rainfall	512.72mm
Maximum annual rainfall	680.32mm (in 2009)
Minimum annual rainfall	326.00mm (in 2016)

The wettest months were observed to be October, November and December, with very similar average rainfalls of 82.67, 83.77 and 81.68mm, respectively. The driest month was July, with an average rainfall in this period of 0.12mm.

These data are summarised in Figure 4.

The annual rainfall totals are plotted for year in Figure 5. The data from 1980-1999 are also included in this chart. There appears to be a generally increasing trend in total rainfall from 1980 to 1999, of approximately 11mm per year, although there is considerable variation. The data from 2007 to 2017 show a trend of rainfall reducing by 22mm each year, with much less variation. These trends are probably artificial patterns, caused by the small data subsets, rather than an indication of meteorological trends. Climate change is expected to reduce the amount of rainfall in the coming decades. However, the annual effects are likely to be small, and currently difficult to differentiate from the natural variation.

In the decade 2007 to 2017, on average 93% of rainfall fell in the period from September to April, inclusive. The other 7% fell in the five summer months.

Evapotranspiration will be relatively high over much of the year, due to the mild climate, and will be higher in summer and, due to the low rainfall.

Evapotranspiration will result in the development of a high soil moisture deficit. This deficit is a major barrier to the recharge of groundwater resources.

Rainfall is generally sporadic, usually with several dry days between days with showers. This will mean that the soil is only likely to become sufficiently saturated for infiltration to be effective for a small number days each year. If the soil is too saturated, and for too long, further rainfall will runoff as overland flow and could be lost to the sea via ephemeral streams.

2.1.3 Geological strata

The bedrock on the site are primarily strata of the Lower Coralline Limestone formation, of Oligocene age. According to the report by Adrian Mifsud, some thin beds of the overlying Globigerina Limestone formation, of Miocene age, are visible in the south-eastern part of the site.

The "Globigerina Limestone" is generally a massive and porous formation,30 to 210m thick, although only the lowest 2-3m is likely to occur on site. The full profile contains some thin hardgrounds, phosphoritic and clayey beds, which act as aquitards, creating localised "perched" water tables. These are unlikely to be present on or near the site of the new landfill.

The Lower Coralline Limestone formation comprises the lowest exposed strata on the Maltese islands. The rockmass is typically moderately weak to moderately strong and massively bedded. The strata form sea cliffs in many locations. Up to 100m of the formation outcrops on the western side of the island, with a shallow dip in an easterly direction. The formation extends below sea level and a total thickness of 450m has been measured in reconnaissance oil-well logs. Coral-reef formations have been observed in some locations which are generally more porous than the main part of the rockmass.

Karstic features are present in the limestone bedrock of the Maltese islands. These are typically present in the upper beds of the Lower Coralline Limestone. A horizon of karstic features has been found on site, at a depth of 20m, at the boundary between the upper Xlendi member and the lower Attard member of the formation. This is illustrated in Figure 2. These features comprise irregular, partly connected voids with some staining by red clay. The voids are too small to be accessible and seem to be joints that were enlarged by percolation of rainfall at a wetter period in the past. The karstic processes are unlikely to be active in the present day due to the low rainfall. Due to the topography, they are not expected to extend far from the new landfill.

There are no superficial or soil deposits on site because the new landfill will be constructed partially in the area where the previous hazardous waste landfill cell was constructed and partly in an existing excavation.

2.1.4 Geological structure and seismicity

Malta sits on the northern edge of the African continental tectonic plate, close to the suture which connects to the Eurasian crustal unit. A major north-west to south-east trending fault line (the Victoria Fault) marks a division of Malta into two parts: north-west and south-east. The north-western part is bisected into a series of small rift valleys, separated by ridges. Geological faults are mainly associated with these rift systems and have north-east to south-west trends. There is a less-well developed conjugate set of faults. Jointing in the limestone follows similar trends, with some variation.

Most seismic activity in the region is connected with the subduction zone to the north of the continental suture. As such, Malta has relatively low seismicity, which is mainly connected to the fault systems in the rift valleys. The shocks from large earthquakes which occur to the north of the suture can produce relatively strong effects in Malta. Six such earthquakes have occurred in the last 150 years, producing the equivalent of magnitude 5-7 events in Malta. The 2013 Euro-Mediterranean Seismic Hazard Model predicts low ground accelerations, of less than 0.05g.

2.1.5 Hydrogeology

The Lower Coralline Limestone forms an unconfined fracture-flow aquifer over much of south-eastern Malta which is exploited for public water supply and irrigation. The permeability is due to discontinuities and will, therefore be variable. Coral reef structures, believed to produce higher permeability zones, do not appear to have been encountered in the excavation for the new landfill.

Recharge of the aquifer is relatively low and occurs from infiltration of rainfall and leaks from the water-supply system. The latter is not so important near the new landfill. Infiltration of rainfall into the aquifer is attenuated by evapotranspiration and the soil moisture deficit in the soil and subsoil. Runoff into surface water is low because of the high infiltration. Therefore, although Malta has well developed aquifer strata, the water resources are fragile as a result of the climate.

Deep groundwater in the aquifer is saline, due to inflow from the Mediterranean Sea. In common with many islands, a layer of less dense freshwater occurs on top of the seawater, with a zone of brackish groundwater at the interface between the two types.

The thin layer of groundwater is extracted for public supply from systems of horizontal galleries. The extraction rate has exceeded recharge in recent times and, as a result, brackish water is encountered by the many wells, with chloride concentrations up to 2000 mg/l. Nitrates are also of concern in some parts of Malta. Agricultural sources tend to be vertically drilled wells.

The HRA for the hazardous waste landfill cell noted that chloride concentrations immediately up gradient of the site ranged between 1,275mg/l and 1,700mg/l. Chloride concentrations in the nearby agricultural wells (also up-gradient) were between 1,723mg/l and 3,068mg/l. The chloride concentration immediately down gradient of the site was 4960mg/l. The groundwater under the site, therefore, is brackish and the flow direction is towards an area of increasing salinity.

The Magħtab area is not identified as an area of protected groundwater and there are no public supply wells near the site of the new landfill. Some private wells occur to the south west, which are probably farm water supplies. It is not known if these are in use because treated sewage effluent is understood to be a source of irrigation water in the Magħtab area.

Boreholes completed on the site did not encounter groundwater, which is understood to be close to sea level under the site. Groundwater has not been encountered in previous boreholes or in excavations on the site. The HRA for the hazardous waste cell predicted a groundwater level of 0.75m above sea level under the site, based on projections from a previous regional study.

The base of the excavation will have an elevation of 7m above mean sea level, groundwater will be close to the base of the cell. This is likely to be brackish, possibly with a thin layer of freshwater at the top. For modelling purposes, a range between the current level and a higher water level has been assumed. This is due to the long time periods involved, and the need to include the possible effects of climate change and increasing sea level.

If the water table levels are similar to the topography, the new landfill is located on a groundwater divide. This, combined with the low hydraulic gradient and reduced infiltration due to interception of rainfall by the nearby landfill sites, will result in low groundwater flow rates towards the coastline.

2.1.6 Hydrology

The new landfill is located in an area where the landform and elevations have been greatly modified by the development of the waste management facilities. Much of this area is at a high level than the new landfill. Runoff from rainfall that is incident on closed landfills, roads and other areas, will be collected in the site drainage system and will not affect the new landfill site, either as a flood risk or as potential water for infiltration into the ground.

The new landfill may, on topographical basis, be located in the same catchments as the agricultural land to the east and south of the site. The previous HRA report includes a calculation of the areas of adjacent catchments and potential quantities of runoff.

During operations, most incident rainfall would contribute to the formation of leachate, which will be managed by the site facilities. After closure and capping of the new landfill, there may be occasional runoff, if the field capacity of the cover soil is occasionally exceeded. This surface water will be diverted into a balancing pond and may be available for technical or irrigation use on site, or, if the quality is assured, for controlled infiltration into the aquifer.

The drainage measures on site isolate the site from the adjacent land and there is no hydrological continuity between the site and the adjacent catchments. Therefore, the site will not suffer from, or contribute to, flood risk on adjacent land.

2.1.7 Possible effects of climate change

The sea level of the Mediterranean Sea is expected to rise by up to 96 cm by 2100. This will cause a rise in groundwater levels, possibly by a similar amount. As the layer of freshwater is relatively thin, the freshwater–saltwater interface will also rise. This interface has already risen because of over-abstraction. A climate-change related increase in sea level will make abstraction sources more likely to encounter brackish water.

The possible rise in groundwater level is will affect the new landfill by reducing the thickness of the unsaturated zone of strata under the lining system. The unsaturated zone will provide attenuation to the migration of some contaminants, in the distant future after the lining system is expected to have degraded. This is covered in the modelling in this report.

Annual rainfall in Africa and southern Europe is expected to fall by between 10% to 40% by 2100. This is expected to be accompanied by a shorter rainy season with higher-intensity storms. These factors could decrease the quantity of water that can infiltrate into the aquifers, thereby making the water balance more negative and reducing available resources.

A reduction in rainfall and potential recharge will have a positive effect in reducing the quantity of leachate generated, either before the site is capped or in the future when the capping system is expected to degrade.

2.2 Design and operation

2.2.1 Dimensions

The footprint of the new landfill will have dimensions of approximately 110m by 300m, i.e. covering an area of 3.4 hectares. A conventional landfill with sloping sides would have had a maximum depth of 20m and a disposal capacity of approximately 600,000 cubic metres. The innovative design of this site has vertical side slopes and a greater depth, providing a waste disposal capacity 2.5 times larger than would be possible with the conventional construction methodology. Achieving the same capacity with a conventional construction would have required a land area almost 1.8 times larger. Reducing impact on the land bank is one key environmental benefit of the innovative design.

The geometry of the new landfill, with vertical sides, will produce significantly less leachate than a landfill with conventional sloping sides. The latter would have a surface area 1.8 times greater to achieve the same basal dimensions and depth. Incident rainfall would be 1.8 times greater, as would subsequently infiltration.

The vertical-sided design will result in lower leachate levels and treatment requirements in the operational and after-care periods. In the long-term, this will reduce the potential infiltration and thereby reduce the relative impact of the new landfill on groundwater.

2.2.2 Lining system - base

The new landfill will have a containment system that is compliant with the requirements of the EU Landfill Directive, as transcribed into Maltese Law.

The base of the landfill will be sealed with a composite lining system, comprising

2mm HDPE geomembrane

Geosynthetic Clay Liner (GCL)

Engineered mineral liner

Geological barrier

The HDPE liner will be constructed from specially produced geomembrane materials which are effectively impermeable. Leakage can realistically only occur through defects and to reduce this possibility, the geomembrane will be installed by a specialist company with independent quality assurance monitoring. The final installation will be subject to geophysical testing, after the leachate drainage system is placed, which can effectively guarantee the absence of defects immediately prior to operations.

There is a lack of suitable soils which can be used to produce engineered mineral liners, without some augmentation. This is a common issue in many areas, which is typically mitigated installing a continuous layer of GCL on top of the mineral liner. The proposed design follows this approach, with a GCL placed between the engineered soil and geomembrane. GCL is a composite material containing a layer of natural sodium bentonite clay which will have a permeability of 1×10^{-11} m/s when placed and hydrated. Overall, the basal lining system will have a hydraulic conductivity of less than the required 1×10^{-9} m/s for an equivalent 1 m thickness.

There is potential for cation exchange in the GCL, which may reduce permeability in the long term. This will be mitigated by the reduced availability of water under normal operating conditions.

The geological barrier will be the natural limestone strata. The hydraulic conductivity will be variable due to the zones of discontinuities. As this formation is classified as an aquifer, the strata are not relied on as part of the impermeable lining system. However, the strata will have a role in potential retardation of any seepage, due to physical and chemical processes in the unsaturated zone above the groundwater level.

2.2.3 Lining system - sides

The vertical sides of the landfill will also be sealed with a composite lining system, that is compliant with the requirements of the EU Landfill Directive. This will comprise:

2mm HDPE geomembrane

Engineered mineral liner

Geological barrier

The HDPE geomembrane will be the same material as used on the base, and will be welded into a continuous layer, with quality assurance monitoring. The geomembrane will be mounted onto a modular steel framework, which will allow safe installation in a vertical orientation.

The mineral liner will be formed from a bentonite-enhanced concrete, which will be cast in layers behind the steel framework.

