WasteServ Malta Ltd

Development of Rehabilitation Strategies Magħtab, Qortin and Wied Fulija Landfills

Summary Report

FINAL

March 2004

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1. INTRODUCTION

1.1 Context

The solid waste disposal sites at Magħtab, Qortin and Wied Fulija were developed at a time when the full environmental impacts of such operations were not known. As a result, the Maltese Islands are left with a legacy of landfill sites that have no systems in place for the proper control of landfill leachate or gas and the presence of deep-seated fires is common. The Ministry for Resources and Infrastructure (later WasteServ Malta Ltd) has expressed concern over the potential human health and environmental impacts of these sites and the need to raise the environmental standards associated with the management of wastes in Malta. Movement has been made towards this with the implementation of *A Solid Waste Management Strategy for the Maltese Islands* (October 2001) and the letting of contracts for the appropriate management of wastes. This project is being executed in line with this overall strategy and involves the rehabilitation of the three largest landfills.

As a country due to accede to the European Union in May 2004, the Republic of Malta is obliged to implement the full requirements of EU legislation. The relevant European legislation has been considered and, where relevant, will be applied to this project. The Environmental Protection Act 2001 (and associated legislation), where appropriate, were utilised in the development of strategies for the rehabilitation of the landfills. In addition to European and national legislation, national policies have been consulted and taken into account. In particular, the *Structure Plan (1990-2010) for the Maltese Islands*, *Space for Waste – The Waste Management Subject Plan (2001)* and discussions with the Malta Environment and Planning Authority (MEPA) have been considered in addressing the after-use and development options for all three sites.

1.2 Project Objectives

The overall objective of this project is to contribute to the implementation of the rehabilitation proposals specified in *A Solid Waste Management Strategy for the Maltese Islands*. Principally, these are to close down the Magħtab and Qortin landfill sites and bring these sites, together with the closed landfill at Wied Fulija, back into beneficial use.

1.3 Scope of Services

The Ministry for Resources and Infrastructure commissioned Scott Wilson to develop environmentally sound restoration strategies for three landfill sites. This is a four-part project beginning with an investigation of the sites through to production of designs and documentation to implement the rehabilitation strategies:

Stage I: Consultation, data collation and review;

Stage II: Ground investigation;

Stage III: Risk assessments; and

Stage IV: Design and specification of rehabilitation strategies.

Stages I and II were undertaken in 2002 with Stages III and IV completed in 2003.

1.4 Report Structure

This report summarises the results of the first three stages of the project and includes:

- an overview of the key processes involved in the assessment of the risks presented by the landfills and the identification, selection and implementation of viable rehabilitation strategies (Section 2);
- the initial assessment of each of the three sites undertaken prior to site investigation and risk assessments (Section 3);
- a summary of key issues relating to environmental concerns and after-use aspirations identified during consultations with stakeholders (principally Non-Governmental Organisations, local residents groups and local councils) in 2002 (Section 4);
- a description of site investigation works undertaken in 2002 and presentation of summarised results (Section 5);
- presentation of conceptual models of each of the sites based on the initial site assessment as modified by the results of site investigation works (Section 6);
- a summary of the outcome of quantitative and qualitative risk assessments undertaken which have been used to drive the requirements for rehabilitation by concentrating on reducing the most significant risks identified (Section 7);
- the identification of viable rehabilitation strategies to mitigate the key risks identified (Section 8); and
- an outline of the proposed restoration strategies for each of the sites together with an outline assessment of the risks associated with construction and their mitigation (Section 9).

2. OUTLINE OF REHABILITATION PROCESS

2.1 Overview

To be considered successful, the end product of the rehabilitation of any former waste disposal facility must be achievable, useable and sustainable. The objective of rehabilitation is essentially to turn a current liability into a future asset.

The rehabilitation process typically comprises a number of key inter-related activities. In simplified terms these are:

1. identification of the *hazards*, key *receptors* and *pathways;*
2. quantification of the *impacts* of the *risks;*
3. development of *risk reduction goals;*
4. determine appropriate *after-use* and suitable *landform;*
5. design of appropriate *pollution control systems;*
6. integrate after-use with pollution control systems;
7. prioritise and implement in phases the remedial and restoration *works*; and
8. instigate *monitoring* and *aftercare*.

The key elements of each of these are outlined below.

2.2 Hazards, Receptors and Pathways

2.2.1 Hazards

The environmental hazards normally associated with closed waste disposal facilities primarily comprise the waste materials themselves and their degradation by-products. The hazards can largely be divided into environmental, health and safety and nuisance hazards, although there is considerable overlap between the three classes of hazard.

Environmental

There is potential for waste materials and their degradation products to have a direct impact on the immediately surrounding area (local ecology or human health for example) more widely (such as global warming). Examples of hazards present on these landfills include landfill gas, aerially emitted particulates and the products of burning and landfill leachate. It is known that the landfills have accepted a wide variety of wastes over a number of years and the potential for hazardous materials to be present within the waste mass exists.

Health & safety

The potential health and safety hazards are those that could have a direct effect on human welfare. For example, landfill gas is an asphyxiant and is potentially explosive. Also, the deep-seated fires within the landfills present their own health and safety problems by way of potential toxic by-products of combustion. In addition, direct contact with hazardous wastes could present a health risk particularly to those employed on the sites or involved in their rehabilitation, as they would have greater exposure to the materials and any gases or leachates associated with them. Other potential health and safety hazards include reductions in groundwater or bathing water quality due to off-site migration of contaminated materials and the presence of vermin, which can spread diseases.

Nuisance

In addition to the potential hazards there are other negative effects of former waste disposal facilities. These include issues such as litter, vermin and (perhaps most importantly) visual intrusion.

2.2.2 Receptors

For hazards to have an impact there must be receptors that can be potentially affected by the hazards. In the situation in Malta and Gozo these receptors are readily defined as:

- the local terrestrial, avian and marine ecology;
- the local population;
- tourists;
- site workers;
- local groundwater and surface watercourses; and
- seawater quality.

2.2.3 Pathways

For a hazard to have an impact on a receptor there must exist a link between the two. Such links are pathways whereby a hazardous substance actually reaches a receptor. Such emissions may be physically transported, carried in percolating water or aerially discharged. Thus there is a potential for the hazard to reach the receptor.

2.3 Risk Assessment

Risk assessment is the procedure by which the impact a particular hazard may be having on a specific receptor is assessed. The impact is usually assessed by determining the concentration or quantity of a particular hazardous substance reaching a receptor and comparing this to local, nationally or internationally recognised criteria.

A tiered approach is taken whereby ever more detailed assessments are carried out if initial coarse assessments indicate that risks are potentially unacceptable. This is used to fine-tune the risk-based model until a clear understanding is gained of the most significant risks.

2.4 Risk Reduction Goals

Identifying risk reduction goals is the key to determining the scale of remediation or mitigation necessary to reduce the impact of the hazard at the receptor. These are effectively the levels at which impacts are considered acceptable. Thus risk reduction goals can be set for each medium at each receptor (air, water and visual impact etc.). Such standards are typically contained in national or international standards such as those for occupational exposure and air and water quality. If required, site-specific risk reduction goals may also be set based on the outcome quantitative risk assessments. It is also important that such risk reduction goals are allied to the after-use requirements.

2.5 After-use

Determination of the after-use for each site is crucial to the selection of the most appropriate rehabilitation strategy. Any proposed after-use has to recognise a number of issues. Initially land use, planning and development legislation and policies must be understood in order to set out parameters by which after-use options are measured. Secondly, consultations with the affected local communities are essential in determining the needs and aspirations of those concerned. Finally, there are physical constraints that will be unique to the landform at each site. Examples of such constraints include the land area available or the volume of material present. The above considerations will give rise to a number of feasible options to which the sites may be restored. These can then be assessed further.

The physical constraints are particularly important for the current situation. The driving reason for the existing (and likely final) geometry of each site is the local requirement to dispose of the maximum volume of waste within the smallest area. This has resulted in high waste mounds with steep slopes and only small, level upper plateaux. Such landforms limit the options for re-use unless there is significant re-contouring of the waste mound; this may be constrained by land ownership boundaries.

2.6 Pollution Control Systems

There are two components to the works required to mitigate the risks posed by the landfills. These are essentially the actions required to eliminate immediate safety hazards (such as the fires) and the longer-term engineering systems necessary to reduce the environmental and health risks.

The engineering systems may include barriers, such as a capping over the sites to reduce aerial emissions and limit rainfall infiltration (and thus the production of leachate). Gas management and utilisation systems would also be categorised as a longer-term control system. However, based on current patterns of the type and quantity of waste disposed to landfill, it is considered unlikely that there is sufficient landfill gas generation potential at any of the sites to warrant the installation of any gas utilisation systems (electricity generation for example).

2.7 Integration of after-use and control systems

It is crucial that the after-use for each site is determined early in the design process as this has a major influence on the landform and deployment of the pollution control systems. As noted above, each site is characterised by steep side slopes and a small top plateau. Thus to develop a suitable end-use there will necessarily be substantial re-contouring and consequently the production of surplus quantities of waste materials.

It is unlikely that complete translocation (i.e. the complete removal of all of the wastes down to original ground level and re-deposition elsewhere) of any of the landfills would constitute an acceptable environmental rehabilitation strategy. Similarly, strategies incorporating the complete 'mining' of the waste could lead to years of activity similar to those at the currently active sites. Whatever after-use is decided upon it is likely that there will be a need to re-grade existing slopes to provide usable platforms and access to environmental control equipment.

Above any "engineering capping" system considered necessary to contain emissions and reduce infiltration a "restoration cap" may be required. This is the base on which restoration planting and landscaping would be undertaken. There is a paucity of suitable material locally and it would be necessary to develop large quantities of a suitable growing medium. There are currently trials devised by the Parks and Landscape Conservation Department of the Works Division of the MRI section into the establishment of vegetation on rubble filled areas utilising soils manufactured from compost and screened fines. These soils could be improved by incorporating pre-treated sewage sludge to provide potential nutrients and better water retention characteristics thus ensuring a better growing medium on each site. This work has clear benefits for any landfill rehabilitation strategy.

2.8 Prioritisation and Phasing

It is intended that essential remedial works be carried out soon where safety is considered to be compromised.

It must be stressed that to successfully rehabilitate the landfills will take a substantial amount of time. In addition to the re-profiling and processing of surplus material the initial engineering works are likely to take many months (and possibly over a year on the larger site at Magħtab). It will take many more years for the restoration cap to be established and placed unless large volumes of restoration cover are imported. Thus, it is likely that the restoration works will need to be phased; the more sensitive parts of each site being restored earlier in the programme.

Additionally there is an intermediate option; that of "interim restoration" whereby certain areas are restored early allowing establishment of vegetation and the development of soils before the final after-use is developed some time in the future.

The new-engineered landfill for Malta will be sited at Għallis, immediately adjacent to Magħtab. The construction of the new landfill would need to be integrated with the proposed after-use for the restored existing landfill and would influence the uses to which the restored site could be put.

2.9 Monitoring and Aftercare

It is essential that the rehabilitated sites are maintained and monitored. The responsibility for the aftercare of the pollution control systems needs to be considered. Such liability could be retained by central government or it could be devolved to the local authority or the end-user of each site.

3. INITIAL SITE ASSESSMENT

3.1 Magħtab

3.1.1 Background

The Magħtab landfill site is the only operational landfill site on the island of Malta authorised to take non-inert waste. It is located on the north coast of the island 3 kilometres north of Naxxar and 1½ kilometres east of Bugibba. It has been in operation since 1977 and has taken most of Malta's waste since the closure of Wied Fulija in 1996. Prior to 1997 no detailed records were kept of the quantity and type of wastes deposited. However since this time a weighbridge has been installed and records have been made of all wastes deposited.

The site was developed on areas of garigue and some former agricultural land. Before waste disposal operations began, the natural topography of the area was a valley lying between two ridges (Figure 3.1); the general slope of the land was towards the sea. Currently, the valley is entirely buried and the ridges form the land surfaces at the base of the western (Il-Għallis ta' Gewwa) and eastern (Ta' Ħammud) sides of the landfill.

Current land use on the former ridges is predominantly agricultural, although fields adjacent to the landfill are disused on the northeastern and southern sides of the site. An area of garigue is present at Xagħret Franklin to the west of the site, whilst in the north, the site is encroaching on a small area of garigue at Il-Għoqod beyond which lies the main coast road from St Julian's to St Paul's Bay.

The footprint area of the landfill is currently around 40 hectares although the area of land owned by the Government is larger at around 60 ha. The main waste filling area forms a complex shape (Figure 3.1) with wastes rising steeply from natural ground level in benches to a flat upper plateau around 6 hectares in area (Figure 3.1). The maximum thickness of waste over the buried valley at June 2002 was around 70 metres (Plate 3.1). This has increased and is likely to increase further as the landfill continues to receive waste up until its projected closure during 2004.

Table 3.1 shows a breakdown of waste inputs to Magħtab in 2001. All waste types produced in Malta (in particular municipal solid wastes, industrial and hazardous wastes) were co-disposed at the site. The amount of Construction and Demolition Waste accepted at Magħtab has fluctuated over the past five years, from some 745,000 in 1997 to 940,000 tonnes in 2001 (although in 2000 it peaked at around 1.2 million tonnes). Construction and Demolition waste ceased to be deposited at Magħtab in late summer 2003.

Municipal solid waste has seen a significant increase since 1997 when weighbridge facilities were installed, increasing from 136,460 tonnes in 1997 to 157,000 tonnes in 2001. However other non-inert solid wastes (commercial and industrial, mixed trade and other wastes) have decreased over this period, for a variety of reasons, including economic fluctuations and the increase in recycling activities.

Currently, the solid non-inert wastes are deposited in discrete areas by tipping over a nominal 5-6 m high tipping face using a tracked dozer (Plate 3.2). Fines, made from site won crushed construction and demolition wastes, cover these wastes. The site also takes liquid wastes including abattoir wastes, oily sludges and dry dock grit-blasting residues. These are deposited by tanker in an informal lagoon located on top of the main waste mass (Figure 3.1, Plate 3.3). Areas formerly used for liquid waste deposition are likely to be buried within the landfill.

There are currently no surface water, leachate or landfill gas management systems in place. Magħtab landfill is due to close in 2004 and a new-engineered waste disposal facility will subsequently become operational.

Table 3.1 Waste Inputs to Magħtab 2001

Waste Stream	**Tonnage in 2001**	**Percentage**
Municipal Solid Waste	126,164	10.8 %
Mixed Trade & Municipal	50, 967	4.4%
Commercial & Industrial Waste	24,733	2.1%
Other waste (including abattoir, clinical, slurry & sludge)	19,567	1.7%
Special Waste	2,330	0.2%
Construction and Demolition Waste:		
Excavation Waste	781,523	67.2%
Mixed C&D Waste	158, 025	13.6%
TOTAL	**1,163,309**	**100%**

Raw data used for waste arisings in Malta have been taken from recorded waste statistics for the period January – June 2002. The projections have also been based on *"A Solid Waste Management Strategy for the Maltese Islands" October 2001 p88.*

3.1.2 Potential Hazards

There are a number of fires on the landfill caused by the combustion of organic matter (principally within domestic wastes) following burial in areas already burning (the older fires are likely to have resulted from the practice of deliberately burning wastes). Visual evidence of burning consists of venting of highly odorous fumes and smoke from discrete areas of the ground surface with associated discolouration of the surface cover and occasional exudation of condensate from partially combusted materials (Plate 3.4). Burning is concentrated on the upper parts of the windward sides of the landfill and the central plateau.