The geological barrier will be the natural limestone strata, as discussed above.

2.2.4 Operation and leachate management

The landfill has a relatively small footprint for the volume of waste. The vertical sides mean that the surface area of waste will not change greatly during the operations. A significant proportion of rain that falls onto the waste will infiltrate to become leachate.

The base will be divided into two cells of approximately equal size. Thus, for an initial period, any rainwater that accumulates before a cell is used could be removed as clean water.

The cells may be closed and capped in phases, although there is unlikely to be a long time period between the start and finished of capping.

A layer of gravel in the base of the new landfill will ensure that percolating leachate is collected from the base of the waste. This, and pipes within the gravel, will allow the leachate to flow to one of two sumps, from where it will be removed by pumping to storage lagoons and a treatment plant.

Leachate levels are anticipated to be controlled to low levels during the operational period, and also during the period after closure when the site remains in use as a waste management facility.

2.2.5 Cap design

The capping of the new landfill is proposed to be:

Restoration soil (1m)

Protection layer (300mm)

Drainage geocomposite

LDPE geomembrane

Levelling soil (minimum 300mm)

The capping system will be emplaced on a waste surface which is graded to rise in a gentle slope above the level of the top of the side liner. The topography will be designed to maintain slopes and avoid the formation of depressions as the waste settles. The slope will promote runoff from the cap in heavy rainfall events.

The restoration soil will provide an additional barrier to infiltration, due to absorption and evaporation of water by the soil, evapotranspiration if the cap is vegetated. It is likely that rainfall will only reach down to the geomembrane in prolonged periods of wet weather, when the porous capacity of the restoration soil is reached.

The impermeable component of the cap will be the geomembrane, which will be installed with quality assurance verification. The geomembrane will effectively prevent infiltration into the landfill. The drainage geocomposite will prevent saturation by water, which may affect the stability of the restoration soil layers.

2.2.6 Liner service life and potential infiltration

The new landfill, as with any constructed facility will have a service life that is determined by the changing properties of the materials over time.

The degradation of the polymers will occur as a result of oxidation and crystallisation, which will break up the long molecules. This process is typically promoted by exposure to ultraviolet light, and the inclusion of carbon in the resin provides protection for the short periods when the liner is exposed. Thereafter, the oxidation and crystallisation will result from chemical and physical effects in the landfill, for which there is limited data.

The capping membrane will be subject to different temperatures and pressures than the basal liner. The basal liner will initially be exposed to pronged temperatures, up to 60°C, which may influence the material properties. These temperatures will reduce in time, perhaps over several decades, as the exothermic biological decomposition processes run to completion. The basal liner will also be exposed to leachate, which could be chemically corrosive. This material will, however, be subject to only very slight stresses due to the stability of the formation.

In comparison, the capping membrane will be mainly dry but will be exposed to greater stresses as the waste settles, causing deformation of the liner. The capping geomembrane will be thinner and of lower density to accommodate the settlement. This may also affect the durability in the long term.

The best estimate is that the polymer materials (both HDPE and LDPE) will degrade in the long-term, probably at similar rates in relation to the overall lifespan of the landfill. It is difficult to be certain about the period because these materials have only been used for 30-40 years, which has not been sufficiently long to observe and interpret possible effects. It is likely that the geomembrane layers may start to degrade after 100-200 years and be completely ineffective after 1000 years.

After the capping geomembrane becomes ineffective, the infiltration into the waste will potentially increase, although this will continue to be reduced by the processes in the restoration soils. The infiltration rate is likely to be similar in magnitude to the general infiltration of rainfall in natural soils, and therefore relatively low compared to the annual quantity of rainfall.

After the basal geomembrane degrades, the mineral liner will act as the sole low-permeability barrier. The hydraulic conductivity will be low, but will have a value that, with suitable imposed head and passage of time, will allow small quantities of leachate to leave the landfill.

2.3 Potential contaminants and linkages

2.3.1 Sources of waste

The incoming waste will be obtained by municipal collections and will comprise domestic and commercial refuse. The waste deliveries to the landfill complex in 2017 amounted to 613,000 tonnes. There quantities of waste delivered was relatively constant throughout the year. The average daily delivery was 1585 tonnes/day in the six months of October to March. The average was 1783 in the other half of the year. Approximately half of this quantity was disposed into the landfill cells, after removal of recyclables.

The incoming waste is understood to originate from:

Households

Shops and commercial premises

Industrial sites

There will be no disposal of institutional medical wastes and commercial hazardous wastes to the new landfill.

The waste recycling facility removes recyclables from the waste stream, and the quantity of waste going to landfill is approximately 50% of the incoming waste deliveries.

The removal of recyclables and diversion of suitable waste to the incinerator is likely to increase the proportion of organic material and moisture content of the waste delivered to the new landfill.

2.3.2 Leachate composition

Leachate is formed from the release of moisture held within waste, usually as the organic materials decompose, and from the infiltration of rainfall onto the surface of the waste. Leachate quantities can be high, even in semi-arid climates, if the organic content is high and if rainfall infiltrates quickly, before much is lost by evaporation.

The leachate generated within the waste will be contaminated by soluble substances within the decomposing materials. This fluid, and leachate generated from rainfall, will become contaminated by soluble materials from passing through the waste towards the base of the landfill. Some contaminants may also be fine-grained suspended particles, such as humic substances, especially in older leachates.

The composition of leachate changes during the life cycle of a landfill. Soon after a site is opened, the concentration of easily soluble substances increases. Recently filled wastes become acidic during anaerobic decomposition and produce organic compounds such as fatty acids.

Rapidly degrading waste during produces methane from decomposition of the organic compounds, producing high concentrations of ammoniacal nitrogen.

The leachate in an operational site typically has high chemical and biological oxygen demand, many times greater than domestic sewage for example. It is usually close to neutral but can become weakly acidic, increasing the solubility of metals from the waste.

Much of the metal is removed by the MBT and other processes on site, however, it is possible that small quantities of items such as dry-cell batteries and electronic components may be included in the landfilled waste, which could be a source of metals.

Leachate may also become contaminated with chemicals, such as pesticides, or immiscible fluids, such as hydrocarbons. However, the waste currently deposited in the landfill is sorted before disposal and there is low probability of significant amounts of such contaminants.

2.3.3 Pathways - landfill

Leachate that is produced from decomposing waste within a landfill, or by infiltration of rainfall into the waste, will percolate towards the base of the landfill by gravity. The movement will be vertically downwards, although minor diversions may be caused by areas of waste or daily cover with lower permeability.

The leachate will be contained by the basal lining system and will saturate the drainage layer and lower parts of the waste profile, requiring regular removal for treatment. Seepage out the landfill may occur though any defects that are present in the basal liner.

In a typical landfill, much of the percolating leachate will encounter the drainage layer on the side slopes and will then flow downwards towards the saturated zone at the base of the landfill. Seepage out of the landfill may also occur through any defects in the liner on the slopes.

The design of the new landfill has vertical side slopes, with a parallel protection layer. This will effectively prevent any flow out of the landfill on the side slopes, even if defects are present in the liner. The most important part of the containment system will be a basal liner, as this has with multiple components (mineral liner, GCL and geomembrane) the probability of a leak pathway will be greatly reduced.

2.3.4 Pathways - ground

The lining system will prevent leachate from flowing out of the landfill. The operational life of the HDPE geomembrane is not known, but estimates are in the range of several hundred years for degradation to commence. At this point, small quantities of leachate will pass through defects and will be contained by the GCL and the engineered mineral liner. This will have a low hydraulic conductivity but, depending on the head of leachate, small quantities will be able to flow from the base of the new landfill into the unsaturated strata below.

The flow rate and direction will be determined by the characteristics of the underlying strata. In a rockmass, the flow of liquid is controlled by discontinuities. Geotechnical surveys of the site of the new landfill have shown that many discontinuities are tightly closed and with limited persistence. However, the surveys identified several zones with more persistent discontinuities, which were also open to some degree. These zones would be preferential pathways for the movement of fluid. These zones of discontinuities had similar orientations, with a strike trend of 076 degrees. This is the dominant orientation of discontinuities in Malta and is also the direction from the new landfill to the closest area of coastline.

Water can also flow though limestone in karstic features, such as caves and smaller solution voids. A series of small solution features were encountered at approximately 12m depth in the excavation for the new landfill, which appeared to have formed above a layer of less permeable rockmass. Further solution features were not discovered by the excavation, although the possibility of such features occurring below the base of the landfill cannot be discounted.

The excavation for the new landfill did not encounter groundwater, and so any hypothetical seepage would initially move through unsaturated rockmass. Flow in the unsaturated zone is generally vertically downwards, although diversions can be created by changes in permeability and the presence of openings such as joints and karst.

Flow in the unsaturated zone can be slower than in the water table. Geochemical processes may also be different due to the presence of a gas phase.

The direction of flow will change when the phreatic groundwater is encountered. The base of the new landfill will be excavated to a level, at the sump, of 7m above mean sea level. The elevation of groundwater is not known but is estimated to be only a few metres higher than sea level.

The direction of groundwater flow from the new landfill is expected to be approximately eastwards, towards the sea, with the actual direction probably influenced by the strike trend of the main discontinuity orientation. Other flow directions, particularly westwards along the discontinuity strike, is considered unlikely because of the tendency for groundwater levels to be higher inland, especially if affected by irrigation. This may be altered if there are large-scale abstractions from wells. However, this is considered unlikely in this area, where irrigation is believed to utilise treated sewage effluent, rather than groundwater.

2.3.5 Receptors

The primary receptor of seepage from a landfill is the groundwater immediately beneath the site. In this case, the groundwater is expected to occur within 5m of the lowest part of the base of the liner. Whilst there may be a small layer of freshwater, the groundwater may be brackish due to the proximity of the sea.

The lined landfills may restrict the potential for seasonal recharge. The older, unlined landfill may cause some seepage to the groundwater, although this will be attenuated by capping and leachate control measures.

The groundwater is not utilised in the vicinity of the site.

The most likely secondary receptor, if groundwater flows eastwards, will be the sea along the nearby coast. Groundwater flow rates are likely to be low, due to the low hydraulic gradient and low rate of recharge. Therefore, dilution effects will be large.

If there is the possibility of flow to the west, caused by abstraction wells for agricultural irrigation, this will be a more sensitive potential receptor.

3. Hydrogeological risk assessment

3.1 Nature of the Hydrogeological Risk Assessment

This hydrogeological risk assessment has involved:

- Preparing a conceptual model of the site
- Undertaking numerical modelling of potential impacts

This approach was adopted due to the nature of the development, i.e. a waste disposal site. Leachate from municipal waste sites is potentially harmful and the production storage and treatment of leachate presents potential risk to the environment.

The new landfill has been designed with a composite containment system that will comply with the requirements of Maltese law and the EU landfill directive. As a result, the likelihood of the risk being realised is low. This is illustrated by the approach chosen to assess the risks.

This hydrogeological risk assessment considers the full lifecycle of the new landfill: construction, closure works, managed aftercare and the long term thereafter.

3.2 Lifecycle phases – construction details

The construction aspects of the lifecycle scenarios are:

- Excavation of the void and installation of the containment system

Infilling with waste

Closure of the new landfill

No seepages have been observed in the excavation. The excavated ground is clean and uncontaminated.

These scenarios may overlap. For example, the lining system on the vertical sides will be installed incrementally during the operational life of the landfill. Also, the closure and capping of part of the cell may commence, while waste is still be placed into the remaining part. These overlaps can be accommodated in the analysis of results and will not affect the conclusions of the risk assessment.

The detailed plans for capping and closure will need to be confirmed, but these will comply with the landfill directive. The capping system will connect to the vertical side-wall liner in order to isolate the waste in the cell, allowing control of leachate and gas.

The phased installation of the vertical side liner system will reduce the risk of damage. The liner will be installed in sections, 3-5m high around the perimeter of the landfill, which will be protected immediately with a thick protection layer. The newly installed liner will quickly be "covered" by infilling with waste in the adjacent area. The liner will not experience vertical pressure and potential damaged caused by drainage stone. The protection layer will accommodate potentially damaging shear forces from the settlement of waste.

3.3 Lifecycle phases – hydrological and leachate issues

The production and potential migration of leachate will vary between the scenarios. The composition of leachate will also change over time.

Leachate will not be produced during the construction phase. Rain that falls into the unlined excavation will initially absorb into the exposed rock strata until the capacity of the porosity is reached. Then, excess water will flow into low points, causing temporary puddles. This water will either infiltrate into the ground or evaporate. Infiltration may be reduced due to suspended solids, which may block the opening of discontinuities. Large accumulations of water may need to be removed to allow construction to continue.

Most leachate will be produced during the operational phase, when waste is being deposited into the new landfill. Leachate will be generated by decomposition of organic materials in the waste and by the infiltration of rainfall into the waste. Leachate composition is likely to change with time, with concentrations of organic and inorganic compounds increasing as the fluid is in contact with waste for longer. The decomposition of waste will also occur at different rates and will release contaminants into the leachate. As the waste pile increases in thickness, leachate and infiltrating rainwater will travel further to the base of the cell, interacting with more waste.

After the landfill is fully closed and infiltration is prevented the leachate composition will continue to be affected by ongoing decomposition of the waste. As the decomposition of waste reduces, it is likely that the leachate composition will become more stable. The biodegradable compounds will be greatly reduced.

As the cap degrades in the distant future, infiltration will start again into the waste pile. The impact is difficult to predict because this will leach materials from the upper parts of the waste but may also dilute compounds already in the leachate. The model assumes that the concentration of selected components decreases with time due to dilution and utilisation of the source.

In the distant future, as the geomembrane liner degrades, small quantities of leachate will seep out of the base of the landfill. The compounds dissolved in the leachate may be selectively attenuated by materials though which the leachate flows, by mechanisms such as reaction, absorption, biodegradation and cation exchange. These processes may reduce the concentrations of contaminants that escape or reduce the rate at which they spread. These reactions are complex and difficult to predict. Therefore, they have not been included in the model. The effects of limited dispersion in the groundwater have been included.

4. Numerical modelling

4.1 Modelling approach and software

The numerical modelling of potential leachate releases into the environment was undertaken using the software package "LandSim 2.5", which was commissioned by the UK Environment Agency. The latest version, revised in 2017, was used.

The model predicts the flow and composition of leachate away from a site at specific locations, such as the mineral liner, the unsaturated zone and the eventual receptor. Long timescales are used because of the high durability of modern landfill lining systems and the likely slow rate of contaminant transport in the subsurface.

The numerical modelling has been conducted using site specific data where possible, and otherwise using realistic, although conservative, assumptions regarding the source, pathway and receptors.

The values of input parameters are modelled using probability density functions to allow for variations, such as natural ranges or uncertainty in the data.

There are many uncertainties in predicting future conditions in landfills. The modelling software accommodates uncertainty by using the statistical Monte Carlo method to provide outputs in terms of levels of confidence.

4.2 Model parameterisation

4.2.1 Organisation

The input data for the LandSim model are grouped into thematic sets:

Geometry and time

Leachate physical parameters

Leachate inventory, i.e. expected chemical characteristics

Drainage system

Engineered barrier

Flow in the unsaturated strata below the landfill

Flow in the groundwater below the landfill

Each of these sets includes several parameters. The values used in the modelling are summarised in the following sections.

4.2.2 Geometry and time

These parameters represent the dimensions of the site and the time over which potential impacts are considered. Mostly, the values are obtained from the design or experience.

Parameter	**Value**	**Justification**
Landfill dimensions	125m x 300m	Actual size, long dimension towards NW.
Domain area	500m x 1200m	Long dimension towards NE
Receptor	Sea	Based on expected groundwater flow. Agricultural wells may also be a receptor, if operating
Distance to receptor	800m	Distance to the sea. (This is also a likely distance to the nearest agricultural wells, if groundwater flows inland. This is probably unlikely)
Landfill phases	1	The landfill comprises one cell
Time periods for hydraulic modelling, years	3/10/30/100	Short times selected to focus on impacts in a few generations. The model runs to a final long-term (20000 years) by default.

Parameter	Value	Justification
Period of site management	50	Estimated life of site and future developments
Waste thickness, m	60	Based on geometry of the excavation and anticipated final waste surface.
Waste porosity	50%	Estimated average value
Waste dry density, kg/l	1	Estimated average value
Waste field capacity	20%	Estimated average value
Head of leachate required for breakout, m	32	Based on geometry of the excavation, assuming leakage through join between side liner and cap

4.2.3 Leachate physical parameters

These parameters represent the dimensions of the site and the time over which potential impacts are considered.

Parameter	Value	Justification
Infiltration into the open waste mm/year	Min 200 Expected 400 Max 600 (triangular distribution)	Rainfall onto the waste surface is expected to infiltrate readily due to the open structure and existing moisture. Estimate 66% of annual mean rainfall. Supported by observations on other sites.
Infiltration through cap mm/year	Min 0.1 Expected 1 Max 5 (triangular distribution)	Conservative assumption of how much water could pass through the cap, via defects. Installation with QA procedures likely to result in much lower figures.
Infiltration into soil with grass cover	Min 50 Expected 100 Max 200 (triangular distribution)	Includes reduction due to evapotranspiration and warm climate
Duration of filling, years	6	Estimated from the design dimensions and waste delivery rate.

Parameter	Value	Justification
Type of cap	LDPE geomembrane	Expected approach, covered with restoration soil
Time when cap starts to degrade	120	Estimate, assuming protection from UV and corrosive fluids
Time at which cap is fully degraded	1000	Estimate, assuming protection from UV and corrosive fluids

4.2.4 Leachate inventory, i.e. expected chemical characteristics

The modelling has focussed on three potential leachate parameters, to demonstrate the scale of likely flow and contaminant transport. Other contaminants can be modelled, if necessary, depending on results.

Ammonia was selected as it is a common component of leachate, produced as a result of biodegradation and it's an important agent in eutrophication of receiving water.

Chloride was selected as it is a major inorganic component which accumulates in natural water and is a key agent in reducing potability and use for agriculture.

Mercury was selected as an example of a List 1 substance from the groundwater directive, with a history of impacts in marine systems.

Concentrations in the leachate are modelled to reduce with time, as a function of the quantity of infiltration, which dilutes the original sources.

Retardation is assumed to occur due to dispersion. The possibility of microbiological or other decomposition or complexing in the ground was not considered.

Parameter	Value	Justification
Ammoniacal nitrogen Initial concentration in leachate, mg/l	Min 0.1 Expected 1 Max 5 (log-triangular distribution)	Typical constituent of leachate, a product of decomposition of organic materials and a potential source of oxygen demand Values obtained from previous leachate analyses on adjacent landfill sites.
Ammoniacal nitrogen Source reduction constant, kg/l	m =0 c= 0.59	Retarded during flow through liner and strata Default value in the software, used in UK.
Chloride	Min 5000 Expected 6000	Typical inorganic constituent of leachate produced by solution. Important for water

Parameter	Value	Justification
Initial concentration in leachate, mg/l	Max 7000 (log-triangular distribution)	quality, although groundwater is likely to be impacted already by this parameter. Values obtained from previous leachate analyses on adjacent landfill sites.
Chloride Source reduction constant	m = 0.0298 c = 0.2919	Less retardation during flow through liner and strata. Default value in the software, used in UK.
Mercury Initial concentration in leachate, mg/l	Min 0.0006 Expected 0.0008 Max 0.0013 (log-triangular distribution)	Rare inorganic constituent of leachate, with high potential for ecological impact at extremely low concentrations. Values obtained from previous leachate analyses on adjacent landfill sites.
Mercury Source reduction constant	m = 0.0767 c = 0.1643	Default value in the software, used in UK. Model does not retard concentrations in the unsaturated zone.

The HRA for the intended hazardous waste landfill cell selected a different set of parameters, as a result of the predicted type of waste being very different.

4.2.5 Drainage system

The leachate drainage system inside the landfill is modelled using design parameters. The importance to the model is to assess how quickly the leachate can be removed from the base of the waste (during the management period) and also how the leachate can pool against the liner (in the longer-term).

The parameter values used were:

Parameter	Value	Justification
Drainage blanket hydraulic conductivity	Min 0.001 Expected 0.01 Max 0.1 (log-triangular distribution)	Expected value and range for clean gravel, allowing or some clogging with time
Drainage blanket thickness, m	0.5	From the design

Parameter	Value	Justification
Gradient on base of drainage layer, %	Mostly 3%, locally steeper (33%)	From the design
Maximum leachate head	Min 0.5 Max 1.5 (uniform distribution)	Assumed controlled level (with removal for treatment) during managed period. Subsequent levels calculated from infiltration and leakage (mass balance).

4.2.6 Engineered barrier

The Engineered barrier is the name that the software uses for the artificial containment system. In this case, we modelled a composite single liner, based on the design of the new landfill.

The HDPE geomembrane is treated as impermeable, with all flow occurring through defects. Defects increase with time due to degradation. During this time, the flow rate through the mineral liner becomes the controlling factor.

The mineral liner is a combination of GCL and compacted soil. This was modelled as an equivalent 1m thick engineered mineral liner. This assumption is conservative.

Parameter	Value	Justification
Geomembrane defects Pin holes (1-5mm^2) Holes (5-100mm^2) Tears (100-10000mm^2)	Max. № per ha 5 0.25 0.05	Estimated values after CQA monitoring during construction and geophysical verification of the basal liner.
Time of onset of degradation, years	120	Estimated by Rowe, based on data by Koerner
Time taken for № of defects to double, years	120	Estimate, based on an assessment by Rowe
Mineral liner hydraulic conductivity, m/s	1×10^{-9}	Requirement of the EU Landfill Directive
Mineral liner thickness, m	1.0	Requirement of the EU Landfill Directive

4.2.7 Flow in the unsaturated strata below the landfill

The base of the landfill is required to be situated above the groundwater level. The groundwater level is not accurately known, but there is a limited range of possibilities.

Parameter	**Value**	**Justification**
Thickness	Min 1 Expected 3 Max 5 (uniform distribution)	Possible groundwater depth below the formation, based on a range of likely hydraulic gradients between the site and the coastline. The range includes an allowance for sea level rise as a result of climate change. These values are very conservative, and more than cover the likely future effects of climate change and rising sea level. The HRA for the hazardous waste cell predicted a groundwater level of 0.75m above sea level under the site, i.e. equivalent to the “Max” value in our range.
Hydraulic conductivity, m/s	Min 1×10^{-7} Expected 1×10^{-6} Max 1×10^{-5} (log-triangular distribution)	Values assumed to be a typical range for the unsaturated zone of a limestone aquifer with dual porosity
Fissure porosity	Min 0.01 Expected 0.05 Max 0.2 (triangular distribution)	Based on mapping of the site – locally high values in joint zones, rather than an overall average.
Matrix hydraulic conductivity, m/s	Min 1×10^{-9} Expected 1×10^{-8} Max 1×10^{-7} (log-triangular distribution)	Values assumed to be typical for a limestone aquifer with dual porosity
Matrix porosity	20% Single value	Values assumed to be typical for a fine grained partially recrystalised limestone

4.2.8 Flow in the groundwater below the landfill

This part of the model calculates the flow of groundwater under the site and the likely impact of seepage through the unsaturated zone into the aquifer.

Parameter	**Value**	**Justification**
Pathway length, m	800	Distance from the new landfill to the coastline.
Pathway width, m	315	Width of the new landfill, perpendicular to the estimated flow direction.
Aquifer thickness, m	100	An assumed value – likely to be higher. But only the upper part will be affected by groundwater flow due to the freshwater "lens"
Dispersivity, m	2	An assumed value for the depth of mixing during groundwater flow
Hydraulic conductivity, m/s	Min $1x10^{-6}$ Expected $1x10^{-5}$ Max $1x10^{-4}$ (log-triangular distribution)	Values assumed to be typical for a limestone aquifer with dual porosity. Assumed to be higher than the values in the unsaturated zone.
Hydraulic gradient	Min 0.00125 Expected 0.00375 Max 0.00625 (triangular distribution)	Calculated from the possible groundwater depth below the formation and the distance to the coastline
Pathway porosity	20% Single value	Assumed to be relatively high to account for the possibility of relatively fast flow on joints or in karst.

4.3 Results

4.3.1 Leachate levels and flows

The model assumes that leachate levels will be controlled during the operations and after-care period by removal for treatment. This leachate is effectively the rainfall that infiltrated when the site was open. Leachate generated by the waste is not included.

The results of simulating leachate head and flow through the liner, using the data summarised above, are included in Annex A.