Although the majority of waste deposited at Magħtab is construction and demolition waste (the bulk of which is inert) the presence of smaller, but still significant, quantities of domestic and industrial wastes (including some clinical and hazardous or special waste) deposited without proper engineering management means that the site has the potential to cause a detrimental environmental impact on the surrounding area.

The principal contaminants that may be associated with wastes deposited at Magħtab of particular concern are:

- heavy metals;
- hydrocarbons (principally oils);
- asbestos;
- volatile organic compounds (principally solvents and fuels);
- semi-volatile organic compounds (including polyaromatic hydrocarbons and phenols);
- polychlorinated dibenzo dioxins (PCDDs)/furans (PCDFs) popularly known as “dioxins” and PCBs;
- pesticides; and
- pathogens.

In addition, decomposition of landfill wastes may produce emissions of landfill gases, whilst combustion of organic wastes containing chlorine will produce dioxins and furans (PCDDs/PCDFs)

These potential contaminants could impact on the adjacent environment by:

- leaching of contaminated material from the waste by infiltrating rainfall to contaminate groundwater;
- contamination of rainfall run-off by leachable or entrained contaminants deriving from waste materials and subsequent migration onto surrounding land;
- contamination of the marine environment by inflow of contaminated groundwater or rainfall run-off;
- aerial dispersion to surrounding areas of volatile organic compounds and landfill gases; and
- aerial dispersion and deposition of contaminated dusts on the surrounding area.

The conceptual site model for Magħtab is summarised in Table 3.2 using a hazard-pathway-receptor framework. The initial Conceptual Model is intended to summarise and present the potential hazards, pathways and receptors, taking into account available information on the landfill itself and the surrounding environment. This initial Conceptual Model was used as an aid to designing the site investigation works and a revised version is presented in Section 6.

Table 3.2: Initial Conceptual Pollution Model for Magħtab Landfill

Hazard (see Table 3.3)	**Pathway**	**Receptors**
Leachable contaminants in the waste	Downwards infiltration of rainwater/leachate through waste into underlying bedrock	Groundwater in mean sea level aquifer and nearby agricultural abstractions
		Marine environment (seawater and sediment)
	Rainwater run-off containing dissolved contaminants and suspended solids	Surrounding agricultural land
		Marine environment (seawater and sediment)
Airborne emissions from fires, waste degradation and physical disturbance	Aerial dispersion of gases, dust and particulates	Inhabitants in and visitors to: Magħtab Salina Bay, Qawra and St Pauls Swieqi Għargħur Naxxar Mosta Local ecology
Toxic waste materials within the waste mass	Ingestion/inhalation/dermal contact	Site Workers

Greenpeace Mediterranean undertook chemical analyses of soils near Magħtab in July 1999 in which contamination of waste materials located on the periphery of (but not within) the landfill was monitored. The samples taken were analysed for the presence of heavy metals and dioxins together with a screening (but not quantification) for the presence of volatile and semi-volatile organic compounds by GC-MS (gas chromatography – mass spectroscopy) techniques (Table 3.3).

Table 3.3: Summary of Greenpeace Chemical Analyses July 1999 (all mg/kg except where noted)

Sample >	*9091*	*9092*	*9093*	*9094*	*9095*
Determinands Analysed	Ash from burning of PVC coated copper cable		burnt area of landfill edge	grey sludge (sewage?)	Dust next to leaking barrel
Cadmium	8.3	14.3	1.0	nd	nd
Chromium	57.9	30.4	71.9	27.8	7.0
Cobalt	4.8	4.0	3.7	8.5	3.5
Copper	129,206.4	42,192.0	59.9	25.9	5.3
Lead	13,242.1	8,562.5	129.2	49.1	829.4
Manganese	138.5	82.1	155.2	147.2	55.3
Mercury	1.0	1.1	2.1	0.6	0.1
Nickel	12.7	13.8	13.5	18.4	6.1
Zinc	3,213.9	5,111.6	201.0	69.8	491.7
Dioxins (mg/kg ITEQ)	0.05	-	-	-	-
GC-MS Screen (concentrations not quantified)	41 Compounds including: chlorinated-benzenes naphthalenes alkanes	167 Compounds including: alkenes PAHs chlorinated-benzenes cyclo-alkanes furans	130 Compounds including: phenyl benzenes chlorinated-benzenes alkanes and cyclo-alkanes alkenes PAHs p-p'DDE PCB-153	40 Compounds including: chlorinated-benzenes alkanes and cyclo alkanes thiophenes PAHs	201 Compounds including: alkenes alkanes and cycloalkanes

The results are generally typical of burnt cable and cable casing, burnt PVC and fuel hydrocarbons. The analyses also confirm the potential for burning of PVC to generate dioxins and that pesticide and PCB containing wastes were identified close to the landfill. These analyses have been the subject of further comment by the Environment Directorate.

3.1.3 Air Quality

The principal mechanisms by which the landfill could potentially impact on air quality are:

- dispersion of gases produced by degradation and combustion of wastes; and
- dispersion of contaminated and uncontaminated particulate matter (dust).

Given that the bulk of the wastes within Magħtab are biologically inert and of high air permeability, it would be anticipated that biological degradation of organic wastes within the landfill would be primarily aerobic producing carbon dioxide as a by-product. Limited anaerobic degradation of wastes may occur within the centre of waste masses (particularly during the wet season) producing methane and possibly hydrogen sulphide (if sulphate containing wastes such as plaster are present). Sulphur dioxide might also be generated by oxidation of biologically produced hydrogen sulphide.

Combustion of organic waste materials is likely to produce smoke, odours, carbon dioxide, carbon monoxide and, if chlorine containing materials such as PVC are present, could produce dioxins and furans.

Aerial emissions from fires are known to have reduced in recent years following the introduction of a crushing plant to provide daily cover of non-inert waste. This has helped reduce the intensity and impact of fires on the site. However, fires producing smoke, fumes and odours still occur.

Similarly, recent resurfacing of internal roads and use of dust suppression during dry weather have reduced, but not eliminated dust generation caused by vehicle movements. The majority of dust particles emitted might be expected to be uncontaminated. However, a proportion of the dust emissions may include some contaminated material.

In Malta winds are strong and frequent; the most common is the cool north-westerly (*majjistral*) followed in frequency by the dry north-easterly (*grigal*), and the hot humid south-easterly (*xlokk*). In addition to this regional pattern, local winds around Magħtab are likely to be modified by on-shore breezes (particularly during the summer months) and local convection caused by the presence of highly reflective construction and demolition wastes. The presence of thermals associated with fires may be likely to enhance any local convection effect. The net effect of these winds is that dispersion of gases and particulates may occur in any direction but that dispersion in a south-eastward direction (by the *majjistral*) is the most likely to occur.

The principal receptors at risk from aerial emissions from Magħtab are:

- local agricultural land and garigue in all directions;
- urban areas of St Julian’s and Għargħur to the south-east;
- tourism development at Baħar iċ-Ċagħaq to the south-east;
- tourism development at Salina Bay, St Paul’s Bay and Bugibba to the north-west;
- the urban areas of Naxxar and Mosta to the south.

3.1.4 Groundwater Quality

The impacts on groundwater quality by landfills are typically associated with leachate generation within wastes in response to rainfall infiltration and delayed migration through the base of the landfill to groundwater receptors. Whilst the possible presence of localised accumulations of leachate within lenses of domestic waste cannot entirely be excluded (due to the size of the site) it is considered unlikely that there are any significant bodies of leachate within the waste mass at Magħtab due to a combination of the following:

- the raised elevation of the site;
- the lack of any lining systems;
- the highly permeable nature of the wastes themselves;
- the fractured and karstic nature of the underlying bedrock (with a significant thickness of unsaturated zone);
- the low effective rainfall; and
- the predominantly non-organic nature (and hence low water retention capacity) of the majority of the wastes.

It is therefore anticipated that the principal means by which contaminated materials within the landfill may affect groundwater quality would be via direct leaching and transport to the water table. The potential for heavy metal species to be mobilised by leaching was studied as an undergraduate dissertation in 1999 using large-scale leachability tests on waste from Magħtab (Saliba, 1999). This study found that lead, nickel, copper and manganese were all leachable from waste under laboratory conditions in potentially significant concentrations.

The presence of these metals could be related to the presence of the following in the landfill:

- lead-acid batteries;
- slurries derived from the electro-plating industry;
- domestic solid waste; and
- grit-blast waste from dockyard activities.

Saliba found that chromium, cadmium and copper were less mobile (or present in lower quantities within the wastes).

Groundwater is a precious resource in Malta. Groundwater abstractions provide approximately 50% of Malta’s potable water supply as well as much water used for irrigation purposes. Rainfall in the Maltese islands is highly seasonal with an average precipitation of 535 mm, the bulk of which falls in the months of September to April. Most rainfall is lost by evapotranspiration (70-80%) or run-off (6%) with the remainder (16-25%) providing groundwater recharge.

In the east of Malta fresh groundwater is contained within the limestones and carbonate mudstones of the Oligocene Lower Coralline Limestone Formation (Table 3.4). The aquifer consists of a lens of freshwater floating on top of denser saline groundwater. The water table is generally at around 3.5 m above sea level in the centre of Malta, falling to sea level towards the coast (Dr. J. Mangion *Pers. Com*). Hydraulic gradients and groundwater flow velocities are therefore likely to be low.

Table 3.4: Geology of Magħtab Area

Stratum	**Thickness**	**Water Level**
Made Ground:		
Landfilled Waste	0-c.84 m	Possible discontinuous leachate toward base in centre of landfill?
Globigerina Limestone Fm:	0-15 m	Unsaturated
Lower Coralline Limestone Fm:		
Xlendi Member (coarse grained limestones)	Up to 22m	Water table at or around sea level in Lower Coralline Limestone Formation
Attard Member (grey limestones)	10-15 m	
Magħlaq Member (carbonate mudstones)	up to 38 m	

Groundwater is abstracted for potable use both by pumping stations and mined galleries. The bulk of these are located to the south-east of the major fault that bisects the island of Malta. The nearest public water abstraction is located to the south-east of the Great Fault at Wied Il-Għasel several kilometres to the south of Magħtab landfill.

Local to the site are a number of small, unlicensed abstractions used for agricultural irrigation. Information on their locations is held by the Malta Water Services Corporation. Whilst the general direction of groundwater flow is towards the coast, abstractions close to the landfill in any direction are potentially at risk from contamination given the very low hydraulic gradient. The typical flow rate abstracted for irrigation purposes (around 50 m^3/d, J Mangion, *pers. comm.*) may be sufficient to cause radial flow into these wells from all directions including groundwater beneath the landfill.

The presence of contaminants potentially deriving from Magħtab in the groundwater environment has only been investigated by Saliba in 1999. Five agricultural/irrigation abstractions located around the southern end of the landfill were sampled and the waters analysed for a range of heavy metals. The results are summarised in Table 3.5 and compared to standards for drinking water quality in EC Directive 98/83/EC. Chromium was observed in all wells in concentrations thought likely to be similar to background. Lead, nickel, copper, cadmium and arsenic were identified concentrations exceeding local background in two of the boreholes both located close to the landfill (although only nickel exceeded EU Drinking Water Quality Standards) but in a direction against the regional groundwater flow direction (which is presumed to be towards the coast).

Despite this up-gradient location of the impacted wells, at present it seems reasonable to assume that these elevated concentrations are related to the presence of the landfill. The differences in contaminant concentrations between the boreholes containing lead, nickel and copper and the others, where background concentrations were observed may be explained by one or more of the following:

- the presence of preferential flow paths due to the fractured and karstic nature of the aquifer (i.e. groundwater flows along fractures, fissures and through solution features rather than through the rock mass);
- variations in abstraction rate at the monitored boreholes affecting the zone of influence of each abstraction; and
- variations in the distribution of leachable contaminants within the landfill.

Table 3.5: Summary of Groundwater Quality Monitoring in Unlicensed Groundwater Abstractions (Saliba, 1999). ND – not detected. Samples exceeding EU quality thresholds for drinking water in bold.

Sample	*Pb μg/l*	*Ni μg/l*	*Cu μg/l*	*Cr μg/l*	*Cd μg/l*	*As μg/l*
2026	9.56	**165.00**	19.02	ND	0.424	1.73
2027	ND	4.56	ND	0.3	0.219	0.51
2041	5.72	7.62	ND	ND	0.032	0.13
2604	ND	ND	ND	0.1	0.019	ND
2130	ND	ND	ND	ND	0.003	ND
EU Directive 98/83/EC	<10	<20	<2000	<50	<5	<10

3.1.5 The Marine Environment

Given the proximity of Magħtab landfill to the coast at Qalet Marku and Baħar iċ-Ċagħaq, which are areas used for recreational activity, concerns have been raised over the potential impact of contaminants on the marine environment. Published monitoring of the marine environment by the Department of Public Health relates to microbiological analysis of bathing waters only. However, some limited academic research on concentrations of heavy metals in both marine biota and sediments has been conducted.

Evidence of elevated concentrations of heavy metals (cadmium, copper and zinc) in locally occurring mollusc species (marine snails) at Baħar iċ-Ċagħaq was recorded by Pace (1998). The same study provided evidence of concentrations of cadmium, copper, lead and zinc elevated above regional background in sediments from the same location.

Further sampling of the coast closer to Magħtab (to the north of Qalet Marku) was undertaken at five locations by Saliba (1999) who noted concentrations of lead, nickel and copper that were elevated above local background. Concentrations of chromium, manganese, cadmium and arsenic were not elevated. Concentrations were higher in more sheltered locations where accumulating sediments are less likely to be disturbed by wind and wave action. They also appeared to be seasonably variable.

These metallic contaminants in the marine environment were demonstrated to be both present and mobile within Magħtab landfill wastes by Saliba. Potential mechanisms by which contamination of near-shore sediments and biota by the landfill could occur are:

- contaminated surface run-off from the landfill entering the sea during heavy rainfall events; or
- discharge of contaminated groundwater to the sea bed.

Both of these are possible but the former is considered possibly the more significant given the very low hydraulic gradients within the mean sea level aquifer that will restrict the rate of groundwater discharge to the marine environment. There is anecdotal evidence from local residents of surface run-off from the landfill entering the sea, either from the northern face of the landfill and across the coast road or via the site entrance and then along the minor road to the coast road. Drainage from the coast road runs directly onto the foreshore.

Saliba also investigated the potential for contamination of rainfall run-off from the landfill by soluble heavy metals by collecting and analysing samples of rainfall run-off from Magħtab during autumnal rainfall events. For reference, these results were compared to EU drinking water standards and on this basis only concentrations of lead, nickel, chromium and cadmium in run-off were very slightly elevated in some samples (Table 3.6).

Table 3.6: Summary of Analyses of Magħtab Run-off (Saliba, 1999) ND – Not detected. Samples exceeding EU quality thresholds for drinking water in bold.

	Concentration Range (mg/l)	EU Directive 98/83/EC Quality Threshold (mg/l)
Lead	ND - **0.03**	0.01
Nickel	ND - **0.05**	0.02
Copper	0.01 - 0.04	2.00
Chromium	0.002 - **0.068**	0.05
Manganese	ND - 0.908	
Cadmium	ND - **0.006**	0.005
Arsenic	ND - 0.007	0.01

In addition to dissolved contamination, run-off would contain suspended solid material, some of which could potentially contain contaminated material.