After the theoretical end of leachate removal, the quantity of leachate is calculated from the infiltration of rainfall that can enter the site due to the theoretical degradation of the cap. This is attenuated by evapotranspiration from the restoration soils and any vegetation.

At the same time, the landfill liner is assumed to be degrading. The seepage rate from the becomes controlled by the hydraulic conductivity of the mineral liner, rather than the almost complete impermeability of the geomembrane.

The leachate level rises inside the new landfill until the head causes an annual flow rate equivalent to the infiltration, at which point the site is in equilibrium. The model accommodates the possible range of variables in the statistical approach. The effect of annual variations is not considered deterministically. The model predicts that the leachate depth will reach equilibrium occur after approximately 1000 years, with a leachate depth of 35m above the base.

The leachate flow through the liner is initially zero and starts to rise as the containment system degrades and the leachate head rises. The flow reaches approximately 11.5 cubic metres per day after 1000 years, increasing by a further 10% up to 2000 years, after which time the modelled flow is constant. This calculated flux is equivalent to approximately 350ml per day for each square metre of the landfill base, averaged over a year.

This calculated infiltration rate is consistent with the average effective precipitation in the area. These results are valid and can be used to model contaminant transport.

4.3.2 Contaminant transport - ammonia

The predictions for the migration of ammonia into the natural strata are shown graphically in Annex B. These are presented at the 50th percentile confidence level, i.e. the mean of calculated results in the Monte Carlo simulation. All quoted numbers are approximate, but this is not repeated for clarity.

The level of ammonia in the landfill leachate is predicted to reduce from 600 mg/l at the end of operations to 100 mg/l after 2000 years. It will be effectively zero after 5000 years.

The relatively thin unsaturated zone allows the ammonia to reach the aquifer. At the same level of confidence, the concentration peaks at 600 mg/l after 250 years. The concentration drops to zero after 6000 years, as the source becomes depleted. The concentration reduces more significantly during transport in the aquifer, with a maximum of 40 mg/l at the coastline being reached after 1900 years. The duration of the peak and reduction are increased, with the theoretical value of zero occurring after 8000 years.

As a comparison, the value of ammonia (as nitrogen) in BH1, which is near the Magħtab landfill has been determined as approximately 30 mg/l.

These results indicate that, if the groundwater under the site is the controlled receptor, then the site could, after 250 years, cause a discharge of ammonia which will, with 50th percentile probability, exceed the allowable values.

However, if the controlled receptor is the sea (or possibly a well) located at a distance of 800m, the concentration of ammonia is unlikely to cause concern at any time. The predicted concentration is equal to the limit for discharge into coastal water. However, it will be less in reality due to the diffuse nature of groundwater flow and the dilution that is likely to be provided by dispersion.

4.3.3 Contaminant transport - chloride

The predictions for the migration of chloride into the natural strata are shown graphically in Annex C. The same comments apply concerning precision.

The level of chloride in the landfill leachate is predicted to reduce from 5800 mg/l at the end of operations to 800 mg/l after 2000 years. It will be effectively zero after 5000 years.

At the same level of confidence, the concentration entering the groundwater peaks at 6000 mg/l after 250 years. The concentration drops to zero after 6000 years, as the source becomes depleted. The concentration reduces more significantly during transport in the aquifer, with a maximum of 350 mg/l at the coastline being reached after 1900 years. The theoretical value of zero occurs after 7000 years.

As a comparison, the value of chloride in BH1, which is near the Magħtab landfill has been determined as approximately 3000 mg/l. The level in BH4, which is near the new landfill, was determined as 492 mg/l in 2018. If this is representative of background levels in the aquifer, the chloride concentrations emanating from the new landfill will need to be combined with these values in proportion to the quantity of flow, to account for dilution. The resulting levels are unlikely to change the assessment.

These results indicate that, if the groundwater under the site is the controlled receptor, then the site could, after 250 years, cause a discharge of chloride which will, with 50th percentile probability, exceed the allowable values. Groundwater in this area is already impacted with chloride. The results may be acceptable if groundwater in a utilised area of the aquifer is not affected.

However, if the controlled receptor is the sea (or possibly a well) located 800m from the new landfill, the concentration of chloride is unlikely to cause concern at any time. The predicted concentration will be much less than the natural concentration in seawater.

4.3.4 Contaminant transport - mercury

The predictions for the migration of mercury into the natural strata are shown graphically in Annex D. The same comments apply concerning precision.

If the level of mercury in the leachate of the new cell is similar to leachate in the nearby landfills, the level of mercury in the landfill leachate is predicted to be 0.87 µg/l at the end of operations. This reduces exponentially to effectively zero after 18000 years.

At the same level of confidence, the concentration entering the groundwater peaks at 0.95 µg/l after 125 years. The concentration halves within 4500 years and is close to zero after 20000 years.

The concentration does not reduce during transport in the aquifer, with a maximum of 1.0 µg/l at the coastline being reached after 2200 years, after which time the concentration drops relatively constantly and is close to zero after 20000 years.

The modelling results indicate that, if the groundwater under the site is the controlled receptor, then the site could, after 250 years, cause a low-concentration discharge of mercury with 50th percentile probability. The default position of the groundwater directive is to prevent any discharges of List 1 substances, and so this situation is technically non-compliant. However, there is a requirement to define suitable exceptions on a site-specific basis. The environmental agency will need to determine the necessity and requirements for such a study.

The modelling results are probably conservative, due to the assumptions made in the parameterisation. Preventing discharge of a List 1 substance effectively means setting the control limit at a concentration that is realistic to measure. For mercury this is likely to be 0.1 µg/l. As a comparison, the value of mercury in groundwater from BH2, which is near the Magħtab landfill was determined in 2018 as being less than 0.05 µg/l. The typical concentration of mercury in the Mediterranean Sea has been reported as 0.1 µg/l. The quantity of seepage of leachate from the site into groundwater will be very low, even in the long term. And the quantity of groundwater seepage at the coastline will be extremely low compared to the volume of seawater. The dilution rates will be extremely high and there is effectively no risk of increased mercury levels in the groundwater or sea in the site area due to leachate seepage into the groundwater.

4.3.5 Comparison with local hydrogeological conditions

The area between the new landfill and the coastline (receptor) is largely occupied by existing landfills. These facilities will also have a potential impact on the groundwater and seawater, with the magnitude depending on the construction details of the sites and the thickness of the unsaturated zone of aquifer. It will be difficult to separate the effects of the different landfills and it may be necessary to treat the area as a single system.

The potential impact on the groundwater in the distant future may be enhanced due to low groundwater flow rates. Slow flow rates are expected due to the low recharge and low hydraulic gradient on the area around the landfills. However, in the long-term, when potential impacts are predicted, climate change may also have an effect.

5. Conclusions and recommendations

5.1 Assessment of potential impact

The new landfill will be constructed to an innovative design which greatly reduces the footprint in proportion to the quantity of waste. In addition to reducing impact on land, this design will greatly reduce the generation of leachate by the landfill.

The containment system of the new landfill will be constructed in full compliance with the EU Landfill Directive. The construction will exceed these requirements by quality assurance techniques which will ensure that the liner and capping are effectively free of defects. The geomembrane layers will be effectively impermeable.

The longevity of geomembrane liners has not been proven by experience because the materials are relatively new. Materials seem to be serviceable after several decades. Predictions based on laboratory tests suggest that degradation may commence after 100-200 years and be complete in approximately 1000 years. The basal liner includes a mineral component as well as a polymer. The mineral component will have longer life and low hydraulic conductivity, but this will allow a small rate of flow after the geomembrane has degraded.

Conceptually, the leachate in the landfill is expected to remain isolated for one or two centuries after closure. Then, if the materials degrade as predicted, small quantities of seepage may occur. This prediction is the same for any landfill constructed with polymer materials.

Any leachate that seeps out of the landfill will flow vertically downwards through the unsaturated zone of the underlying strata until it meets the groundwater in the saturated horizon. The base of the new landfill is 7m above sea level and so the unsaturated zone is constrained and is estimated to extend for 1 to 6 metres. The effects of climate change may reduce the depth in the long-term.

The area around the new landfill may be located on a groundwater divide. The low recharge rates and low hydraulic gradient will result in slow groundwater flow rates towards the coastline. As a result, small seepages from the landfill could be significant in comparison to the groundwater flow rate.

The sea is the most likely the receptor for any seepage from the site. The area between the new landfill and the coastline is developed with extensive landfills, which are expected to have similar hydrogeological impacts as the current site. Therefore, the effects may need to be considered as single system.

The leachate will contain a range of chemicals, many of which are potential contaminants. In the long-term, leachate seeping from the base of the new landfill will be depleted in biodegradable organic materials. The composition of leachate may not change greatly unless infiltration of rainfall over a long period in the distant future results in dilution and exhaustion of the sources within the waste.

The compounds in the leachate could be attenuated by physical and chemical processes in the strata. However, as a conservative assumption, only dispersion in the groundwater has been considered.

Conceptually, the new landfill will have no discernible impact on groundwater for a period of several hundred years. After this, the effects may be moderate due to the conditions under the site.

The conceptual model was examined numerically using software for hydrogeological risk assessment which was developed for use in the UK. This uses probability functions to accommodate the uncertainty inherent in prediction of future conditions.

As with any model, it is a simplification of reality and the results are dependent on the assumptions that are made. The potential for long-term migration of three compounds was studied.

Concentrations of ammonia, a principle biodegradation product and potential agent for eutrophcation, were determined to reduce relatively quickly in the leachate source, being exhausted within 5000 years. The model predicted that levels in the leachate were likely to be approximately 700 mg/l. These levels could reach the groundwater after 250 years. Dispersion and degradation would result in the levels reaching the receptor were within the allowable limits for coastal discharges.

Concentrations of chloride accumulate, especially in semi-arid climates. The model predicted that leachate would have a concentration of 6000 mg/l, which would reduce to 800 mg/l after 2000 years and zero after 5000 years. The peak concentration would reach the groundwater after 250 years. Dispersion would reduce the peak concentration at the receptor to 130 mg/l after 1400 years. This would be insignificant as a seepage into seawater. In the unlikely event that groundwater flows inland, possibly because of sea level rise, these levels would not unduly impact any groundwater abstracted for irrigation. These values would need to be added to current and future chloride levels, which may already be elevated due to abstraction and seawater incursion into the aquifer.

Concentration of mercury were modelled to be low but with a long period. This is partly due to the conservative handling of List 1 substances by the model. Discharges of any list 1 substance are precluded by default. However, some discharges cannot be avoided and there is a requirement to set realistic exceptions that recognise such cases but continue to provide protection. In this case, the model suggests that the levels of mercury reaching the receptor (the sea) will be very low and will be subject to enormous dilution. There is no risk of accumulation to cause levels of concern.

5.2 Proposed monitoring requirements

The group of landfills in this area would be best treated as a single system, with combined resources for data collection, monitoring and risk assessment. Therefore, the monitoring requirements for the new landfill cell would be most effective if coordinated with the existing network of monitoring points and the existing strategy for sampling, analysis and evaluation.

Installing monitoring wells specifically to focus on the new landfill would be unrealistic, due to the presence of the adjacent landfills. Therefore, the most appropriate monitoring strategy would be to augment the existing data collection and evaluation system.

Five monitoring boreholes were previously installed in the area, as shown on Figure 1. One of these is close to the new landfill. The data obtained from these wells will record any potential impact from the new landfill, as it will form part of a continuous waste management facility in the area.

Two additional monitoring boreholes are recommended in specific locations to provide more comprehensive data on groundwater flow and quality in the area of the environmental facility. The data from these new wells would augment data from the existing wells and would also allow the conceptual model of the site to be assessed. These new monitoring boreholes should be located approximately 650m to the north east and the south west of the new landfill, as shown on Figure 2.

The water levels in all monitoring boreholes will need to be measured simultaneously. If the current monitoring strategy is acceptable to the regulator, then it is likely that this will continue. The results of the modelling show that any potential impacts from the site are likely to be very gradual changes, and so the monitoring frequency will need to be appropriate to such timescales. We would be pleased to review the overall monitoring schedule to coordinate with this study, if required.

We anticipate that the suite of groundwater analyses is already agreed with the regulator. As this new landfill will accept the same types of waste, there is little reason to change the list of determinands. However, we would be pleased to review this if necessary. We suggest that groundwater characterisation parameters, such as pH, conductivity and major ions would be sufficient for validating the hydrogeological model of water flow. Contamination markers could be tested as required by the licence.