The potential for impacts on the marine environment (however small) has led to the precautionary recommendation by the Public Health Department that the foreshore at Qalet Marku is not used for bathing until the risks have been fully assessed.

When considering the potential impact of the landfill on the marine environment, it should also be noted that other sources of contamination exist, most notably surface run-off from the heavily trafficked main road from St Julian's to Bugibba, which runs close to the foreshore at Baħar-iċ-Ċagħaq and Qalet Marku. Road run-off typically contains elevated concentrations of both toxic metals and hydrocarbons that may potentially impact on the quality marine environment.

3.2 Qortin

3.2.1 Background

Il-Qortin, Gozo has been in operation as a landfill since 1968. It is located approximately 2 kilometres north of Xagħra, and 1 kilometre to the east of Marsalforn on the north coast of the island of Gozo (Figure 3.2). To the east is Ramla Bay, an important tourist beach.

The site was developed on the high level (around 100-110 mASL) garigue limestone plateau of il-Qortin ta' Għajn Damma and areas of garigue remain on the plateau to the west (Plate 3.5). A small private dwelling has been built on the highest point of the plateau immediately to the west of the landfill (Plate 3.6). The limestone plateau to the south and east consists of rubble walled fields. Although the fields immediately adjacent to the landfill are disused, the remainder are currently in agricultural use (Plate 3.7).

The limestone plateau terminates to the north and west with a cliff face around 10-15 m high below which are steep *Rdum* clay slopes descending to the sea at Marsalforn and the coastline to the east where limestone again outcrops at sea level (Plate 3.8).

The current landfill footprint occupies an area of around 3.5 hectares. The shape of the landfill at the present time is a flat-topped mound with very steep side slopes (approaching 1v:1h) with a summit plateau approximately 1.5 hectares in area (Figure 3.2). On the seaward side, the base of the waste encroaches to within 2 or 3 m of the cliffs at the edge of the limestone plateau. The maximum depth of waste in June 2002 was around 17 metres.

All the waste deposited at Qortin originated in Gozo and historically, the composition of the waste was mainly municipal solid waste (over 90% of all wastes deposited) with more limited quantities of industrial waste. With recent increases in tourist development on Gozo the distribution of wastes deposited altered dramatically to containing predominantly construction and demolition waste (68% in 2001) much of which is soft-stone excavation waste. The site accepted about 72,000 tonnes of waste in 2001 of which 22,300 tonnes was municipal solid waste and non-construction and demolition waste.

It is intended to close the landfill during 2004 when waste from Gozo will be transferred to Malta for treatment and subsequent disposal in a new-engineered waste disposal site. Over the intervening period the landfill will continue to increase in size. However, as the landfill footprint is strongly constrained by the presence of the limestone cliff to the north, the area of garigue to the west and agricultural land to the south and east, the landfill will have to rise. If present rates of waste deposition are maintained the landfill may not have the capacity to take all the wastes due at the site before the new transfer station opens mid-2004.

Historically, there have been frequent fires on the landfill caused by the combustion of organic matter (principally within domestic wastes) following burial (although older fires are likely to have resulted from the practice of deliberately burning wastes). At present there is only limited visual evidence of burning consisting of surface discolouration of the surface cover. However, more widespread and uncontrolled burning has occurred in the recent past and it is likely that burning is present at depth with fires covered by more recent deposits of waste. Current evidence of burning is concentrated on the upper parts of the western and north-western sides of the landfill and this distribution is confirmed by available aerial photography from 1998.

3.2.2 Potential Hazards

Although the majority of waste currently deposited at Qortin is construction and demolition waste (the bulk of which is inert) the presence of significant quantities of domestic and industrial wastes deposited in an uncontrolled manner means that the site has the potential to cause a detrimental environmental impact on the surrounding area. However, unlike landfills on Malta, Gozitan waste is unlikely to contain hazardous wastes from heavy industry. However the following types of potentially contaminated wastes are still likely to be present:

- abattoir wastes;
- health-care wastes;
- agricultural wastes;
- food wastes; and
- used oils.

The following contaminants are likely to be of concern (but in lower concentrations than at Magħtab):

- heavy metals;
- hydrocarbons (principally oils);
- asbestos;
- volatile organic compounds (principally solvents and fuels);
- semi-volatile organic compounds (including polyaromatic hydrocarbons and phenols);
- PCBs;
- pesticides; and
- pathogens.

In addition, decomposition of landfill wastes may produce emissions of landfill gases, whilst combustion of organic wastes containing chlorine will produce dioxins and furans (PCDDs/PCDFs).

These potential contaminants could impact on the adjacent environment by:

- leaching of contaminated material from the waste by infiltrating rainfall to contaminate groundwater;
- contamination of rainfall run-off by leachable or entrained contaminants deriving from waste materials and migration onto surrounding land;
- contamination of the marine environment by inflow of contaminated groundwater or rainfall run-off;
- aerial dispersion to surrounding areas of volatile organic compounds and landfill gases; and
- aerial dispersion and deposition of contaminated dusts on the surrounding area.

There are no available chemical analyses of waste materials at Qortin.

The conceptual site model for Qortin is summarised in Table 3.7 using a hazard-pathway-receptor framework. This initial Conceptual Model is intended to summarise and present the potential hazards, pathways and receptors, taking into account available information on the landfill itself and the surrounding environment and is discussed in greater detail in the rest of this section. The Conceptual Model is used as an aid to designing the site investigation, and is subject to continual refinement.

Table 3.7: Initial Conceptual Pollution Model for Qortin Landfill

Hazard (see Table 3.3)	**Pathway**	**Current Receptors**
Leachable contaminants in the waste	Downwards infiltration of rainwater/leachate through waste into underlying bedrock	Groundwater in perched aquifer and nearby agricultural abstractions
	Rainwater run-off containing dissolved contaminants and suspended solids	Surrounding agricultural land
		Marine environment (seawater and sediment)
Airborne emissions from fires, waste degradation and physical disturbance	Aerial dispersion of gases, dust and particulates	Inhabitants and visitors at Marsalforn Ramla Bay Xagħra Victoria Żebbuġ Local ecology
Toxic waste materials within the waste mass	Ingestion/inhalation/dermal contact?	Site Workers

3.2.3 Air Quality

As indicated above, the principal mechanisms by which the landfill could potentially impact on air quality are:

- dispersion of gases produced by degradation and combustion of wastes; and
- dispersion of contaminated and uncontaminated particulate matter (dust).

Landfill gas production at Qortin is likely to be primarily aerobic producing carbon dioxide as a by-product, the presence of greater quantities of municipal solid waste and agricultural wastes in Qortin than at Magħtab may lead to greater anaerobic degradation of organic wastes within the landfill producing methane and possibly hydrogen sulphide (if sulphate containing wastes such as plaster are present). Sulphur dioxide might also be generated by oxidation of biologically produced hydrogen sulphide.

A survey of landfill gas emissions at Qortin was prepared by Secor for the Ministry of Gozo in 1997. The survey confirmed the presence of the landfill gases methane (0-12.4%, typically 7%) and Carbon Dioxide (0-20%, typically 7%) but showed that the rate of production was not very high. The report noted that gas (i.e. methane) production did not appear to be affected by the presence of underground fires.

Combustion of organic waste materials within the landfill is likely to produce smoke, odours, carbon dioxide, carbon monoxide and, if chlorine containing materials such as PVC are present, dioxins and furans. Carbon monoxide concentrations were not monitored during the Secor study.

Aerial emissions from fires appear to have reduced in recent years as a result of rapid burial of organic wastes by inert construction and demolition wastes. However, visual evidence of burning implies that fires still occur but are likely to be present at depth.

There are no mechanisms in place to limit dust generation caused by vehicle movements at Qortin and although the majority of dust particles emitted might be expected to be uncontaminated, a proportion of the dust emissions may include some contaminants. In particular, heavy metals, asbestos or adsorbed dioxins may be present.

The predominant wind directions in Gozo are anticipated to be similar to those in Malta modified by on-shore breezes (particularly during the summer months) and local convection caused by the presence of highly reflective construction and demolition wastes. The presence of thermals associated with fires may be likely to enhance any local convection effect. The net effect of these winds is that dispersion of gases and particulates may occur in any direction but that dispersion in a south-eastward direction is the most likely to occur.

The principal receptors at risk from aerial emissions from Qortin are:

- local agricultural land to the south and east;
- the beach at Ramla Bay to the east;
- the urban area of Xagħra to the south; and
- the tourist resort of Marsalforn to the west.

3.2.4 Groundwater Quality

The impacts on groundwater quality by landfills are typically associated with leachate generation within wastes in response to rainfall infiltration and delayed migration through the base of the landfill to groundwater receptors. It is considered unlikely that there are any significant bodies of leachate within the waste mass at Qortin due to a combination of the following:

- the raised elevation of the site;
- the lack of any lining systems;
- the highly permeable nature of the waste themselves;
- the fractured and karstic nature of the underlying bedrock (with a significant thickness of unsaturated zone);

- the low effective rainfall; and
- the predominantly non-organic nature (and hence low water retention capacity) of the majority of the wastes.

It is therefore anticipated that the principal means by which contaminated materials within the landfill may affect groundwater quality would be via direct leaching and transport to the water table. There was no monitoring data for perched groundwater quality within the Upper Coralline Limestone near Qortin landfill available at the time of the initial site inspection.

Groundwater abstractions provide all of the island's potable water supply as well as water used for irrigation purposes. The public water supply in Gozo is from the mean-sea level aquifer, in the Globigerina Limestone Formation and underlying strata. In many parts of Gozo the mean sea level aquifer is overlain by the thick (up to 75 m) aquitard of the Blue Clay Formation, overlying which are the limestones of the Upper Coralline Limestone Formation (Plate 3.8). The Blue Clay acts to protect the underlying mean sea level aquifer from contamination whilst allowing perched groundwater to be contained within the upper limestones (Table 3.8).

Table 3.8: Geology of Qortin Area

Stratum	**Thickness**	**Water Level**
Made Ground:		
Landfilled Waste	0-17 m	Possible discontinuous leachate toward base in centre of landfill
Upper Coralline Limestone Fm:		
Tal-Pitkal Member (grey/brownish grey limestones)	1-30 m	Perched water table of unknown thickness at base of Upper Coralline Limestone Formation.
Mtarfa Member (Carbonate mudstones)	2-26 m	
Għajn Melel Member (Glauconititc formaniferal limestones)	up to 16 m	
Greensand Formation	May not be present at Qortin.	
Globigerina Limestone Fm:		
Upper Globigerina Limestone	0-15 m	Water table at or around sea level in Globigerina Limestone Formation

Groundwater within the perched aquifer is close to the ground surface and could easily become contaminated. It is usually used for irrigation purposes rather than drinking water. Historically it was usual practice to intercept springs at the junction of the limestone and Blue Clay. However, continued abstraction has dried up many of the springs and perched water is now usually abstracted from wells.

Whilst the general direction of groundwater flow in the lower mean sea level aquifer will be toward the coast, groundwater in the perched aquifer will flow in the direction of discharge. At Qortin, this is likely to be either through spring discharges at the base of the limestone scarp (which may only be seasonally present at best) or from a number of small unlicensed abstractions used for agricultural irrigation and pumped by windmills located several hundred metres to the south of the site. Information on their locations is held by the Malta Water Services Corporation. These are potentially at risk from contamination from the landfill.

3.2.5 The Marine Environment

Given the proximity of Qortin landfill to the coast at Marsalforn and Ramla Bay there is a potential for contaminants to impact on the marine environment. Published monitoring of the marine environment by the Department of Public Health relates to microbiological analysis of bathing waters only. Potential mechanisms by which contamination of near-shore sediments and biota by the landfill could occur are:

- contaminated surface run-off from the landfill entering the sea during heavy rainfall events; or
- discharge of contaminated groundwater through springs to the sea bed.

Both of these are possible but the former is considered likely to be more significant given that groundwater discharge to the marine environment must occur via springs (which may well be dry for most of the year) and then surface run-off over the Blue Clay to the sea. The proximity of the base of the waste to the cliffs means that both waste and surface run-off may spill over the cliffs. Aerial photography (reproduced as Plate 3.9) produced by Project GAIA, a Maltese coastal conservation organisation, shows what appear to be liquid wastes pouring over the cliffs from the landfill onto Għajn Barrani (see http://www.projectgaia.org/herakles.htm for details). Evidence of impact from run-off can only be found by sampling the Blue Clay slopes below the landfill and marine sediments at the foreshore.

3.3 Wied Fulija

3.3.1 Background

Unlike the other two sites in this study, the landfill at Wied Fulija is no longer active. It commenced operations in 1979 and ceased to accept waste from 1996. The only activity that now takes place there is the temporary storage of material for recycling (such as glass) and the storage of compost from the Sant Antnin Composting Plant.

The landfill site is situated on the south coast of the island of Malta in the hamlet of Wied Fulija approximately 1½ kilometres south of the town of Żurrieq. The site comprises two separate bodies of waste on the eastern and western sides of the Wied il-Ħallelin (Figure 3.3, Plate 3.10). The seaward side of the site lies within 10-25 m of a cliff edge, where there is a sheer drop of around 100 m to the sea (Figure 3.3 and Plate 3.11). The top of the waste is up to 25 m above the surrounding natural ground level on the seaward side but is thinner (around 10 m) on the landward side. The total footprint is in the region of 6.5 hectares. Both the eastern and the western halves are steep sided, benched and flat-topped. The top area of the western side is approximately 0.9 hectares, and the eastern side about 1.5 hectares.

The landfill was mainly founded on rock although some of the waste has been placed on the agricultural fields that surround the site as the landfill has grown. The valley beneath the two land-raises generally follows the route of Wied il-Ħallelin but contains a limited thickness of waste (Plate 3.12). The original outfall from Wied il-Ħallelin is now a route for some waste spilling down the cliffs into the sea below. The maximum depth of waste is around 30 metres; the deeper zones overlying the infilled former valley.

There are no formal records of either the type or quantity of waste deposited at Wied Fulija as no weighbridge was installed. However, it is understood that generally the proportion of organic waste was higher than debris waste, perhaps in the ratio 80% to 20%. In common with other Maltese landfills the percentage of construction and demolition waste increased in more recent years to around 70% with the remainder comprising predominantly municipal solid waste and trade waste. All waste types produced on Malta, including hazardous wastes, are likely to have been disposed of at this site. The exposed faces appear to contain a significant proportion of partially consolidated municipal solid waste. Thus there is potential for some continued settlement over the next few years and this will be taken into account in the development of the rehabilitation strategies.

Wied Fulija landfill has been abandoned (although fenced) since closure and there are no leachate and gas management systems in place.

There are a number of fires on the landfill caused by the (possibly deliberate) burning of organic matter (principally within domestic wastes). In recent years there have been occasions when subterranean fires have ignited the stored compost leading to surface fires. Visual evidence of burning consists of venting of highly odorous fumes and smoke from discrete areas with associated surface discolouration of the surface cover and occasional exudation of condensate (Plates 3.13 and 3.14). Current evidence of burning appears to be concentrated on the upper parts of the seaward sides of each half of the landfill with evidence for former fires located along the western side of the valley between the two waste masses (Plate 3.15). It is likely that the vents represent the results of deep-seated fires from long-term combustion of organic wastes at depth.

3.3.2 Potential Hazards

The presence of significant quantities of domestic and industrial wastes deposited in an uncontrolled manner at Wied Fulija means that the site has the potential to cause a detrimental environmental impact on the surrounding area. Hazardous waste types at Wied Fulija are likely to be largely similar to Magħtab.

The conceptual site model for Wied Fulija is summarised in Table 3.9 using a hazard-pathway-receptor framework. The intitial Conceptual Model is intended to summarise and present the potential hazards, pathways and receptors, taking into account available information on the landfill itself and the surrounding environment. It is discussed in greater detail in the remainder of this section. The Conceptual Model is used as an aid to designing the site investigation, and is subject to continual refinement as the work progresses.

Table 3.9: Initial Conceptual Pollution Model for Wied Fulija Landfill

Hazard (see Table 3.3)	Pathway	Current Receptors
Leachable contaminants in the waste	Downwards infiltration of rainwater/leachate through waste into underlying bedrock	Groundwater in mean sea level aquifer (and nearby agricultural abstractions?)
		Marine environment (seawater and sediment)
	Rainwater run-off containing dissolved contaminants and suspended solids	Surrounding agricultural land
		Marine environment (seawater and sediment)
Airborne emissions from fires, waste degradation and physical disturbance	Aerial dispersion of gases, dust and particulates	Inhabitants and visitors at; Wied Fulja Żurrieq Local ecology.
Toxic waste materials within the waste mass	Ingestion/inhalation/dermal contact	Site Workers

3.3.3 Air Quality

Landfill gas and combustion issues are likely to be similar to those at Qortin. Aerial emissions from fires appear to have reduced in recent years (Charlie Zerafa, *Pers. Comm.*) as a result of burn-out of organic wastes since new sources of combustible material have not been added since 1996. However, visual evidence of burning implies that fires still occur but are likely to be present at depth. Dust generation caused by vehicle movements is not currently a significant problem at Wied Fulija. However, dust generation could become an issue during rehabilitation works. As with other sites a proportion of the dust emissions may include some contaminants, in particular heavy metals, asbestos or adsorbed dioxins may be present.

Dispersion of gases and particulates in a south-eastward direction is the most likely to occur. The principal receptors at risk from aerial emissions from Wied Fulija are:

- local agricultural land to the east;
- the village area of Wied Fulija to the north; and
- the town of Żurrieq to the north.

3.3.4 Groundwater Quality

Again the geology of the site means that it is considered unlikely that there are any significant bodies of leachate within the waste mass. The site is located on the Lower Coralline Limestone Formation (Table 3.10). There are three existing water-monitoring boreholes at Wied Fulija drilled in April 1995. Their depths and monitored water levels in 1995 are summarised in Table 3.11. Of particular note is the significant thickness of limestone strata between the site and water level at mean sea level. The locations of nearest public water abstractions and unlicensed groundwater abstractions are to be provided by the Water Services Corporation.

The general direction of groundwater flow in the mean sea level aquifer will be toward the coast. A single round of groundwater quality sampling and analysis from one of the existing boreholes (BH3) was undertaken in 1995 by PURA GmbH of Munich, Germany on behalf of the Works Division, Department of the Environment. The results are summarised in Table 3.12. Although the holes were not purged before sampling (which reduces the confidence that the results accurately reflect groundwater conditions) the samples contained elevated sodium, chloride and sulphate (attributable to saline groundwater) and elevated lead, iron and manganese (which may be related to the presence of the landfill).

Table 3.10: Geology of Wied Fulija Area

Stratum	Thickness	Water Level
Made Ground:		
Landfilled Waste	0-25 m	Possible discontinuous leachate toward base in centre of landfill
Lower Coralline Limestone Fm:		
Il-Mara Member (carbonate mudstones and limestones)	0-20m	Water table at or around sea level in Lower Coralline Limestone Formation
Xlendi Member (coarse grained limestones)	Up to 22m	
Attard Member (grey limestones)	10-15 m	
Magħlaq Member (carbonate mudstones)	up to 38 m	

Table 3.11: Depths and Water Levels at the Wied Fulija Boreholes

	Approximate Ground Level (mASL)	Depth of Borehole (m)	Depth to Water Level (m)	Approximate Water Level (mASL)
1	108	154.7	108.3	0
2	95	123.0	95.7	0
3	102	124.2	101.9	0

Table 3.12: Summary of Groundwater Quality Monitoring at Wied Fulija 1995 (BH WF3)

Determinand	*Concentration*	*EU Directive 98/93/EC*
pH	7.27	
TOC	<0.10	
Al (µg/l)	33.6	200
Sb (µg/l)	0.10	<5.0
As (µg/l)	0.67	<10.0
Ba (µg/l)	65.6	
Pb (µg/l)	118.0	<10
Cd (µg/l)	1.9	<5.0
Cr (µg/l)	23.2	<50
Fe (µg/l)	214	<200
Cu (µg/l)	33.0	<2000
Li (µg/l)	1.0	
Mn (µg/l)	50.0	<50
Ni (µg/l)	13.0	<20
Hg (µg/l)	<0.30	<1.0
Se (µg/l)	0.20	<10.0
Ag (µg/l)	0.07	
Zn (µg/l)	72.0	
Na (mg/l)	1410	200
K (mg/l)	54.9	
Ca (mg/l)	140.3	
Mg (mg/l)	145.9	
Sr (mg/l)	2.88	
Mn (mg/l)	0.05	
F (mg/l)	0.63	
Cl (mg/l)	2431.8	<250

Determinand	*Concentration*	*EU Directive 98/93/EC*
Br (mg/l)	5.1	
NO_3 (mg/l)	61.2	
SO_4 (mg/l)	352.1	<250
HCO_3 (mg/l)	230.3	
HPO_3 (mg/l)	<0.5	
Speciated PAHs (ng/l):		
Individually	<2.0	
Total	<30.0	<100

3.3.5 The Marine Environment

Given the proximity of Wied Fulija landfill to the coast at Il-Borg Ta' Wied Fulija there is a potential for contaminants to impact on the marine environment. Published monitoring of the marine environment by the Department of Public Health relates to microbiological analysis of bathing waters only. Potential mechanisms by which contamination of near-shore sediments and biota by the landfill could occur are:

- contaminated surface run-off from the landfill entering the sea during heavy rainfall events; or
- direct discharge of contaminated groundwater to the sea.

Both of these are possible. The former is considered likely to be more significant during heavy rainfall as there are no mechanisms in place to direct or divert the drainage channel that seasonally runs through the site along the line of the Wied Il-Hallelin. During periods of intense rainfall in the winter, this ephemeral stream will carry significant volumes of water and presumably carry suspended waste materials to the sea.

4. STAKEHOLDER ISSUES

4.1 Magħtab

4.1.1 Environmental Concerns

As the largest site under consideration, Magħtab is the most visible from many locations around the central and northern part of the island. This visual intrusion is considered to be unacceptable in itself but also of concern are other environmental impacts, most notably:

- the presence of contaminated and potentially hazardous materials within the landfill;
- emissions of potentially toxic fumes from areas of combustion;
- aerial emissions of contaminated dusts;
- emissions to groundwater and the marine environment;
- rodent infestation; and
- offensive odours.

With the exception of the last two, these issues are discussed more fully in the next section.

There are known to be a large number of rodents scavenging at the site and local communities are gravely concerned that when the landfill closes such vermin may relocate to other areas closer to local populations.

The odours emanating from the site are considered to be offensive and the associated gases reportedly have exacerbated difficulties for asthma sufferers in the vicinity and lead to headaches for many local people. However, it is acknowledged that the smell from the landfill has lessened in recent years and that there are other potentially malodorous sources in the vicinity; notably decaying seaweed on the local shore, blocked drains and stagnant water in the nearby ‘canal’ in addition to the possible emissions from the saltpans in Salina Bay.

4.1.2 After-use Aspirations

Although this is a large site and there are numerous potential after-uses there is a general perception amongst the local community that the site should be returned to community benefit; i.e. a form of compensation for the prolonged nuisance the local population has endured due to the presence of the landfill in the area. Suggestions have been made that a survey of all local communities should be held to identify all potential aspirations for the after-use.

The initial results of consultations indicate that returning the land to passive recreational use such as forestation, walks, lookout points, picnic areas etc provided it is 'safe' to do so would be most acceptable to the largest number of people. Other points of view (including development of the site for off-road vehicles for example or hard development) have been expressed but do not command widespread support.

Whatever the after-use selected there is a generally held view that there should not be wholesale removal of waste material from the site for transportation and disposal elsewhere.

4.2 Qortin

4.2.1 Environmental Concerns

Although small, Qortin is highly visible from many locations around the central and northern part of the island of Gozo, particularly the town of Xagħra and Ramla Bay. This visual intrusion is considered to be unacceptable in itself but also of concern to stakeholders are other environmental impacts, most notably:

- the presence of contaminated and potentially hazardous materials within the landfill;
- emissions of potentially toxic fumes from areas of combustion;
- aerial emissions of contaminated dusts;
- emissions to groundwater and the marine environment; and
- rodent infestation.

With the exception of the last, these issues are discussed more fully in the next section.

There are known to be a large number of rodents scavenging at the site and local communities are gravely concerned that when the landfill closes such vermin may relocate to other areas closer to local population.

4.2.2 After-use Aspirations

There is a desire for the site to be restored for local community leisure use; including forestation, landscaping, playing fields and possibly an open-air theatre.

4.3 Wied Fulija

4.3.1 Environmental Concerns

In contrast to the other landfills in this study, Wied Fulija is only visible in the immediate vicinity and other environmental impacts are more significant, notably:

- the presence of contaminated and potentially hazardous materials within the landfill;
- emissions of potentially toxic fumes from areas of continued combustion;
- aerial emissions of contaminated dusts; and
- emissions to groundwater and the marine environment.

4.3.2 Restoration

Locally the site is viewed as an opportunity to develop an area for formal recreational use; a sports theme park has been suggested including facilities for soccer, athletics, shooting, tennis, and possibly motor sport (the latter as set out in the North-west Local Plan). It is envisaged that this is allied to more informal leisure activities such as parkland with benches, kiosks/café etc.

5. INVESTIGATION WORKS

5.1 Introduction

5.1.1 Objectives

Site investigation works were undertaken from July to September 2002 in order to collect data to allow revised conceptual models of each of the sites to be prepared and risk assessments to be undertaken. In summary, the investigation comprised the following elements:

- thermal surveys to determine the extent and degree of landfill heating and combustion;
- drilling of boreholes in waste and installation of gas/leachate monitoring wells to allow monitoring of landfill/combustion gas concentrations and leachate quality (if present);
- drilling of boreholes in bedrock around Magħtab and Qortin and installation of monitoring boreholes to allow monitoring of groundwater quality;
- monitoring of concentrations of landfill and combustion gases in surface gas/smoke emissions;
- sampling and laboratory analysis of surface samples of waste and cover materials from the landfills; and
- sampling and laboratory analysis of off-site soil samples, marine water, marine sediment, gaseous emissions and particulates in air to allow assessment of potantial off-site impacts.

The investigation works are discussed in general below and then detailed for each of the sites in Sections 5.2-5.4. Conceptual models for each of the sites based on an interpretation of the results of the site investigation works are set out in Section 6.

5.1.2 Thermal Survey

Aerial thermal imaging using a thermal camera coupled with a digital video camera was undertaken using a light aircraft to identify general areas of heating on each landfill. This was supplemented with ‘walkover’ imaging surveys using the thermal camera to obtain specific measurements of surface temperature (Plate 5.1). The aerial thermal and visual imaging of each landfill is reproduced as a digital video file (MPEG format) on the appended CD-ROM. The results from the thermal survey were verified by physical measurement of surface temperatures using a hand held temperature probe on a notional 50 m grid pattern across each site. In addition temperature measurements were recorded at 1m depth intervals in the boreholes drilled through the waste mass at each site (see below).

5.1.3 Drilling

Landfill Monitoring Wells

Holes were drilled within the waste mass at each site with the objectives of:

- identifying the thickness of wastes present and, if possible, their composition;
- monitoring concentrations and flow rates of hazardous and toxic gases;
- monitoring leachate levels and composition (if present); and
- measuring vertical variations in temperature within the waste mass.

The holes were drilled using a rotary drilling rig at a variety of diameters using fresh water flush and with temporary steel casing to keep the hole open during drilling (Plate 5.2). Galvanised steel monitoring wells with gravel pack and bentonite seal were installed in each hole. Full details of each of the monitoring wells are summarised in Sections 4-6.

Off-site Monitoring Boreholes

Off-site monitoring boreholes were drilled in natural bedrock strata adjacent to the waste masses at Magħtab and Qortin with the objective of monitoring groundwater level and composition. Existing monitoring wells at Wied Fulija were used for the same purpose.

The holes were drilled using a rotary drilling rig at a variety of diameters using fresh water flush. No temporary casing was required. PVC monitoring wells with gravel pack and bentonite seal were installed in each hole.

5.1.4 Monitoring

Landfill Gases

Landfill gases were monitored in monitoring wells within the wastes by direct connection to a gas tap mounted on the monitoring well. Gases emitted from the landfill surface were also monitored on a notional 50 m grid over the surface of each site using a hollow stainless steel probe (Plate 5.3).

The following landfill gases were monitored using a GA2000 portable landfill gas analyser:

- methane
- carbon monoxide
- carbon dioxide
- hydrogen sulphide

Measurements of gas flow rate, atmospheric and differential pressure were also taken in monitoring wells.

Concentrations of total volatile organic compound (VOC) concentrations were measured using a MiniRAE 2000 Portable VOC Monitor.

A GA94 analyser was used to monitor for sulphur dioxide and nitrogen oxides.

The results of this monitoring are presented in Appendix A.

Air

Monitoring of concentrations of total suspended particulates (TSP) was undertaken using Andersen high volume particulate samplers at two locations on Magħtab. The samplers were run continuously for two weeks in each location with filters changed daily to enable daily concentrations of TSP to be measured.

5.1.5 Sampling

Soil and Waste

Samples of surface soil (to 5 cm depth) were taken from around each of the three sites using a stainless steel trowel and stored in appropriate sample containers (Table 5.1 and Plate 5.4). Sampling equipment was cleaned with hexane between samples. Representative samples of waste and cover materials on the surfaces of each site were taken using the same method.

Marine Sediment

Marine sediments were sampled along the coast near Magħtab and Qortin. Samples were taken using brown borosilicate glass jars in accessible locations (maximum water depth 0.5m). No suitably accessible sediment was identified at Wied Fulija due to water depth.

Marine Water

Marine water samples were taken at each of the sites. At Magħtab and Qortin samples were taken from accessible coastal locations (maximum water depth 0.5m). At Wied Fulija a sample was taken from a boat due to the depth of water. Samples were stored and preserved using the bottles and preservatives listed in Table 5.1.

Groundwater

Groundwater samples were taken from:

- newly installed monitoring boreholes at Magħtab and Qortin;
- existing monitoring boreholes at Wied Fulija;
- nearby agricultural abstractions at Magħtab and Qortin;
- a spring near Qortin; and
- the public water supply pumping station near Magħtab (Wied il-Għasel).