Leachate levels should also be monitored on the same schedule as the other landfills.

It would be useful to confirm the location and status of private abstraction wells within 1km of the new landfill. If possible, groundwater levels and basic chemistry could be sampled.

It would also be useful to confirm the meteorological parameters for the site, from nearby weather stations. Predictions on how these may change as a result of climate change would be useful, and possibly research that is already underway.

6. References

Construction of a Steep Wall Non-Hazardous Waste Landfill, Conceptual Design Statement, CQA International Ltd, February 2019

Excavation and construction of a steep wall non-hazardous waste landfill, Magħtab Environmental Complex, Malta. Rep. no.: 1 Rock mass analysis and proposals for stabilization, Adrian Mifsud, early 2020

Ghallis Hazardous Waste Landfill - Hydrogeological Risk Assessment, SLR Ltd, May 2008

Hydrogeological Risk Assessment

LandSim 2.0 user manual, plus addenda for versions 2.5 and

Magħtab Landfill Site, Construction of Steep-Wall Disposal Cell, Specification and Construction Quality Assurance Plan, CQA International Ltd, April 2020

Magħtab Landfill Site, Assessment of stability issues, CQA International Ltd, December 2019

Rowe RP & Sangam HP, 2002, Durability of HDPE geomembranes, Geotextiles and Geomembranes Vol 20 pp77-95

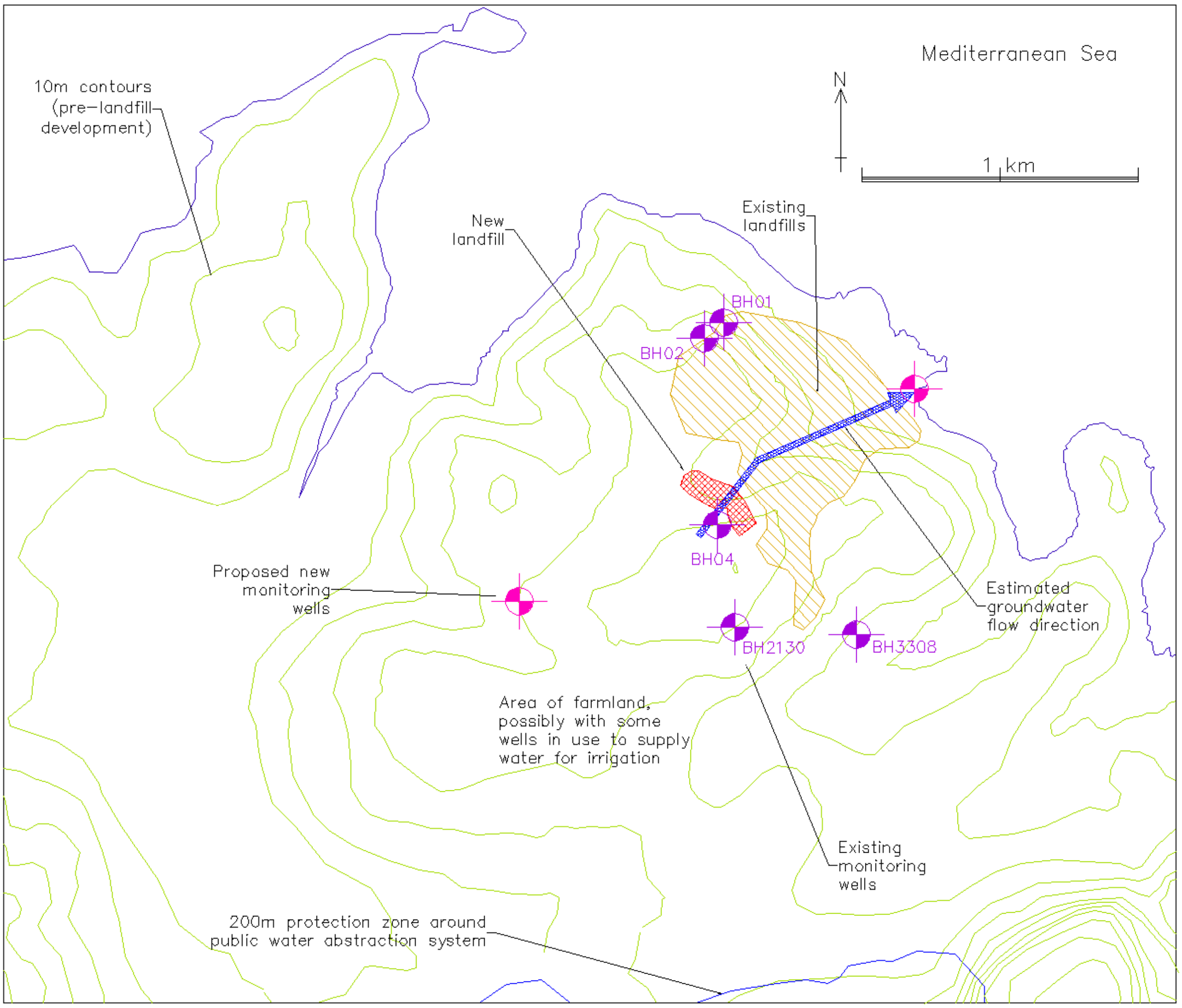
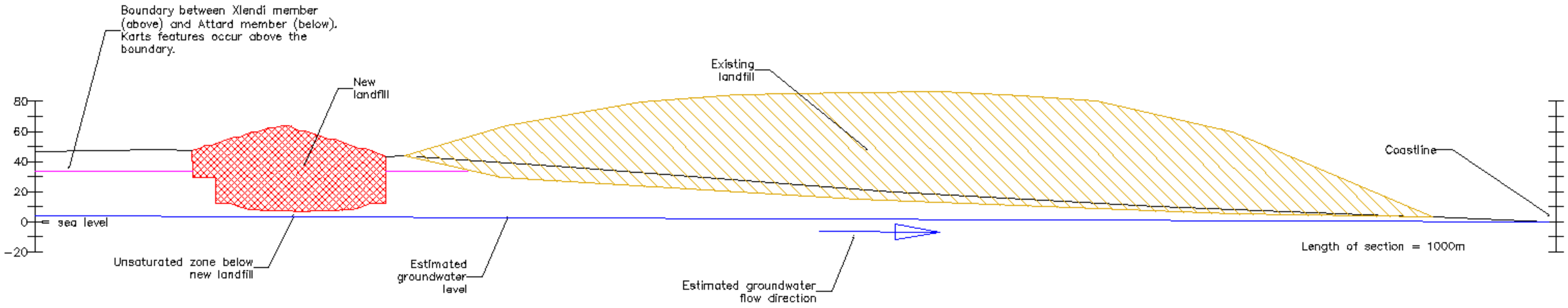


Figure 1 Sketch plan of main elements in the HRA report



Note: section is drawn along line of estimated groundwater flow in Figure 1

Figure 2 Sketch section of main elements in the HRA report

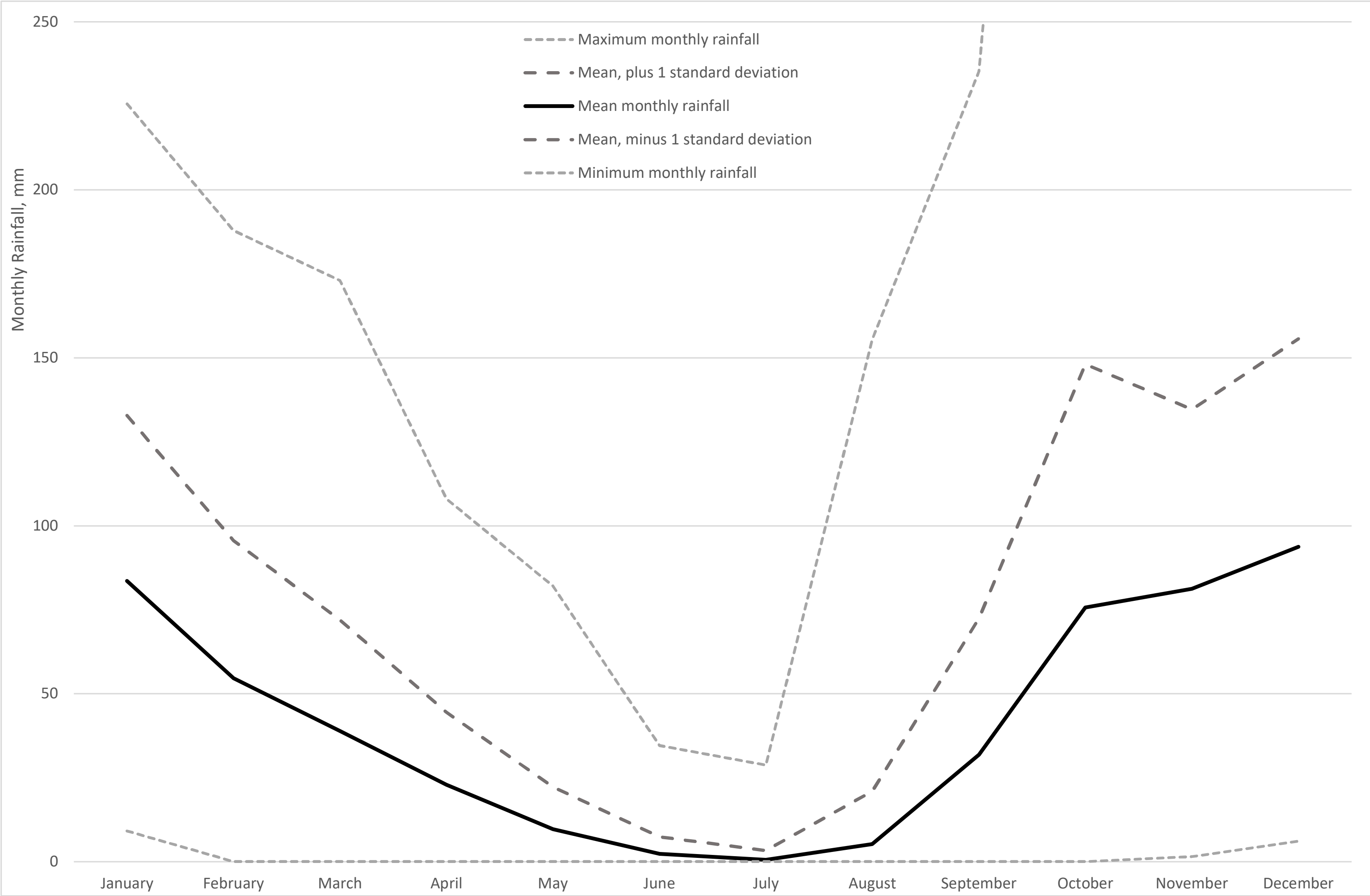

Maximum monthly rainfall
Mean, plus 1 standard deviation
Mean monthly rainfall
Mean, minus 1 standard deviation
Minimum monthly rainfall
Monthly Rainfall, mm
250
200
150
100
50
0
January
February
March
April
May
June
July
August
September
October
November
December