Table 5.1: Sample Storage and Preservation

Determinand	*Sample Bottle*	*Preservative*
Soil		
All soil analysis except volatile organics	1 kg plastic snap-lid tubs	Non required
Volatile organic compounds by GC-MS	40 ml glass volatile vials	Non required
Marine Sediment		
All analyses	1 kg brown borosilicate glass jars	Non required
Water		
Organics	1 litre glass	Non required
Inorganics	1 litre plastic	Non required
Cyanides	250 ml plastic	NaOH
Sulphide	250 ml plastic	Zinc Acetate
Ammoniacal Nitrogen	250 ml plastic	H_2SO_4
Phenol (total)	250 ml plastic	H_2SO_4
Metals (field filtered)	250 ml plastic	HNO_3
Volatile organic compounds by GC-MS	40 ml glass volatile vial	Non required
BOD	1 l sterilised plastic	Non required
Other bacteriological parameters	250 ml sterilised glass for each deteminand	Non required

Samples from newly installed monitoring boreholes were taken using a Grundfoss MP1 submersible pump (Plate 5.5). Due to their large diameter and great depth existing boreholes at Wied Fulija could not be sampled using the Grundfoss pump. Instead a high capacity submersible pump (Caprari EFOR XGS 26, maximum flow rate 15,000 l/hr) was used. New and existing boreholes were purged for three well volumes before sampling.

The public water supply at Wied-il-Għasel was sampled from the dedicated sampling point within the pumping station. Samples from existing agricultural abstractions were sampled using existing pumping equipment (electrical powered) where present (Plate 5.6). In two locations on Gozo, it was necessary to lower a stainless steel bucket into the well to sample. Samples were taken directly from the discharge of Għajn Barrani spring to the sea at Qortin.

Samples taken were stored in dedicated sample bottles with preservatives as set out in Table 5.1. Samples for metals analysis were filtered on-site using a 45µm in-line filter before preservation. Field measurements were made of pH and electrical conductivity.

Landfill Gases

Landfill gases from monitoring wells within wastes and from selected locations of surface gas venting were sampled with Gresham tubes (Plate 5.7). Each Gresham tube was purged three-times with borehole gas before the sample was taken.

Leachate

No discrete leachate was identified in any of the monitoring wells at any site (see Sections 4-6). However, very hot and moist conditions were identified at Magħtab and the resulting condensate was found to collect within the basal sump of some of the monitoring wells installed. Later wells were modified to include an enlarged sump to allow capture of condensate for sampling purposes. Condensate was sampled using a stainless steel bailer.

Air

The high volume samplers at Magħtab allowed sampling of particulate matter captured on the filters for subsequent chemical analysis (Plate 5.8). The high volume samplers were also fitted with a polyurethane foam plug that allowed sampling of gaseous semi-volatile organic compounds, in particular polyaromatic hydrocarbons (PAHs) and dioxins. These were changed weekly during the monitoring.

5.1.6 Laboratory testing

With the exception of bacteriological analysis in water sampling all laboratory testing was carried out in the UK by Alcontrol Geochem in Chester, a UKAS accredited laboratory. Samples were air freighted to the UK in cool boxes containing frozen ice packs. Water samples were stored in a refrigerator in Malta prior to dispatch. Samples for bacteriological analysis were analysed by Malta National Laboratories in Valetta.

Soil Samples

Off-site soil samples were analysed for the following determinands:

- pH, arsenic, cadmium, chromium, lead, mercury, selenium, copper, nickel, zinc, boron, total PAHs, total phenols, free and complex cyanides, thiocyanate, sulphate, sulphide and sulphur.
- total organic carbon
- Dioxins (PCDD/Fs as both speciated and EC/NATO/CCMS/I-TEQ concentrations)

The results are presented in Appendix B.

Waste Samples

Waste samples were analysed for the following determinands:

- pH, arsenic, cadmium, chromium, lead, mercury, selenium, copper, nickel, zinc, boron, total PAHs, total phenols, free and complex cyanides, thiocyanate, sulphate, sulphide and sulphur.
- total organic carbon
- asbestos
- semi-volatile organic compounds by GC-MS
- volatile organic compounds by GC-MS
- dioxins (PCDD/Fs as both speciated and EC/NATO/CCMS/I-TEQ concentrations) in selected samples only
- organotin (tri-butyl and tri-phenyl tin) in selected samples only

The results are presented in Appendix B.

Marine Sediment Samples

Marine sediment samples were analysed for the following suite of determinands:

- pH, arsenic, cadmium, chromium, lead, mercury, selenium, copper, nickel, zinc, boron, total PAHs, total phenols, free and complex cyanides, thiocyanate, sulphate, sulphide and sulphur.
- semi-volatile organic compounds (SVOCs) by GC-MS in Magħtab samples only
- volatile organic compounds (VOCs) by GC-MS in Magħtab samples only
- dioxins (PCDD/Fs as both speciated and EC/NATO/CCMS/I-TEQ concentrations) in Magħtab samples only
- organotin (tri-butyl and tri-phenyl tin) in Magħtab samples only.

The results are presented in Appendix B.

Groundwater and Sea Water

Groundwater and seawater samples were analysed for the following determinands:

- pH
- Electrical conductivity

- Total Dissolved Solids
- Total Suspended Solids
- Chemical Oxygen Demand
- Bacteriological Testing (Biochemical Oxygen Demand, *Salmonella, E-Coli, Listeria monocytogenes, Candida albicans, and Bacillus stearothermophilus*)
- Phenols
- Total Kjeldahl Nitrogen
- Ammoniacal Nitrogen
- Metals (As, Cd, Cr, Hg, Pb, Se, Cu, Ni, Zn, B)*
- Major Ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- SO_4^{2-}, NO_3^-,HCO_3^-)
- Sulphide
- VOCs
- SVOCs (including PAHs)

* saline samples required specific low-level analysis to be undertaken for metals.

The results are presented in Appendix C.

Particulate Matter in Air

Particulate matter retained on the High Volume Sampler filters were analysed for:

- PAHs
- Toxic Metals (As, Cd, Co, Cr, Cu, Hg, Mn, Pb, Ni, Sb, Se, Sn, Th, V)

Gases in Ambient Air

Polyurethane foam plugs from the high volume samplers at Magħtab were analysed for:

- dioxins (PCDD/Fs as both speciated and EC/NATO/CCMS/I-TEQ concentrations) in Magħtab samples only
- PAHs

The results are presented in Appendix D.

Landfill Gases

Gresham tube samples of gas emissions on the landfill surfaces and from monitoring boreholes in waste were analysed for speciated volatile organic compounds by GC-MS. The results are presented in Appendix E.

5.1.7 Visual Inspections

An inspection of the waste mound focussing on identifying areas of combustion, evidence of subsurface combustion and areas of instability or potential instability was undertaken.

5.1.8 Ecological Surveys

Information on the ecology of the areas surrounding each of the landfills was gathered using a desk study supplemented by a walkover survey in January 2003. The results of the ecological surveys are summarised in Appendix F. The aim of the survey was to determine the broad vegetation communities, to highlight any communities or species of particular value, e.g. endemic or red data book species (Schembri, 1989) or Areas of Ecological Importance (Malta Structure Plan, 1992), and to obtain information on any impacts that the landfill may be having on the ecology of the surrounding area. Full details of the ecological surveys are discussed in Section 6 but as with most of the Maltese Islands, much of the habitat around the landfills has undergone intense anthropogenic influence, and as such there is little of the natural climax vegetation.

5.2 Magħtab

5.2.1 Thermal Survey

Thermal Imaging

The aerial thermal imaging survey was undertaken at dawn on 16 July 2002 with follow-up ground surveys at dawn on 17 and 18 July 2002.

Surface Temperature

Surface temperatures were measured at 139 locations over the landfill surface (top and benches) using a digital thermometer and surface probe inserted into the ground (Figure 5.1). Particular attention was paid to areas of current or former combustion where hot gases were being emitted from cracks or vents.

Borehole Temperature

Temperature logs were recorded in all five monitoring wells within the wastes (see below) using a combined dip-meter – digital thermometer. Readings of borehole air temperature were taken at 1m intervals from the top of each instrument to the base.

5.2.2 Boreholes

Six boreholes were drilled through the in-situ Lower Coralline Limestone strata (locally overlain by Lower Globigerina Limestone) around the periphery of the waste

(Figure 5.2 and Table 5.2). Each hole was completed with a perforated well pipe to enable monitoring of groundwater quality and levels.

Table 5.2: Summary of Peripheral Monitoring Boreholes at Magħtab

Hole	*Depth*	*Estimated Ground Elevation (mASL)*	*Comments*
MBH1	40	22	No drilling difficulties. Slotted PVC standpipe installed.
MBH2	71	50	No drilling difficulties. Slotted PVC standpipe installed.
MBH3	50	41	No drilling difficulties. Slotted PVC standpipe installed.
MBH4	15	3	No drilling difficulties. Slotted PVC standpipe installed.
MBH5	20	3	No drilling difficulties. Slotted PVC standpipe installed.
MBH6	57	41	No drilling difficulties. Slotted PVC standpipe installed.

A further five holes were drilled through the waste mound to varying depths (Figure 5.2 and Table 5.3). Perforated galvanised steel well casing was installed to the full depth of each hole to enable monitoring of leachate, landfill gases and temperature.

Table 5.3: Summary of Landfill Monitoring Wells at Magħtab

Hole	*Depth*	*Comments*
MW1	45	Driller recorded difficult ground conditions in waste at 12m, 16m, 18m, 24-26m, 36m (probable top of bedrock). Hole dry. Elevated H2S concentrations recorded on surface from 18 m to base (peak concentrations > 500 ppm). Casing required sealing with bentonite to reduce emissions.
MW2	18	Driller recorded difficult ground conditions in waste at 5m, 9m, 15m and 18m including difficult penetration of casing and hole collapse. Black slurry noted in 1% returns at 16m depth. Hole terminated at 18 m due to difficulty in making progress. Hole dry. Elevated H2S recorded recorded at shallow depths (>9m, peak concentration 67 ppm).
MW3	41	High torque with bit damage occurring. Driller records borehole as being very hot with evidence of burning.
MW4	57	No difficulties recorded during drilling. Well casing too hot to handle during installation
MW5	51	Driller records borehole burning with very hot conditions

5.2.3 Monitoring

Landfill Gases

Landfill Gas Monitoring Results from monitoring wells on the Magħtab site are summarised in Table 5.4.

Table 5.4: Summary of Landfill Gas Monitoring Results at Magħtab*

	Date	*LEL (%)*	*CH4 (%)*	*Peak CH4 (%)*	*CO2 (%)*	*O2 (%)*	*CO (ppm)*	*H2S (ppm)*	*VOCs (ppm)*	*Flow Rate (l/hr)*	*Atmospheric Pressure (mb)*
MW1	09/09/2002	10	0.5	0.5	1.1	16.3	35	2	nd	nd	nd
MW1	23/09/2002	nd	0	0	1.8	16.2	332	0	nd	nd	997
MW1	02/10/2002	0	0.0	0.1	1.1	17.3	95	0	0	0.3	1014
MW2	23/09/2002	nd	1.4	1.4	9.8	7.0	450	0	nd	nd	997
MW2	02/10/2002	36	1.8	1.8	10.2	7	436	0	0	1.8	1014
MW3	15/10/2002	100+	11.6	11.6	19.7	4.3	nd	nd	nd	0.9	1009
MW4	03/10/2002	5	0.3	0.3	7.2	12.2	1111	0	0	0.2	1014
MW5	20/09/2002	nd	1.2	1.2	15.6	3.9	1210	2	nd	nd	996
MW5	02/10/2002	19	0.9	1.0	13.9	4.7	1086	0	0	0	1015

*SOx and NOx not detected.

Surface Gas Monitoring

Concentrations of landfill gases were measured at 139 locations over the landfill surface (top and benches) using a surface probe (Figure 5.1). Particular attention was paid to areas of current or former combustion where hot gases were being emitted from cracks or vents. The results of the gas monitoring are summarised in Table 5.5.

Table 5.5: Surface Gas Monitoring at Magħtab

	Minimum	*Maximum*
Methane %	0	6.8
CO2 %	0	22.1
O2 %	1.7	24
CO ppm	7	>2999
H_2S ppm	0	28
VOCs ppm	0	5900

Air

Monitoring of particulate dust concentrations was made at two locations on Magħtab using high-volume samplers (MHVS1 and 2). The sampling locations are shown on Figure 5.5.

5.2.4 Field Sampling

Surface Soil

Surface soil samples were taken at 15 off-site locations (MSS 1-15) immediately adjacent to the waste mass (Figure 5.3). An additional 12 samples were taken from further away from Magħtab (Figure 5.4):

- 6 approximately 0.5 – 1 km from the site (MSS 16-21); and
- 6 approximately 2 km from the site (MSS 22-27).

These samples were taken with the objective of determining whether off-site contaminant migration (principally by aerial emissions) was impacting on soil quality in the area around Magħtab.

An additional reference sample (MSS 28) was taken from central Malta between Żebbuġ and Rabat (Figure 5.4). This location, some 7 km to the south or the landfill is cross gradient from the prevailing principal wind direction axis (NW-SE for the *Majjistral* and *Xlokk* winds). This sample together with the four off-site samples also located to the south or south-west of the landfill (MSS18, 19, 24 and 25), was chosen as potentially representative of background conditions in soil in central Malta.

Waste Samples

Representative samples of waste materials exposed on the surface of Magħtab landfill were sampled in 25 locations (Figure 5.3). The waste types sampled are summarised in Table 5.6. No obvious industrial or drummed wastes were visible on the landfill at the time of sampling. There were no returns from drilling within the waste mass that were suitable for sampling.

Marine Sediment

Marine sediment samples were taken in three locations (Figure 5.4):

- bay to south of Għallis rocks (MMS1);
- Qalet Marku Bay (MMS2); and
- Baħar iċ-Ċagħaq Bay (MMS3).

MMS1, MMS2 and MMS3 correspond to marine sediment sampling locations 3, 2 and 1 in Saliba (1999) respectively.

Table 5.6: Summary of Surface Waste Samples at Magħtab

Sample ID	*Description*
MSW01	Dark grey granular cover materials with waste (ash? and crushed limestone)
MSW02	Decomposing domestic waste
MSW03	Black/grey organic sludge with strong odour
MSW04	grey/dark brown sludge with strong odour
MSW05	Light grey surface cover material
MSW06	Dark brown vent condensate
MSW07	Surface cover (crushed limestone)
MSW08	Surface cover from bulldozer access track
MSW09	Pale blue dried slurry/filter cake
MSW10	Daily cover with domestic waste
MSW11	Daily cover with domestic waste
MSW12	Daily cover (crushed limestone)
MSW13	Grey silt (dried slurry)
MSW14	Recently burnt waste
MSW15	Surface staining of cover associated with burning
MSW16	Pale grey dried sludge
MSW17	Pale grey/pink sludge from lower slurry lagoon.
MSW18	Pink ochre silt
MSW19	Black sooty material in crushed drum
MSW20	Old ashy degraded waste and plastic
MSW21	Crushed limestone dust from main haul road
MSW22	Old degraded waste
MSW23	Stained and burnt cover materials
MSW24	Burnt waste
MSW25	Burnt domestic waste

Marine Water

A marine water sample, MMW1, was taken from Qalet Marku Bay (Figure 5.4).

Groundwater

Groundwater was sampled from the peripheral monitoring holes MBH1-6 (Figure 5.2) and from the following boreholes (Figure 5.4):

- Agricultural Abstraction (Water Services Corporation Registration No. 2026);
- Agricultural Abstraction (Water Services Corporation Registration No. 2027);
- Irrigation Abstraction (Water Services Corporation Registration No. 3308); and
- Wied il-Għasel Public Water Supply Pumping Station.

These locations were sampled with the co-operation and assistance of the owners, the Water Services Corporation (Tony Mallia) and Malta Resources Authority (Dr John Mangion).

Saliba (1999) sampled from locations 2026 and 2027 whilst location 3308 is close to the location of well 2041 sampled by Saliba. Other licensed abstractions sampled by Saliba were visited but access was not possible as the licence holders were not present.*Landfill Gases*

Samples of landfill gas were taken using Gresham Tubes from the monitoring wells MMW1-5. In addition, 7 samples were taken from locations of surface venting of gases (MGS 1-7, Figure 5.5).

Leachate

No discrete bodies of leachate were identified within the landfill. However, water was found to be condensing within the casing of the boreholes and collecting in the small basal sumps. The last two boreholes to be drilled (MW3 and MW4) were modified to include a 2 m long sump at the base of the well to allow collection of this condensate for analysis. A volume of condensate sufficiently large to allow sampling was only collected in the sump in MW3.

Air

Samples of particulate matter were collected on the filter of the high volume sampler locations MHVS 1 and MHVS2 (Figure 5.5) and samples of semi-volatile gaseous organic pollutants (dioxins and PAHs) were collected on a polyurethane foam plug in each HVS.

5.3 Qortin

5.3.1 Thermal Survey

Thermal Imaging

The aerial thermal imaging survey was undertaken at dawn on 16 July 2002. Following preliminary assessment of the results no follow-up ground survey was deemed necessary.

Surface Temperature

Surface temperatures were measured at 30 locations over the landfill surface (top and lower benches) using a digital thermometer and surface probe inserted into the ground (Figure 5.6). Particular attention was paid to areas of current or former combustion where hot gases were being emitted from cracks or vents.

Borehole Temperature

A downhole temperature log was recorded in monitoring well QW1 (see below) using a combined dip-meter – digital thermometer. Readings of temperature were taken at 1m intervals from the top of the instrument to the base.

5.3.2 Boreholes

One borehole (QBH1) was drilled through the in-situ Upper Coralline Limestone Formation strata and into the underlying Blue Clay Formation near the entrance to the site (Figure 5.7 and Table 5.7). The hole was completed with a perforated well pipe to enable monitoring of groundwater quality and levels.

Table 5.7: Summary of Peripheral Monitoring Boreholes at Qortin

Hole	*Depth*	*Estimated Ground Elevation (mASL)*	*Comments*
QBH1	23	96 m	No drilling difficulties. Driller reports top of Blue Clay at 12 mbgl. Slotted PVC standpipe installed.

A borehole (QW1) was drilled through the waste mound (Figure 5.7 and Table 5.8). Perforated steel well casing was installed to the full depth of the hole to enable monitoring of leachate, landfill gases and temperature.

Table 5.8: Summary of Landfill Monitoring Wells at Qortin

Hole	*Depth*	*Comments*
QW1	18	No significant difficulties. Hole dry. Base of hole within 1 m of base of waste.

5.3.3 Monitoring

Landfill Gases

Landfill Gas Monitoring Results from the monitoring well on the Qortin site is summarised in Table 5.9.

Table 5.9: Summary of Landfill Gas Monitoring Results at Qortin

	Date	*LEL (%)*	*CH4 (%)*	*Peak CH4 (%)*	*CO2 (%)*	*O2 (%)*	*CO (ppm)*	*H2S (ppm)*	*VOCs (ppm)*	*Flow Rate (l/hr)*	*Atmospheric Pressure (mb)*
QW1	25/09/2002	100+	20.4	20.4	24.5	0.5	51	0	nd	nd	994
QW1	02/10/2002	100+	15.2	15.3	23.0	0.6	32	0	0	0.7	1009

Surface Gas Monitoring

Concentrations of landfill gases were measured at 30 locations over the landfill surface (top and benches) using a surface probe (particular attention was paid to areas of current or former combustion where hot gases were being emitted from cracks or vents). The results of the gas monitoring are summarised in Table 5.10.

Table 5.10: Surface Gas Monitoring at Qortin*

	Minimum	*Maximum*
Methane %	0	18.5
CO2 %	0	18.8
O2 %	5.3	20.9
CO ppm	6	2172
H_2S ppm	0	0
VOCs ppm	0	448

*no SOx and NOx detected

5.3.4 Field Sampling

Surface Soil

Surface soil samples were taken at four off-site locations (QSS 1-4, Figure 5.8). Two were taken immediately adjacent to the north-west and south-east of the waste mass (QSS4 and QSS 1 respectively). A further two were taken on the Blue Clay slope to the north of the landfill: QSS2 taken from directly beneath the waste and QSS3 taken in a location unlikely to be affected by the waste.

Waste Samples

Representative samples of waste materials exposed on the surface of Qortin landfill were sampled in five locations (Figure 5.8). The waste types sampled are summarised in Table 5.11. No obvious industrial or drummed wastes were visible on the landfill at the time of sampling.

Table 5.11: Summary of Surface Waste Samples at Qortin

Sample ID	*Description*
QSW01	Dried grey silty run-off from north end of landfill
QSW02	Construction and demolition waste
QSW03	Burnt waste dust
QSW04	Burnt waste
QSW05	Mixed capping domestic waste on top

Marine Sediment

The marine sediment sample could not be taken from the proposed location, as no accessible sediment was present on the foreshore at Għajn Barrani. Instead, a sample of sediment was taken from a small, unnamed beach to the east of the landfill below the cliffs of Rdum tax-Xagħra between Għajn Barrani and Ramla bay.

Marine Water

A single marine water sample, MMW1 was taken to the west of Għajn Barrani immediately below the landfill (Figure 5.8).

Groundwater

Groundwater was sampled from the peripheral monitoring holes QBH1 (Figure 5.7) and from the following agricultural wells (Figure 5.9):

- well on land owned by Michael Zammit - sample directly from water surface using stainless steel bucket (QOW1) and from base of well using wind pump (QOW1D);

- well on land owned by Savior Bonello - directly from water surface using stainless steel bucket (QOW2).

A sample was also taken from a spring from the base of the Upper Coralline Limestone Formation where it reaches the foreshore at Għajn Barrani.

These off-site locations were sampled with the co-operation and assistance of the local farmers, Tony Attard the Mayor of Xagħra and Eucharist Mizzi of the Ministry for Gozo.

Landfill Gases

Samples of landfill gas were taken using Gresham Tubes from the monitoring well QMW1. In addition, two samples were taken from locations of surface venting of gases (QGS 1-2, Figure 5.8).

Leachate

No discrete bodies of leachate were identified within the landfill and none could therefore be sampled.

5.4 Wied Fulija

5.4.1 Thermal Survey

Thermal Imaging

The aerial thermal imaging survey was undertaken at dawn on 16 July 2002. A follow up ground survey was undertaken at dawn on 19 July 2002.

Surface Temperature

Surface temperatures were measured at 44 locations over the landfill surface (top and lower benches) using a digital thermometer and surface probe inserted into the ground (Figure 5.10). Particular attention was paid to areas of current or former combustion where hot gases were being emitted from cracks or vents.

Borehole Temperature

Downhole temperature logs were recorded in the two monitoring wells (WFW1 and 2, see below) using a combined dip-meter – digital thermometer. Readings of temperature were taken at 1m intervals from the top of the well to the base.

5.4.2 Boreholes

No boreholes were drilled through the in-situ Lower Coralline Limestone Formation at Wied Fulija, as three existing monitoring boreholes were available (Figure 5.11 and Table 5.12).

Table 5.12: Summary of Existing Wied Fulija Boreholes

	Approximate Ground Level (mASL)	*Depth of Borehole (m)*	*Depth to Water Level (m)*	*Approximate Water Level (mASL)*
WFBH1	108	154.7	108.3	0
WFBH2	95	123.0	95.7	0
WFBH3	102	124.2	101.9	0

A further two holes were drilled, one through each of the waste mounds (Figure 5.11 and Table 5.13). Perforated steel well casing was installed to the full depth of each hole to enable monitoring of leachate, landfill gases and temperature.

Table 5.13: Summary of Landfill Monitoring Wells.

Hole	*Depth*	*Comments*
WFW1	20.5	Located on western waste mound. No significant difficulties during drilling. Hole dry. Estimated base of waste at 20.5 mbgl.
WFW2	21.25	Located on eastern waste mound. No significant difficulties during drilling. Hole dry. Estimated base of waste at 7.5 mbgl.

5.4.3 Monitoring

Landfill Gases

Landfill Gas Monitoring Results from the monitoring wells on the site are summarised in Table 5.14.

Table 5.14: Summary of Landfill Gas Monitoring Results at Qortin

	Date	*LEL (%)*	*CH4 (%)*	*Peak CH4 (%)*	*CO2 (%)*	*O2 (%)*	*CO (ppm)*	*H2S (ppm)*	*VOCs (ppm)*	*Flow Rate (l/hr)*	*Atmospheric Pressure (mb)*
WFW1	25/09/2002	nd	1.2	1.2	12.7	6.0	nd	0	nd	nd	998
WFW1	03/10/2002	17	0.8	2.0	11.3	7.1	92	0	0	0	1010
WFW2	25/09/2002	100+	14.9	18.5	23.0	4.7	164	0	nd	nd	998
WFW2	03/10/2002	100+	12.6	13.0	14.7	9.2	31	0	0	-0.1	1011

Table 5.15: Surface Gas Monitoring at Wied Fulija*

	Minimum	*Maximum*
Methane %	0	1.1
CO2 %	0	11.1
O2 %	8.9	21.0
CO ppm	15	>2999
H_2S ppm	0	3
VOCs ppm	0	1040

*SOx and NOx not detected

Surface Gas Monitoring

Concentrations of landfill gases were measured at 30 locations over the landfill surface (top and benches) using a surface probe (particular attention was paid to areas of current or former combustion where hot gases were being emitted from cracks or vents). The results of the gas monitoring are summarised in Table 5.15.

5.4.4 Field Sampling

Surface Soil

Surface soil samples were taken at six off-site locations (WFSS 1-6, Figure 5.12), all located on areas of agricultural land.

Waste Samples

Representative samples of waste materials exposed on the surface of Wied Fulija landfill were sampled in nine locations (Figure 5.12). The waste types sampled are summarised in Table 5.16. No obvious industrial or drummed wastes were visible on the landfill at the time of sampling.

Table 5.16: Summary of Surface Waste Samples at Wied Fulija

Sample ID	*Description*
WFSW01	North east end and top of east mound
WFSW02	South end of east mound
WFSW03	Burnt material near top of ridge
WFSW04	Burnt waste
WFSW05	Silt with waste and limestone in base of valley between waste mounds
WFSW06	South end at top of west mound
WFSW07	On top, beneath layer of compost

Marine Sediment

The water depth at Wied Fulija is too deep to allow marine sediment samples to be obtained.

Marine Water

A single marine water sample, WFMW1 was taken from the sea below the cliffs at Wied Fulija. Access was achieved using a boat (Figure 5.12).

Groundwater

Groundwater was sampled from the existing peripheral monitoring holes WFBH1-3.

Landfill Gases

Samples of landfill gas were taken using Gresham Tubes from the two monitoring wells WFW1 and 2. In addition, three samples were taken from locations of surface venting of gases (WFGS 1-3, 5.4) (Figure 5.12).

Leachate

No discrete bodies of leachate were identified within the landfill.

6. CONCEPTUAL SITE MODELS

6.1 Magħtab

6.1.1 Waste mass

Advancement of the boreholes through the waste proved difficult as a result of the frequent obstructions encountered and the thickness of the wastes. The waste mass was fully penetrated in four of the five holes (all except MW2) and a maximum thickness of 57 m of waste was identified in MW4. This agrees with the thickness estimated from a review of the survey data. It is estimated that the total maximum thickness of the waste was up to 70 m thick in February 2003.

Evidence from the drilling suggests that the wastes are reasonably consistent throughout their depth comprising layers of domestic and industrial waste intermingled with inert excavation, construction and demolition wastes. No evidence of leachate or other bodies of fluid within the waste mass were encountered. However, gas emitted from monitoring boreholes was saturated with hot vapour indicating that wastes at depth are moist.

Apart from end tipping and being dozed into position, the waste has not undergone any significant compaction. This has resulted in a largely open textured waste mound with high porosity and significantly differing local densities; ranging from low values associated with the municipal solid waste up to reasonably high densities in areas where excavation waste has been deposited. This high internal permeability has allowed internal fires to migrate upwards and sideways when fresh combustible waste has been placed over hot areas or zones venting hot combustion gasses from depth. The construction and demolition waste, particularly excavated limestone, is capable of retaining heat for considerable periods and also for acting as conductor of heat away from the original source.

The entire waste mass is likely to be undergoing settlement as a result of self-weight consolidation (with burial i.e. the newer layers of waste compressing the underlying materials). Generally combustible and decomposable wastes have been placed as discrete zones within the waste body surrounded by largely inert material. There is evidence of significant differential surface settlement occurring as a result of waste decomposition and combustion. Numerous tension cracks exist, frequently in areas showing either surface staining or direct evidence of subterranean combustion. Surface depressions from settlement of waste are found associated with areas of combustion (Plate 6.1) and there is anecdotal evidence that some of these surface movements are sudden.

The outer surfaces of the waste mound comprise almost entirely of construction and demolition wastes, largely crushed inert material processed from on site sources (Plates 6.1 - 6.7). Typically local slope angles within these materials are 36^o but range up to around 42^o and locally steeper where there is significant quantities of large demolition wastes. Spalling of waste materials occurs around the entire site as the materials regrade to angles of repose and large items become dislodged from the waste mound.

The site has developed in a series of horizontal layers resulting in 'benching' of the outer slopes. These benches have assisted in maintaining stability of the waste mass essentially as reducing overall slope angles and have acted as catch-berms for spalling waste. Over recent months overfilling of some of the flanks of the waste mound has reduced the width of a number of these benches and reduced their efficiency in maintaining stability and preventing spalling waste tumbling down the entire slopes.

Despite the minor surface movements there is no visual or recorded evidence of significant mass slope movements. The waste mass is sited directly onto competent solid rock, which is horizontally bedded.

6.1.2 Surface Contamination

Samples of exposed waste contained elevated concentrations of the following determinands either when compared to background concentrations in Malta (Table 6.1):

- chromium;
- copper;
- nickel;
- zinc;
- lead;
- cadmium;
- mercury;
- PAHs;
- Total phenols;
- tri-butyl tin (organic sludge)
- 4-methyl phenol (organic sludges);
- phenol (burnt wastes);
- PAHs: naphthalene, phenanthrene, fluoranthene, pyrene, benzo(a)anthracene, chrysene (burnt waste and stained cover);
- 2-methyl-naphthalene (burnt waste); and
- dibenzofuran (burnt waste).