Figure 3 Annual rainfall statistics 1841-2000

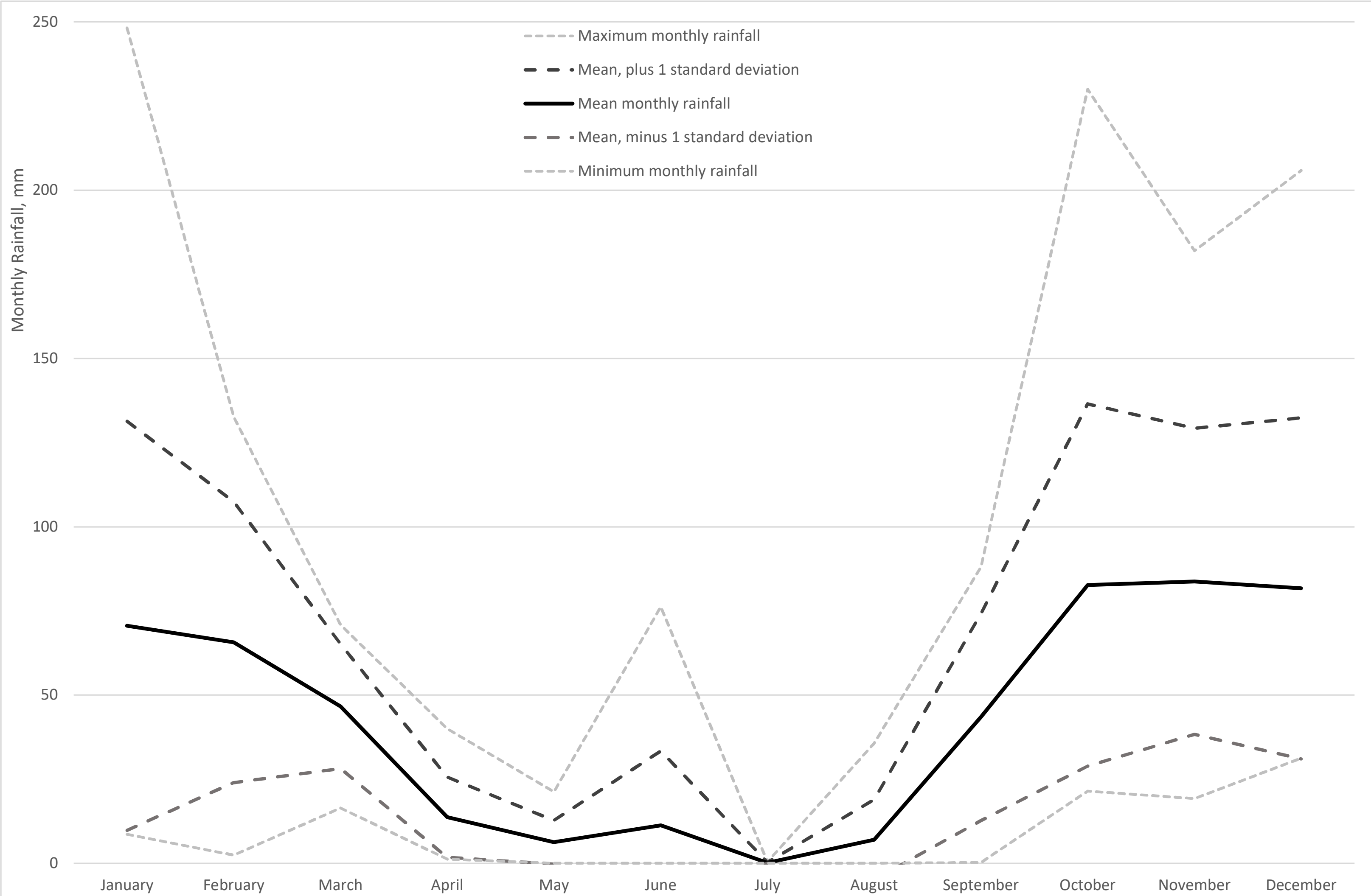

Maximum monthly rainfall
Mean, plus 1 standard deviation
Mean monthly rainfall
Mean, minus 1 standard deviation
Minimum monthly rainfall
Monthly Rainfall, mm
250
200
150
100
50
0
January
February
March
April
May
June
July
August
September
October
November
December

Figure 4 Annual rainfall statistics 2007-2017

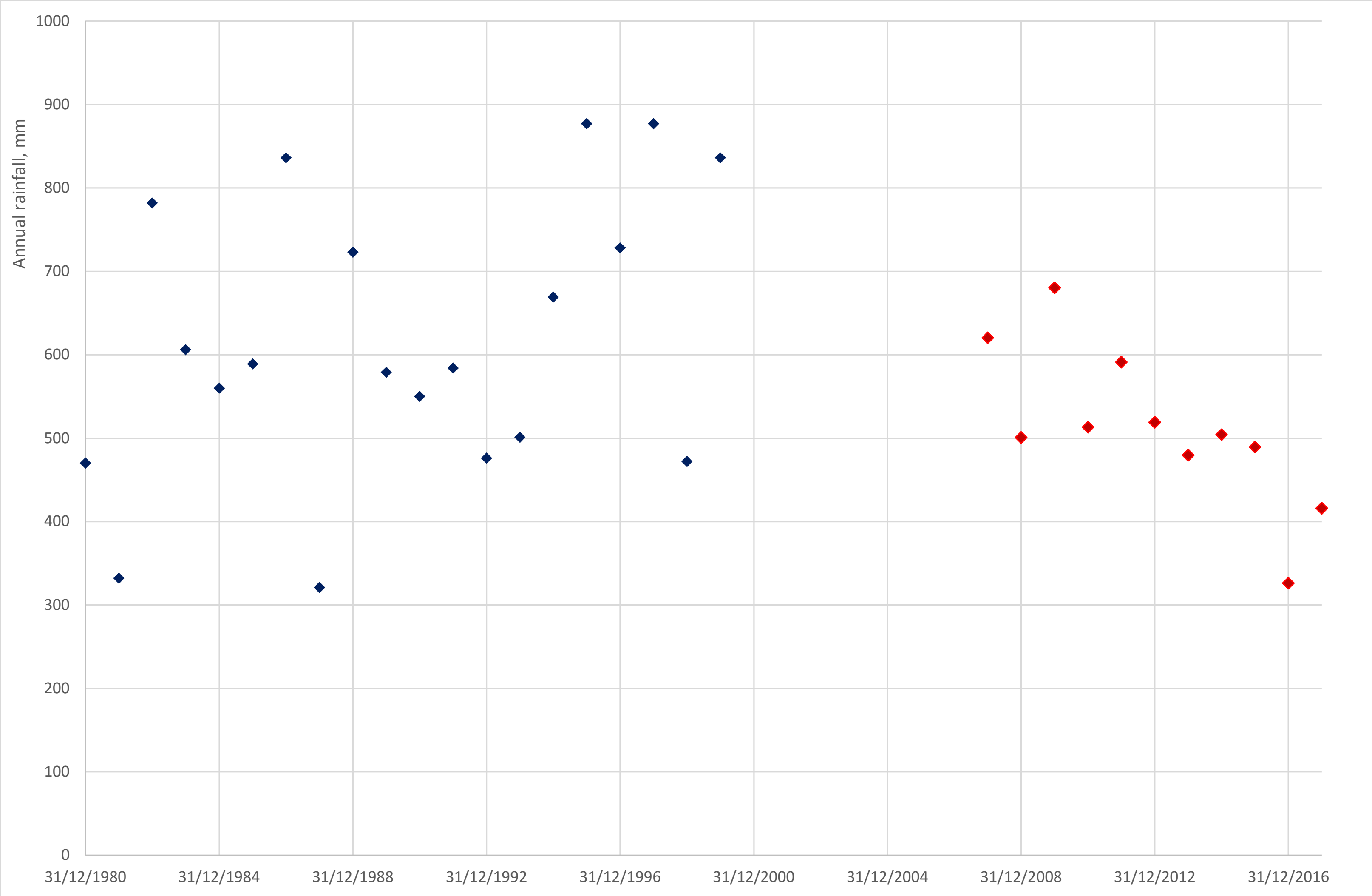
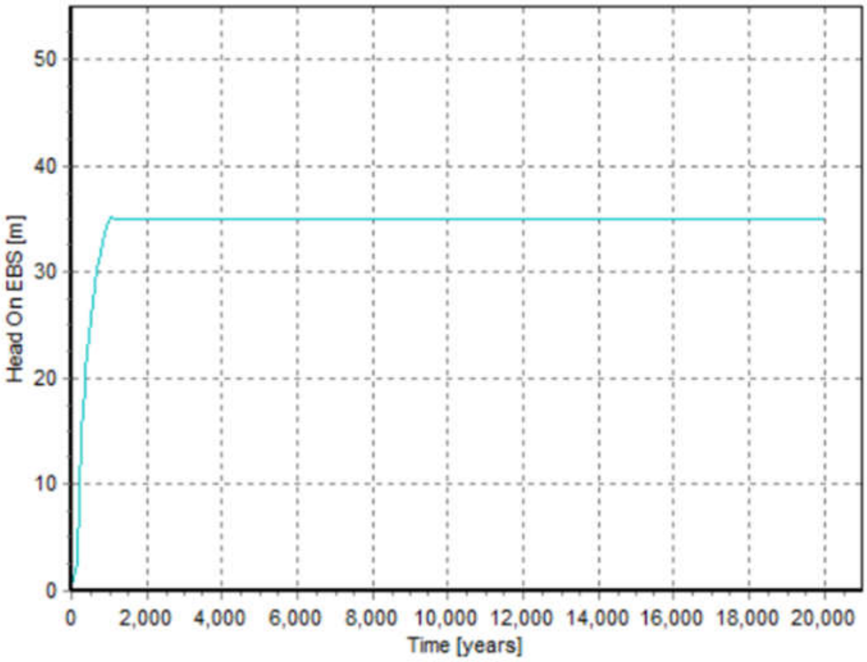
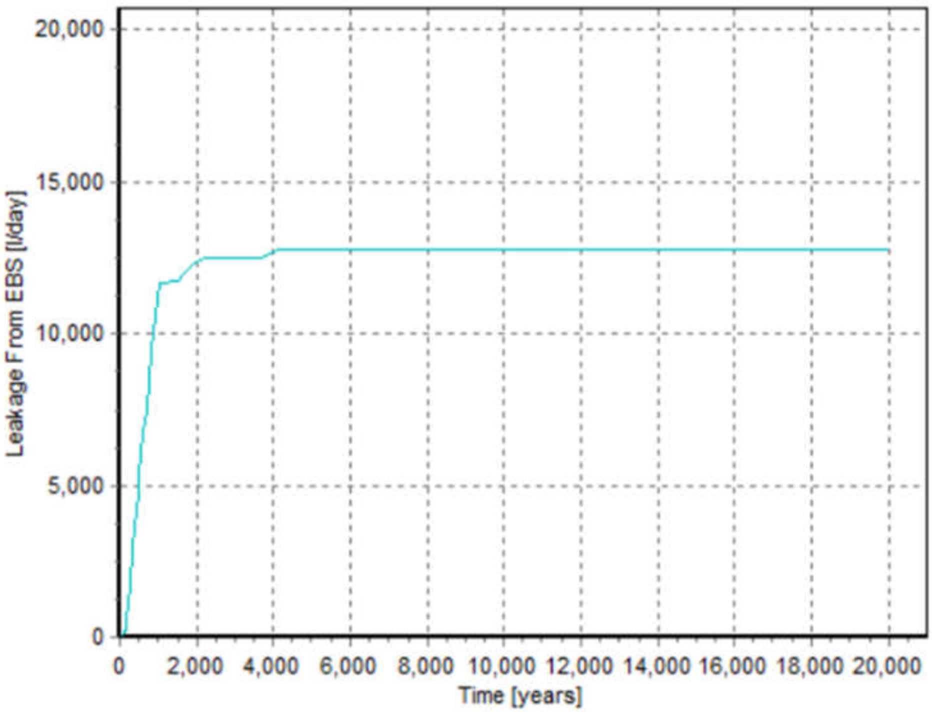

Annual rainfall, mm
1000
900
800
700
600
500
400
300
200
100
0
31/12/1980
31/12/1984
31/12/1988
31/12/1992
31/12/1996
31/12/2000
31/12/2004
31/12/2008
31/12/2012
31/12/2016

Figure 5 Annual rainfall trends 1980-2017

Annex A Output from the numerical model - flow

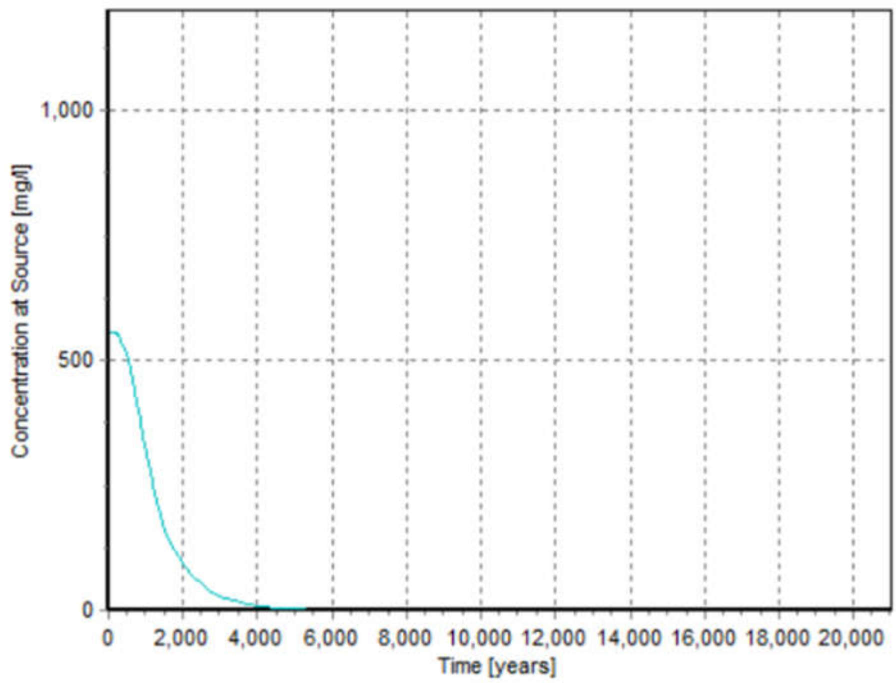


Head on basal liner

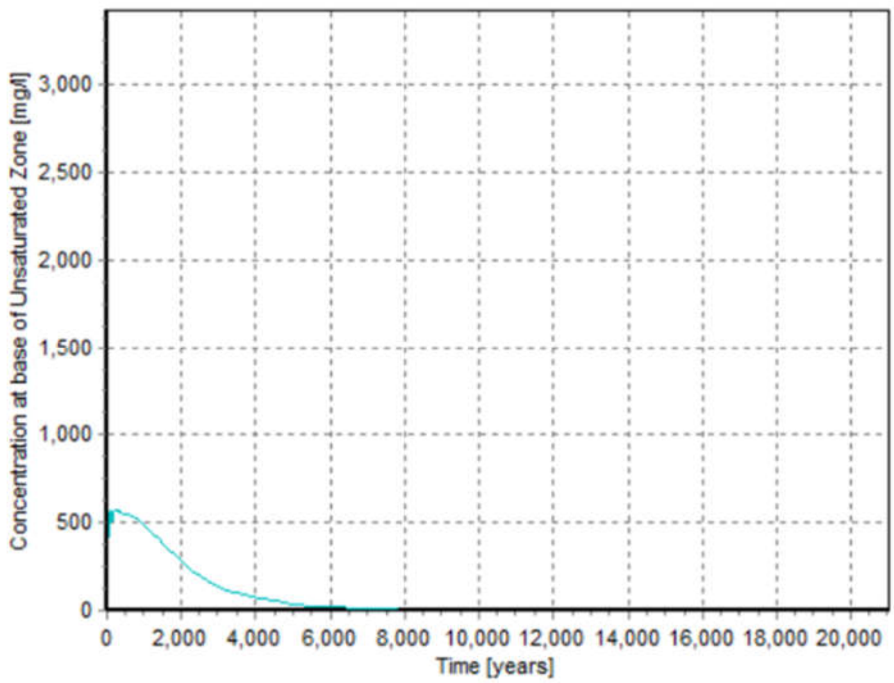


Leakage through basal liner

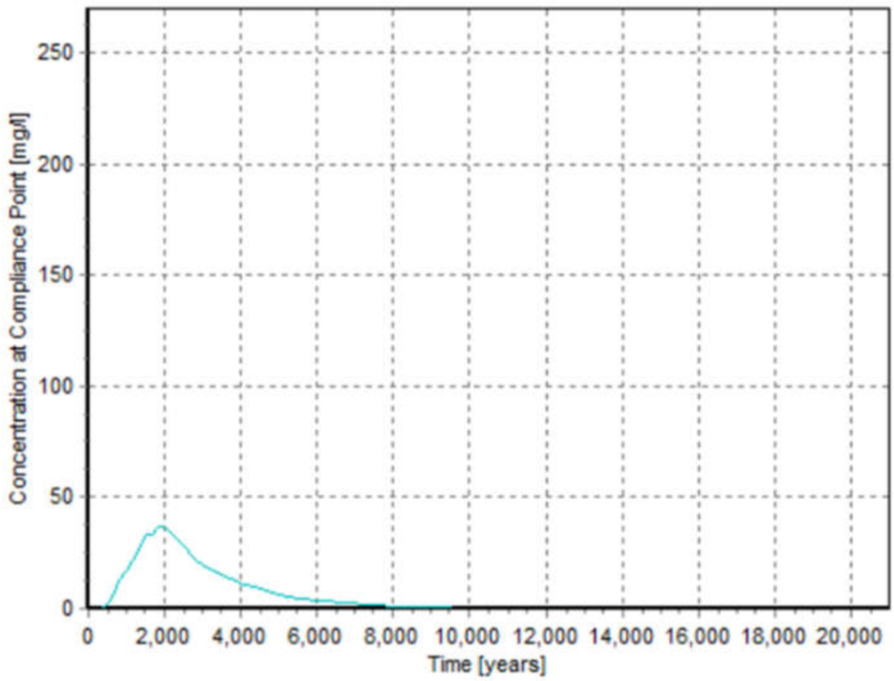
Annex B Output from the numerical model - ammonia



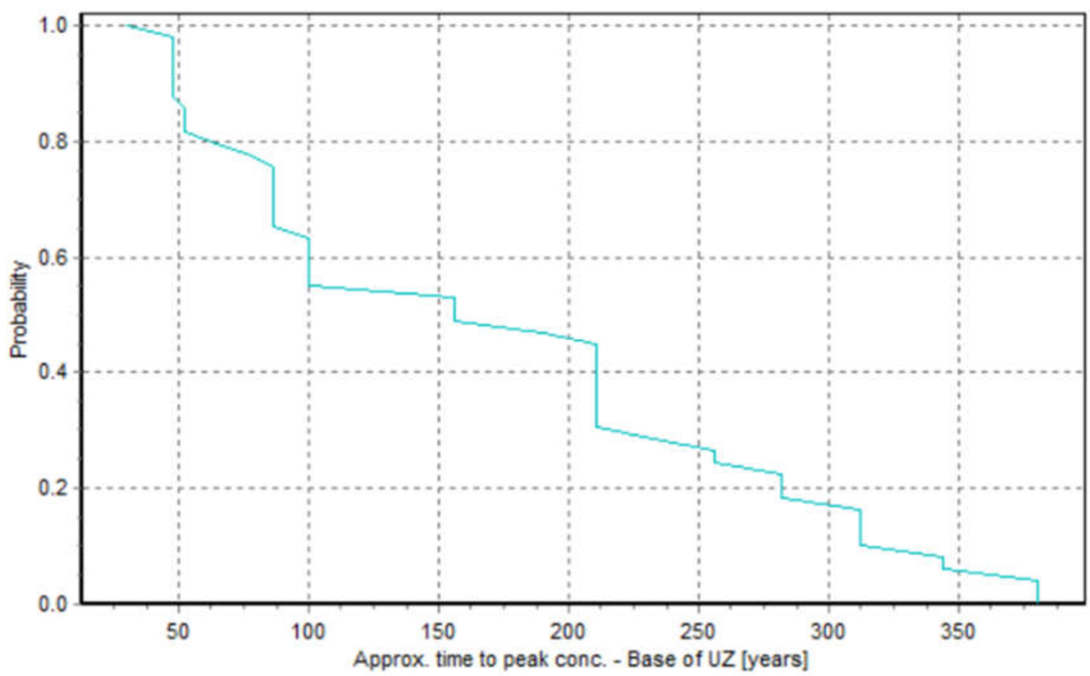
NH4 concentration in leachate



NH4 concentration at base of unsaturated zone

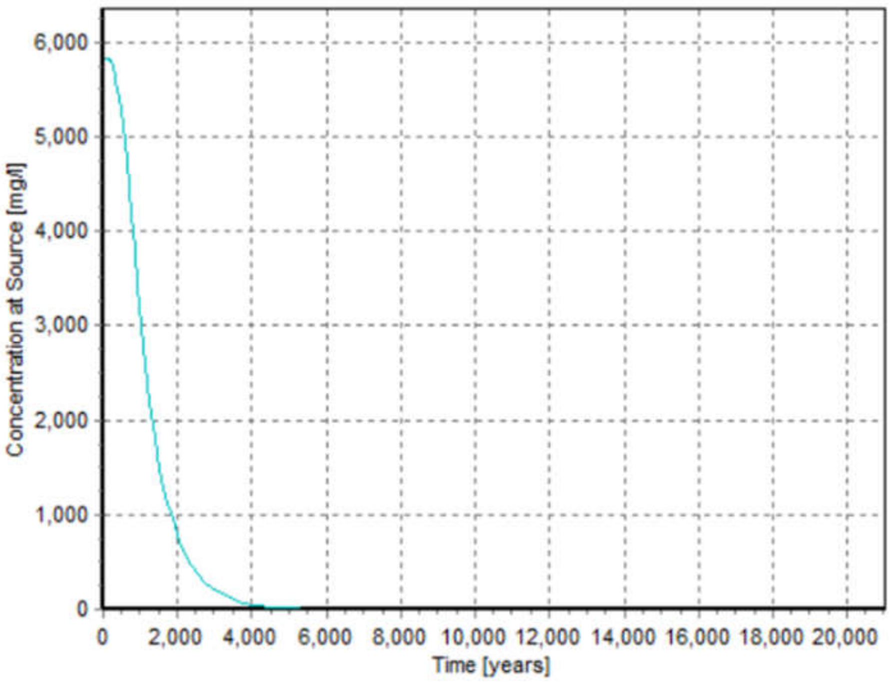


NH4 concentration at compliance point

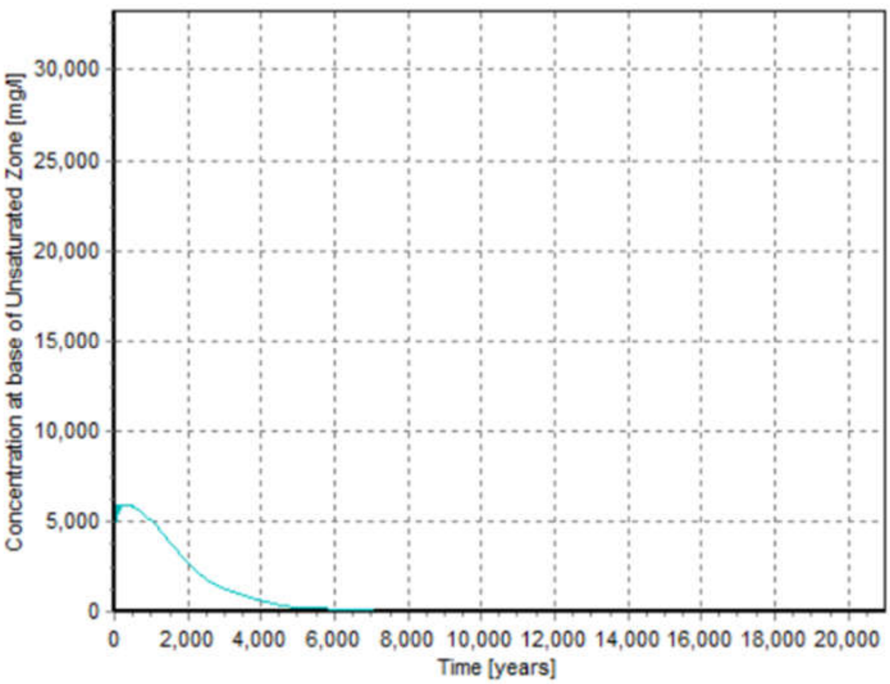


NH4 time to peak concentration at base of unsaturated zone

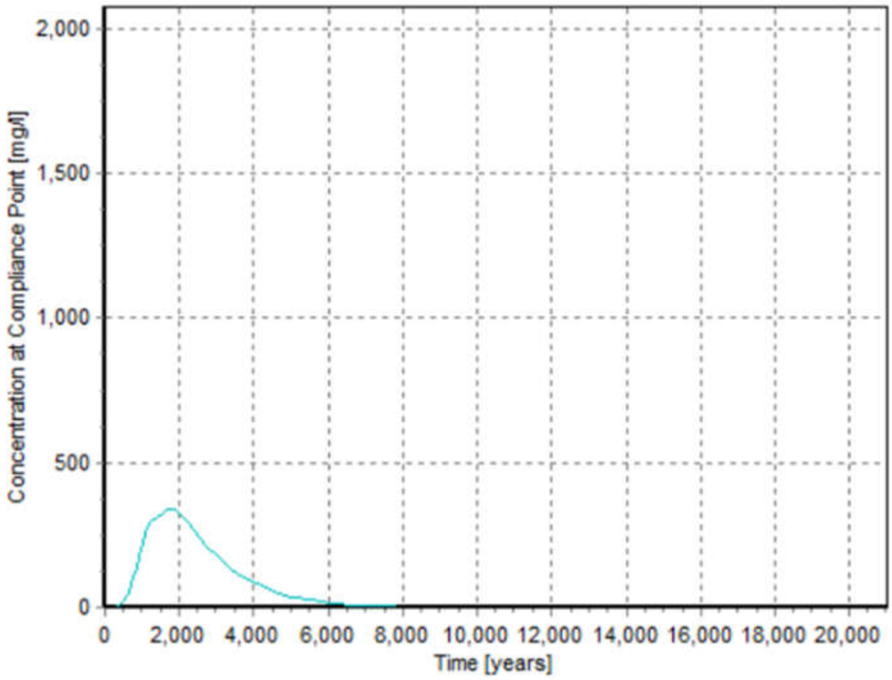
Annex C Output from the numerical model - chloride