Areas where combustion gases vent to the ground surface are typically stained brown and a brown-black, viscous condensate is often found immediately surrounding the vent (Plates 6.1 and 6.2). This condensate typically contains a wide range of volatile and semi-volatile organic compounds resulting from combustion of wastes:

- trichlorofluoromethane;
- chloroform;

Table 6.1: Comparison of Magħtab Samples with Maltese Background Concentrations (all mg/kg except where noted)

	Maltese Background	*Soils on Adjacent Land*	*Cover on Landfill*	*Waste*
Arsenic	5	2	<1	<1
Chromium	34	37	16	58
Copper	21	9	19	73
Nickel	18	25	16	134
Lead	19	266	38	136
Sulphate	1787	1860	2400	4378
Zinc	83	55	78	212
Acid Soluble Sulphide	<10	<10	11	50
Complex Cyanide	<2.5	<2.5	<2.5	<2.5
Thiocyanate	3	3	5	5
Total PAH	3.8	2.0	48.9	13.5
Total Phenols	<0.01	0.02	26.40	1.09
Cadmium	0.5	0.6	0.5	0.7
Mercury	<0.3	<0.3	0.5	<0.3
Selenium	2.8	<0.5	<0.5	<0.5
Total Organic Matter	2.5	2.5	1.5	6.4
pH Value In Soil	7.8	7.8	7.7	8.1
Total Cyanide	<2.5	<2.5	2.5	2.5
Free Cyanide Soil	<2.5	<2.5	2.5	2.5
Total Dioxin ng/kg I-TEQ	<0.01	13.49	NA	297.8

- benzene, toluene, ethylbenzene and xylene;
- tetrachloroethene;
- alkyl benzenes;
- chlorobenzenes;
- dioxins;
- other unresolved organic compounds.

A number of samples of visually clean cover materials on the landfill (crushed limestone) were analysed. These samples, which are considered representative of the majority of the surface cover at Magħtab, contained similar concentrations of contaminants to those detected in off-site soil samples immediately adjacent to the landfill.

6.1.3 Heating / Combustion

The results of the thermographic imaging coupled with the results of the gas monitoring (most importantly notably the CO measurements) and the surface temperature monitoring indicate that areas of the landfill mass are either currently undergoing combustion or have combusted in the past and remain hot.

Thermographic Imaging

Thermographic images of the landfill indicate four main areas of interest:

- northern face (Plate 6.3);
- western side (Plate 6.4);
- landfill top (Plate 6.5); and
- eastern and southern sides (Plates 6.6 and 6.7).

The northern face is characterised by significant evidence of temperatures elevated above background wherever relatively recent waste (characterised by unvegetated cover) is present down to elevations at least 30 m below the top of the landfill (Plate 6.3b). However, there is no evidence of elevated temperatures in the older, vegetated waste at the base of the northern face (Plate 6.3b).

The western side of the landfill is characterised by development of elevated temperatures along the uppermost benches of this area. Wastes lower down show no evidence of heating from a distance (Plate 6.4b). Heating on the eastern and northern faces continue along the benches of the western ridge at Għallis (Plate 6.4c).

The upper surface of the landfill at the time of the survey (since covered with waste) contained isolated hotspots concentrated toward the northern end of the site around the area of then current waste deposition (Plate 6.5b). Heating of the top of the landfill was concentrated in curved zones reflecting the practice of burying municipal solid waste along a curved disposal front (Plate 6.5c) and then covering with inert waste.

The survey identified evidence of localised heating on the eastern (Plate 6.6) and southern (Plate 6.7) sides of the landfill. The thermographic survey suggested that the heat sources on these sides of the landfill were less intense than observed elsewhere.

The following areas showed no evidence of heating in the thermographic survey:

- terraces of old waste in the south of the site (Plate 6.7b);
- terraces of old waste at the base of the north face (Plate 6.3b);
- new arm of inert waste at the eastern extremity of the site (Plate 6.3c); and
- the lower parts of the western (Plate 6.4b) and eastern (Plate 6.6b) faces.

Surface Temperature Measurements

Surface measurements of elevated temperatures where gases and vapours are vent to surface correlated well with the heat distribution measured with the thermographic survey (Figure 6.1); i.e. concentrated on the western and northern faces and the upper surface of the landfill rather than the southern or eastern faces (although local elevations of temperature associated with venting were observed in these areas).

Typically, measured temperatures of venting gases were between 60 and 149 °C. Temperatures in this range are usually taken as being indicative of active combustion at depth within the landfill. In localised areas temperatures at the surface exceeded 150°C and a peak value of 331°C was recorded at a combustion vent on the northern part of the upper surface of the landfill.

Temperature Measurements in Boreholes

Temperature measurements with depth in the five boreholes on Magħtab are shown in Figure 6.2. Borehole temperatures in excess of 60°C were observed in all holes and hole temperatures were typically above 75°C. Temperatures in this range are abnormal in municipal solid waste landfills (maximum temperature typically <55°C) and are usually taken as indicating potential combustion nearby. The variations in the temperature distribution within the boreholes that mirror the observed variation during the aerial survey and during the surface temperature monitoring.

The highest temperatures were identified in the two boreholes behind the north face of the landfill. In MW5 temperatures remained elevated (>80°) to bedrock and generally increased with depth (locally exceeding 100°C). In MW4, located above the lobe of hot waste at low levels in the landfill (Plate 6.3b), temperatures were greater than 90°C throughout and locally (particularly toward the base) were in excess of 120°C and peak temperatures of over 180°C were recorded in this borehole.

Lower (but still high) temperatures were observed in those boreholes located in the southern half of the main waste mass. MW1 temperatures were generally around 80°C dropping to below 60°C some 28 m below the ground surface (around 8 m above original ground level. Temperatures in MW3 were elevated to the base of the waste varying from 70 to 90 °C with a number of distinct peaks in temperature. In MW2, which failed to penetrate the full depth of waste, temperatures varied little with depth but were above 80° throughout.

Gas Monitoring

The results of the surface gas monitoring are summarised as dot-density plots on Figures 6.3 – 6.6 for carbon monoxide, carbon dioxide, methane and hydrogen sulphide respectively.

The presence of elevated surface concentrations of carbon monoxide, a gas indicative of the presence of subterranean fires, correlated well with high surface temperature measurements and the areas where the thermographic survey indicated heating. The most highly elevated concentrations (taken to be indicative of very active combustion causing a low oxygen atmosphere) were observed in the uppermost levels of the landfill. Lower, but still very elevated concentrations were generally observed over the upper parts of the western side of the landfill and unvegetated areas of the north face of the landfill. Low concentrations of carbon monoxide were restricted to areas where there was little other evidence of current heating. Measured concentrations of carbon monoxide in boreholes (Table 5.4) were generally lower than observed by the surface monitoring (Table 5.5) but the measured values were of a similar order of magnitude to nearby surface measurements (implying that near surface conditions may extend to depth within the landfill).

Methane concentrations at the ground surface were generally very low, indicating that the anaerobic waste decomposition processes typical of landfills used for disposal of municipal solid wastes are not occurring. Slightly elevated methane concentrations were only identified in a small number of locations generally on the western side of the landfill. Presumably these were associated with pockets of putrescible waste at shallow depths. More elevated concentrations were observed in the single measurement from MW3 on the eastern side of the landfill.

Carbon dioxide concentrations were generally high in those areas where elevated temperature and carbon monoxide concentrations were also recorded both on the surface and in borehole measurements. These concentrations confirm that aerobic decomposition of waste (including, but not necessarily restricted to, combustion processes) is operating in the landfill. However, in contrast to carbon monoxide concentrations, the most elevated carbon dioxide measurements were restricted to the uppermost areas of the landfill. These are areas where the supply of oxygen to the waste (thus allowing complete combustion) would be greatest.

Elevated concentrations of hydrogen sulphide (over 20 ppm in places) were observed on the south-western corner of the main waste mound. Very elevated concentrations of hydrogen sulphide (peak >500 ppm) were also observed during the drilling of borehole MW1 in this area (although subsequent monitoring for H_2S in the monitoring well installed in MW1 measured low but detectable concentrations). Lower concentrations were also detected during drilling of MW2. The localised distribution of this gas implies that a source of sulphate or sulphur containing wastes is present within the landfill in this area.

Interpretation

The combination of the thermographic survey, surface temperature and gas monitoring has allowed the following conclusions to be drawn regarding the extent of combustion at Magħtab:

- there is extensive evidence of heating at Magħtab;
- whilst most of this evidence relates to the surface of the landfill, evidence from boreholes shows that significant heating extends through the full depth of waste within the landfill in widely separated locations in the main body of waste;
- the most highly elevated temperatures in boreholes were recorded at depth near the base of the north face (MW4) and behind the junction of the western ridge and western side of the landfill at Għallis (MW5);
- the nature of temperature measurements in these boreholes implied the presence of very localised and significant sources of heat at depth, an interpretation supported by the thermographic imaging of the western half of the north face of the landfill (Plate 6.3b);
- the distribution of heating and landfill and combustion gases suggests that actual combustion may be restricted to areas where oxygen supply is more plentiful i.e. to the outer edges and upper surfaces of the landfill in general and where combustible material is present. (This includes material at relatively low elevations on the north face of the landfill where aerial photographic records indicate relatively recent waste deposition.)
- it is likely that the burning waste is being supplied with oxygen from the prevailing wind (NW) through the open textured waste materials and funnelled by the geometry of the site in this direction leading to significantly enhanced combustion (e.g. MW5), it is also possible that air is entering the waste mound through the fractured underlying strata;
- elsewhere, heating of the waste mass may be maintained by an ongoing process of waste smouldering combined with heat retention in the inert limestone waste;
- lower temperatures recorded both on surface and in MW1-3 in the southern half of the main waste mass may reflect either a lack of combustible material in this area (which may have burnt out) or a lack of oxygen or both;
- there is currently insufficient evidence to understand in-detail how the temperature-depth profiles observed in MW4 and 5 relate to those measured in MWs1, 2 and 3, i.e. the extent to which layered heating of wastes at depth extends into the body of the landfill (installation of monitoring boreholes within the centre of the main waste mass being impractical due to operational constraints). However, it is likely that the vigorous, albeit localised, evidence of combustion observed in MW4 and MW5 gradually decreases within the body of the landfill as the deposited waste becomes progressively older to the south and oxygen concentrations decrease.

This interpretation is illustrated diagrammatically in Figures 6.7 (a-c) and 6.8.

6.1.4 Air Quality

The high volume sampler was run continuously between the following dates at a constant flow rate of 285 l air/min:

- Location MHVS1: from 16 October 2002 to 30 October 2002
- Location MHVS2: from 31 October 2002 to 16 November 2002.

The filters were changed daily and weighed to calculate daily average concentrations of total suspended particulates (TSP) in dust. For each location and for each week of operation the dust collected on all except two filters and the gaseous pollutants retained on the polyurethane foam plugs were combined to allow laboratory measurement of concentrations of PAHs and dioxins as weekly average concentrations in air. For each week of operation, two of the filters were analysed for metals to produce average concentrations of metals in air on those days.

The data are summarised in Table 6.2.

Results indicate that dioxins, metals (in particular copper, chromium, mercury, manganese, nickel and lead) and PAHs are emitted from landfill both as dust and vapours. Total suspended particulate concentrations on the landfill site exceed the 50 $\mu g/m^3$ limit for PM_{10} according to EU Directive 1999/30/EC.

Measurements of volatile organic compounds in Gresham tubes are summarised in Table 6.3 together with associated PID readings. Only a limited number of volatile organic compounds were identified in surface soil gas samples despite elevated concentrations of VOCs indicated by the PID readings (which may be affected either by gas temperature or moisture content). Individual VOCs were not detected in borehole samples.

For reference, the measured concentrations are compared to the UK maximum exposure limits (long term 8 hr TWA) or the occupational exposure limits (long term 8 hr TWA) in UK HSE document EH40/2002. Benzene in soil gas is present consistently in greater concentrations than this guidance value whilst other VOCs detected locally exceed the relevant MEL/OEL.

6.1.5 Other Impacts

Soil

Impacts on the soils in the area surrounding Magħtab have been assessed by comparing chemical analyses of soil with measured background concentrations in central Malta (Table 6.1). Soils in the immediate vicinity of Magħtab landfill show concentrations of the following potential contaminants in concentrations exceeding the measured background:

- lead
- total phenols
- dioxins

The fact that concentrations exceed the measured background value does not necessarily mean that the presence of these substances is a risk to human health. The concentrations of phenols detected are very low and unlikely to represent a risk to human health and concentrations of dioxins in soil are not generally elevated when compared to German standards of acceptability in agricultural soils.

Table 6.2: Summary of HVS Analyses at Magħtab

Sample	*MHVS1A*	*MHVS1B*	*MHVS2A*	*MHVS2B*
Mean TSP Conc. (µg/m^3)	880	539	355	73
Dioxins (fg I-TE/m^3)	1392	3046	305	168
PAHs (fg/m^3):				
Naphthalene	592	203	152	137
Acenaphthylene	<17	61	122	46
Acenaphthene	<17	<17	<17	<17
Fluorene	818	365	701	959
Phenanthrene	13924	9950	487	4112
Anthracene	1271	1401	183	137
Fluoranthene	11835	16650	1401	426
Pyrene	6962	13605	<17	<17
Benz(a)anthracene	2089	3046	670	168
Chrysene	8006	9950	701	168
Benzo(b/k)fluoranthene	2611	2640	396	<17
Benzo(a)pyrene	2263	2234	<17	<17
Indeno(123cd)pyrene	296	406	61	<17
Dibenzo(ah)anthracene	261	305	<17	<17
Benzo(ghi)perylene	453	589	152	<17
Metals (ng/m^3):				
Arsenic	<1	1	<1	<1
Cadmium	4	1	<1	<1
Cobalt	<1	<1	<1	<1
Chromium	15	27	11	7
Copper	19	26	26	13
Mercury	6	4	<1	<1
Manganese	19	51	4	10
Nickel	10	17	9	10
Lead	50	51	9	4
Antimony	<1	<1	<1	<1
Tin	4	1	<1	<1
Thallium	2	4	<1	<1
Vanadium	6	10	1	2

Table 6.3: Volatile Organic Compound Measurements at Magħtab (ppm)

	Total VOCs (PID)	*trans-1,2-Dichloro-ethene*	*Carbon Disulphide*	*1,1,1-Trichloro-ethane*	*Benzene*	*All other VOCs*
UK MEL /OEL (8 hr TWA)		5	10	100	3	
MW1	0	<10	<10	<10	<10	<10
MW2	0	<10	<10	<10	<10	<10
MW3						
MW4		<10	<10	<10	<10	<10
MW5						
MGS01	369					
MGS02	74					
MGS03	>9999					
MGS04	5772	<10	<10	<10	**25**	<10
MGS05	8571	<10	<10	<10	**40**	<10
MGS06	>9999	<10	<10	<10	**15**	<10
MGS07	8212	**45**	**45**	**870**	**15**	<10

MEL – maximum exposure limit
OEL – Occupational Exposure Limit
TWA – Time Weighted Average
PID – Photoionisation detector

Saliba (1999) demonstrated by laboratory simulation that landfilled materials from Magħtab had the potential to generate leachate contaminated with heavy metals. However, monitoring of the quality of intercepted surface run-off from Magħtab by Saliba did not identify the presence of metals in detectable concentrations. It is therefore considered unlikely that surface run-off from Magħtab during rainfall events is a source of the contamination of adjacent land. However, as demonstrated by the results of the HVS monitoring aerial deposition of dust or combustion products may be occurring.

Although it is considered unlikely that dioxins or phenols originate from sources other than the landfill, it should be emphasised that the presence of at least some of the lead in soils near the landfill may not be related to the presence of landfill. Other local potential sources of lead contamination in the environment near Magħtab are:

- lead shot from hunting; and
- aerial deposition of vehicular exhaust emissions from the coast road.