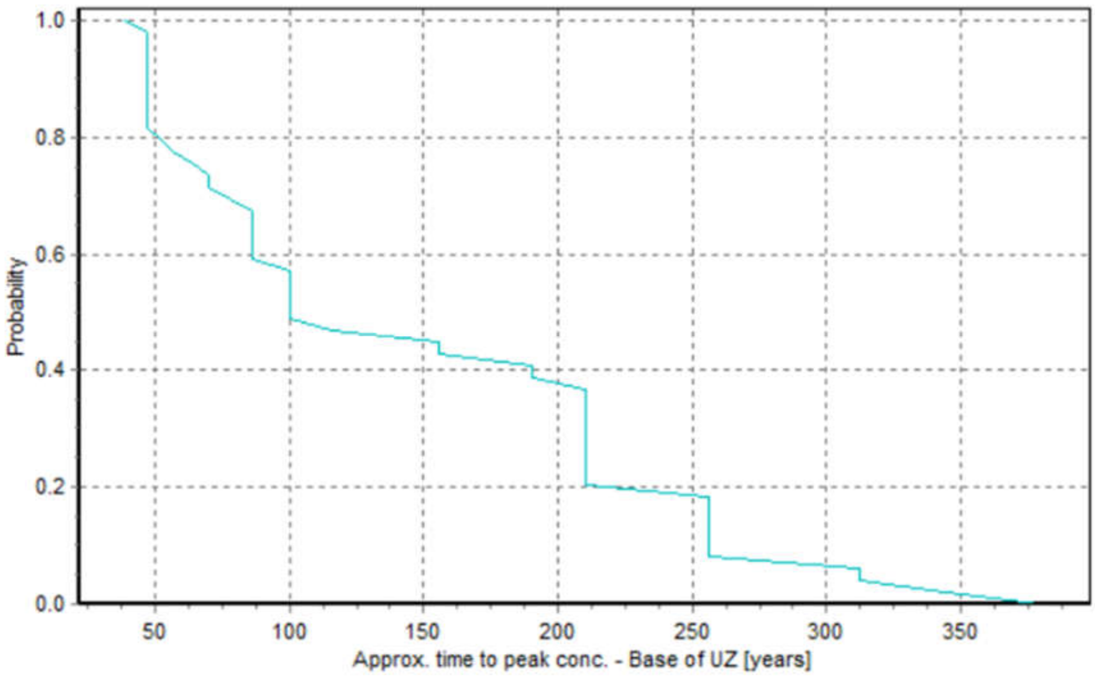
Chloride concentration in leachate



Chloride concentration at base of unsaturated zone

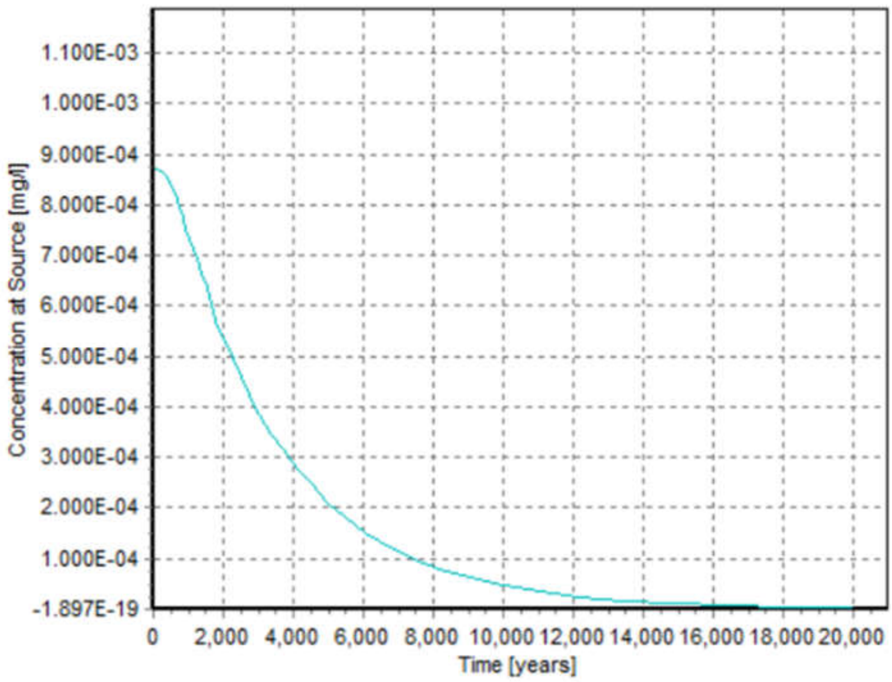


Chloride concentration at compliance point

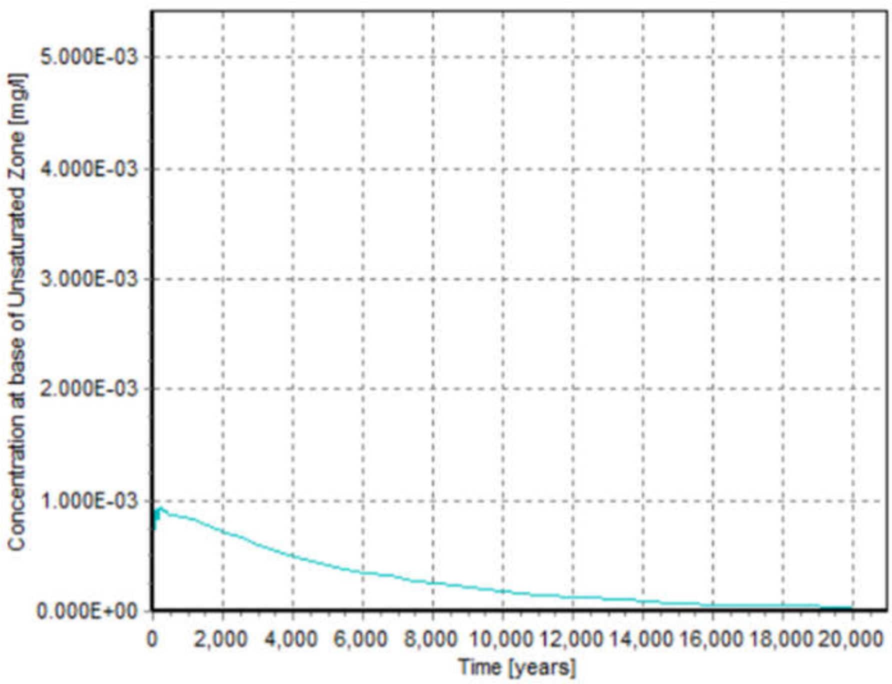


Chloride time to peak concentration at base of unsaturated zone

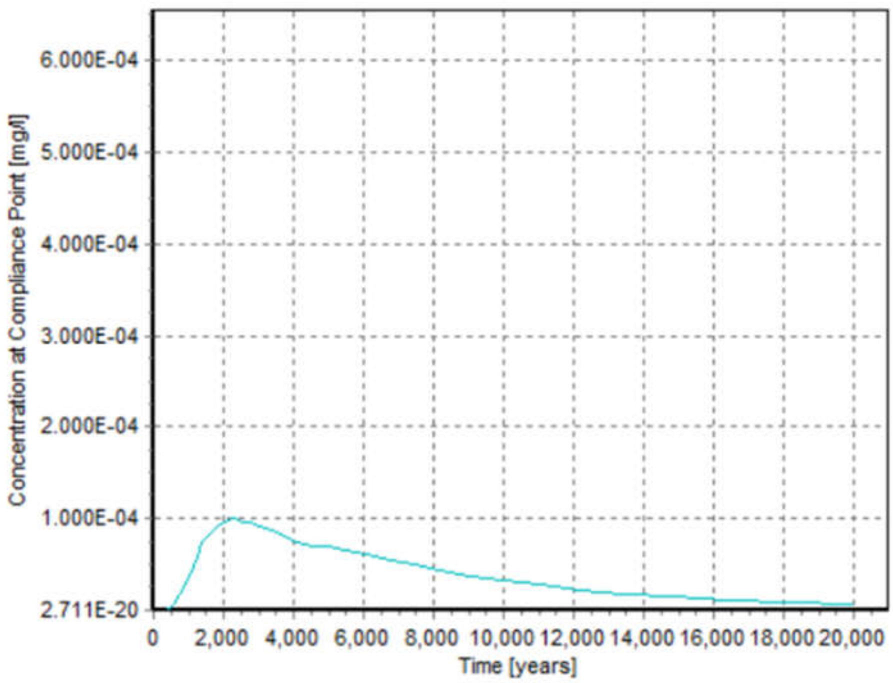
Annex D Output from the numerical model - mercury



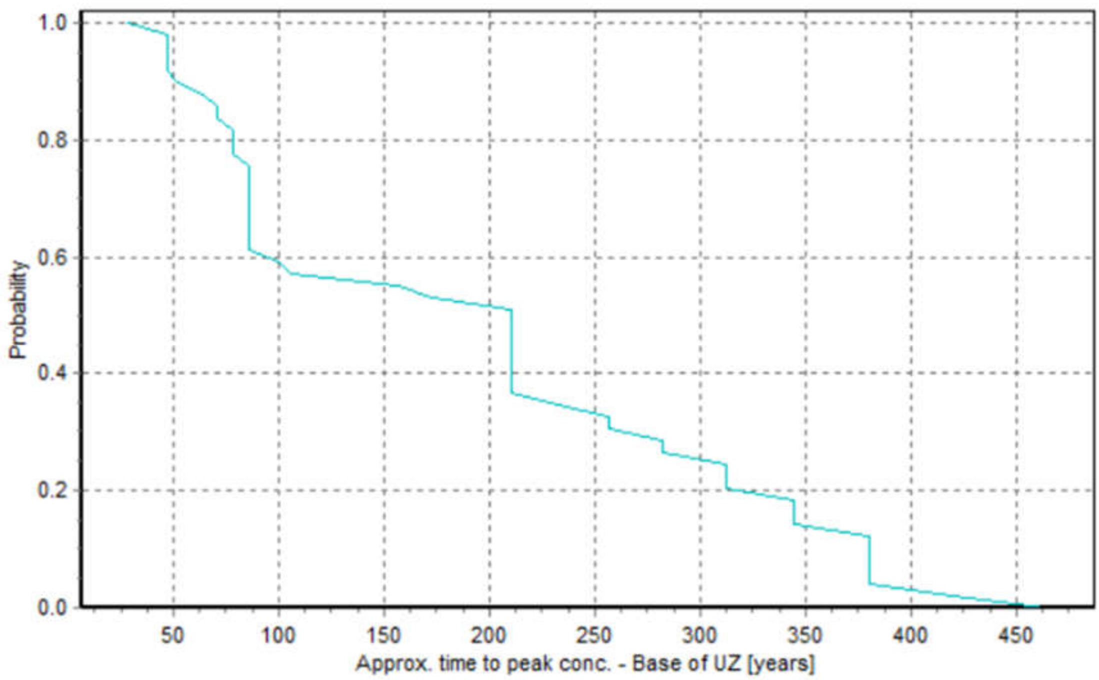
Mercury concentration in leachate



Mercury concentration at base of unsaturated zone



Mercury concentration at compliance point



Mercury time to peak concentration at base of unsaturated zone