Marine Environment

The presence of Magħtab landfill close to the coastline has prompted concerns that contaminated rainfall run-off from the landfill is entering the marine environment with potentially damaging consequences. In particular, there is anecdotal evidence of surface run-off from the landfill during rainstorms travelling through the site entrance and passing northward down the minor road from Magħtab to the coast at Qalet Marku. This has been observed to cause a plume of sediment in Qalet Marku bay. There are also concerns that once in the marine environment this transported material can migrate along the coastline to accumulate at other locations such as Baħar iċ-Ċagħaq bay. There is also concern that surface run-off from the northern face of the landfill could potentially reach the sea at Għallis Rocks.

Saliba (1999) measured sediment quality along the coast near Magħtab rocks and identified greater than background concentrations of metallic contaminants in sediments at Baħar iċ-Ċagħaq and Għallis Rocks but not at Qalet Marku. Monitoring of heavy metals in sediments at Baħar iċ-Ċagħaq, Qalet Marku and Għallis Rocks during this study (samples MMS3, MMS2 and MMS1 respectively) is compared with the results of metals analyses at the same locations by Saliba in Table 6.4.

In addition the Pollution Coordination and Control Unit (PCCU) of MEPA routinely measure metal concentrations in sediments at a large number of locations around the Maltese coastline including Qalet Marku. This data too is summarised in Table 6.4 together with background values for some metallic contaminants for the Mediterranean in general (from Axiak and Sammut, 2002) and Malta in particular (Ramla l-Hamra, Saliba, 1999).

Measured concentrations of metals at Qalet Marku (sample MMS2) were lower than the monitoring of both Saliba and the PCCU (although of a similar order of magnitude). Monitoring by MEPA PCCU indicates that concentrations of metals in sediment at Qalet Marku are generally low by Maltese standards and comparable to Mediterranean background values (Table 5.5 in Axiak and Sammut, 2002). Measured metal concentrations at Baħar iċ-Ċagħaq (MMS3) and Għallis Rocks (MMS1) in this study were lower than observed by Saliba (1999) and similar to those observed at Qalet Marku and Maltese background.

Traces of the organic compounds PAHs and phenols were noted at all three sites monitored and unspecified aromatic organic contaminants were also identified in sediment at Baħar iċ-Ċagħaq. Whilst these could potentially derive from the landfill it might be anticipated that they would be expected to be associated with the presence other organic landfill contaminants such as dioxins, PCBs or organotin (TBT), none of which were detected. Plausible alternative sources for the presence of these species in marine sediments contaminants are:

- run-off from the coast road containing products of particulate vehicular exhaust emissions, leaking oil and diesel fuel and particulates from tyre wear to the sea; and
- marine oil pollution (see Table 5.4 in Axiak and Sammut, 2002).

This study has therefore found no conclusive evidence of any significant impact of landfill-derived contamination on sediment quality. This result is consistent with:

- the fact that Saliba (1999) did not detect significant metallic contamination in intercepted surface run-off from Magħtab; and

- visual observation indicates that the area of Magħtab that drains to the site entrance, and ultimately Qalet Marku bay, is the southern half of the site which is covered with crushed limestone cover materials which chemical analysis has indicated are clean (exposed waste materials and condensate around combustion vents are generally restricted to the top, northern and western faces of the landfill).

The lack of traces of contamination recorded in sediments at Għallis Rocks may indicate that surface run-off from the north-face of the landfill does not reach the sea in significant quantities, but instead infiltrates either into the waste or exposed bedrock between the landfill and the coast.

The marine water sample taken from Qalet Marku was very similar to that taken near Qortin on Gozo (which would be expected to be relatively clean and representative of Maltese background conditions). However, both the Qalet Marku and Gozo sample both contained slightly elevated concentrations of ammoniacal nitrogen. Whilst this substance can be produced by landfill leachate other potential sources, including sewage discharges to the marine environment or fish farms, may perhaps be more likely given that concentrations of ammoniacal nitrogen in groundwater (see below) are lower than detected in the marine environment.

Groundwater

The identification of potentially elevated concentrations of potential contaminants in groundwater was assessed by comparison with EU Council Directive 98/83/EC on the quality of water intended for human consumption. Groundwater quality was also compared with water quality from Wied il-Għasel Public Water Supply pumping station (Figure 5.4), which is assumed to represent background groundwater quality for northern Malta.

The following determinands were found to be elevated above the drinking water standards:

- iron (MBH2);
- chloride (all samples);
- sodium (all samples);
- manganese (MBH5);
- sulphate (all except MBH2, 2027 and Wied il-Għasel);
- ammoniacal nitrogen (MBH5);
- total coliforms (all except Wied il-Għasel);
- E.coli (MBH4 and 2027); and
- Bacillus stearothermophilus (MBH4 and 2027).

Table 6.4: Summary of Metal Concentrations in Marine Sediment near Magħtab

	Mediterranean Background[1]	*Baħar iċ-Ċagħaq*		*Qalet Marku*			*Għallis Rocks*		*Ramla L-Hamra*
		Saliba[2]	*Scott Wilson*	*Saliba*	*Scott Wilson*	*MEPA PCCU*[1]	*Saliba*	*Scott Wilson*	*Saliba*
Lead	20	77	9	12	9	18.4	37	4	4.62
Nickel		5	<1	5	1		5	<1	6.71
Copper	5	11	2	3	1	8.6	5	<1	2.7
Chromium		14	5	12	5		11	9	13.92
Manganese		23		20			16		42.68
Zinc	50		9		14	65		25	
Cadmium	0.25	0.018	<0.5	BDL	<0.5	0.4	BDL	<0.5	BDL
Arsenic		3	<1	1	<1		3	<1	8.53

BDL – below detection limit

[1] Axiak and Sammut (2002).

[2] Saliba (1999)

Iron and manganese are only slightly elevated and are not likely to be of significance being commonly elevated in Maltese groundwater (Water Services Corporation Annual Report 2001).

The presence of elevated concentrations of sulphate, chloride and sodium reflects the general salinity of Maltese groundwater particularly where affected by up-coning related to abstraction. The lowest salinity samples were identified in the public water supply (which is derived from a different part of the mean-sea level aquifer to the remaining samples), MBH 2 and 2027, both of which are located furthest from the sea and the influence of marine saline intrusion. Chloride concentrations at Wied il-Għasel agree with WSC monitoring data on groundwater quality at this abstraction for the last 5 years reported by Axiak and Sammut (2002)[1] whilst concentrations of all other boreholes except MBH 4 and 5 are within the range recorded for other pumping stations in Malta. Chloride concentrations at MBH 4 and 5 are similar to seawater sampled at Qalet Marku (MMW1). These boreholes are very close to the coast and may extend below the base of the freshwater lens - which will be very thin in this area.

Concentrations of metals in groundwater are not elevated either when compared to the values in the drinking water directive or concentrations as measured at Wied il-Għasel. However, there is evidence that some of the metals are present in groundwater as a result of the presence of the landfill. For most metallic species monitored concentrations in groundwater and salinity increase toward the coast. This implies that the distributions of the majority of metallic species in groundwater are controlled by the quality of seawater and the degree of mixing with the freshwater lens rather than the landfill.

In contrast, lead and cadmium concentrations, whilst not elevated when compared to the drinking water directive, are present in greater concentrations in groundwater than in seawater and may therefore be related to the presence of the landfill. Of particular note is that cadmium concentrations around the landfill are greatest in the direction of Agricultural Abstractions 2026 and 2027. These boreholes also contain trace quantities of organotin (TBT), a species associated with shipyard wastes that is unlikely to be derived from any other source than landfill.

Bacteriological contamination of groundwater was identified near the landfill but not at Wied il-Għasel. There are considered to be two possible sources:

a) the landfill; and
b) animal slurries at nearby animal husbandry units and spread on fields.

Whilst the former cannot be excluded, the presence of very significantly elevated total coliform counts in the two farm abstractions sampled (2026 and 2027) may indicate an agricultural origin for this contamination.

Traces of the following volatile organic compounds were identified in the following off-site monitoring boreholes but not the agricultural abstractions or Wied il-Għasel pumping station:

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[1] Axiak, V. and Sammut, A. 2002. The Coast and Freshwater Resources. In: *State of the Environment Report for Malta, 2002*. Ministry for Home Affairs and the Environment, August 2002.

- 2-methyl-naphthalene (MBH1);
- Naphthalene (MBH5);
- 1,1,1-Trichloroethane (MBH1 and MBH3).

Given the semi-rural location of the landfill, the presence of these determinands in groundwater implies that their source is likely to be within the landfill.

The distribution of traces of contamination in groundwater in a number of directions around the landfill cannot be explained using a simple model of groundwater flow from inland, under the landfill and to the sea. In particular, the presence of chemical species that may derive from the landfill in boreholes 2026 and 2027 implies groundwater flow perpendicular to the regional groundwater flow direction which is likely to be to the north-east in the vicinity of Magħtab (BRGM, 1991). This behaviour is not surprising in a karstic aquifer where groundwater flow will be driven by, but not necessarily parallel to, the regional groundwater flow direction. Instead, local groundwater flow directions will be controlled by the orientation of fractures and solution features.

In addition, the identification of potential contaminants, which may originate from the landfill, in some locations rather than others may reflect localised linkages between areas of waste disposal within the landfill (e.g. areas used for disposal of shipyard wastes) and particular boreholes by individual fractures or solution features in bedrock. In addition, the absence of detected organic contaminants away from the immediate vicinity of the landfill may reflect:

- increased dilution with distance from the landfill;
- naturally occurring biodegradation processes in the aquifer (of naphthalenes for example); or
- downward rather than horizontal migration of contaminants that are denser than water (e.g. trichloroethane).

6.1.6 Ecology

Vegetation

The surface of the landfill area itself comprises mainly unconsolidated construction waste, with the older portions of infill in the south-east corner of the site covered by vegetation and trees, mainly *Eucalyptus sp.* More recently utilised areas and the edges of the landfill where it meets the natural vegetation are colonised by ruderal species typical of disturbed areas e.g. Cape Sorrel (*Oxalis pes-caprae*) and Crown Daisy (*Chrysanthemum coronarium*), and early succession communities, dominated by Shrub Tobacco (*Nicotiana glauca*) and Rice Grass (*Piptatherum miliaceum*).

Most of the land surrounding the landfill is either active or derelict agricultural land, with scattered clumps of carob trees throughout. Data on the vegetation communities to the west of the landfill were limited, and therefore no comments can me made as to the value or importance of this area. To the north and east of the landfill, karstic (limestone) terrain occurs, comprising mainly rocky steppe communities. The community to the north shows characteristics of a mixed steppe/garrigue vegetation structure.

Derelict agricultural land contains plant communities at different stages of succession, depending on the length of time that it has been uncultivated. Communities indicative of secondary succession at Magħtab are often characterised by Spiny Asparagus (*Asparagus aphyllus*) and Caper (*Capparis orientalis*) mixed with opportunistic, ruderal species such as Cape Sorrel. More recently cultivated areas contain early pioneer species, such as Sticky Fleabane (*Dittrichia viscosa*) and Fennel (*Foeniculum vulgare*), while areas derelict for longer contain late pioneer stage species, including Great Sage (*Phlomis* fruticosa), which has a special mention in the Red Data Book (RDB) (Schembri and Sultana, 1989). Agricultural land is generally considered to be of lower ecological value than other less disturbed communities.

Of the more "natural" vegetation types, rocky steppe makes up a large proportion of the area to the east of the landfill, adjacent to the coast. Steppe communities, widespread in Malta, are diverse and are generally relatively species-rich. It is unclear whether this community is indicative of succession from agricultural communities or regression from maritime garrigue. The rocky steppe community around Magħtab is dominated by characteristic grass species including Hispid Beard Grass (*Hyparrhenia hirta*) and Mediterranean Steppe Grass (*Stipa capensis*). Several ecologically valuable species, noted in the RDB, occur in the rocky steppe around Magħtab, including Carline Thistle (*Carlina involucrata*), Olive-leaved Bindweed (*Convulvulus oleifolius*), Seaside Squill (*Urginea pancration*) and Mediterranean Thyme (*Thymbra capitata*). Some patches of habitat within the rocky steppe are colonised by species characteristic of maquis or garrigue, including Evergreen Honeysuckle (*Lonicera implexa*), Lentisk (*Pistacia lentiscus*) and Common Smilax (*Smilax aspersa*), which may be indicative of succession between the community types.

Small areas of woodland dominated by Carob (*Ceratonia siliqua*) are widespread throughout the area. Some thickets also include secondary dominant species including Prickly Pear (*Opuntia ficus-indica*). The structure of these woodlands and thickets creates a microclimate that supports the development of vegetation characteristic of pseudomaquis. In addition to these woodlands, a single woodland of mixed Tamarisk/Acacia (*Tamarix* spp./*Acacia* spp.) and a mixed Tamarisk/Shrubby Orache (*Atriplex halimus*) hedge occur adjacent to the coastal road to the north-east of the landfill.

To the north of the site is an area of steppe/garrigue, which has been isolated, by the landfill area, from the steppe community already described. The vegetation structure of this area suggests that it may be in transition between the two vegetation types. Dominant species in this area include Mediterranean Thyme, Olive-leaved Germander (*Teucrium fruticans*) and in some areas Sea Squill achieves local dominance. Vegetation characteristic of maquis includes Evergreen Honeysuckle, Lentisk and Rosemary (*Rosmarinus officinalis*), which is a RDB species with restricted distribution in the Maltese Islands. There is a large area dominated by stands of *Agave sp.* which contains a single Aleppo Pine. Another RDB species found in this area is Maltese Dwarf Spurge (*Euphorbia exigua* var. *pycnophylla*).

Within the steppe/garrigue community, there are a number of freshwater pools, which are important because of the rarity of aquatic habitats on the islands and therefore for the highly specialised communities they support. These ecologically significant areas include several RDB species, including Mediterranean Starfruit (*Damasonium bourgaei*) and Southern Water Starwort (*Callitriche truncata*).

In addition to the freshwater rock pools, there is a seasonally flooded marshland on the north eastern coast at Għadira s-Safra, which is characterised by a generally halophilic terrestrial flora and ephemeral fresh and brackish water species during the wet season. This area is of international importance for its rare and endangered liverwort *Riella helicophylla*, a species listed under Appendix 1 of the Berne Convention as a "species to be strictly protected". *Crypsis aculeata* (a grass species found only at this site) is also a key species here. This area has been described in detail in Lanfranco (1995).

Along the rocky coast, a maritime garrigue/steppe community is dominated by Golden Samphire (*Inula crithmoides*). Halophytic species colonising the area include Shrubby Glasswort (*Arthrocnemum macrostachyum*) and Sea Fennel (*Crithmum maritimum*). Several RDB species are present in the community, including Carline Thistle, Seaside Squill, Mediterranean Thyme, Eastern Phagnalon (*Phagnalon graecum*), Pignatti's Fern Grass (*Desmazeria pignattii*) and Rock Crosswort (*Crucianella rupestris*), all of which have restricted distribution in the Mediterranean. Seaside Lavender (*Limonium virgatum*) is in the RDB for its restricted distribution in the Maltese Islands and at Qalet Marku the endemic Maltese Sea Chamomile (*Anthemis urvilleana*) is also present in the community.

Fauna

The freshwater pools within the steppe/garrigue communities at the north of the area are very important for a number of species of crustaceans. The most abundant species in the water was the cladoceran species *Ceriodaphnia quadrangula* with *Pleuroxus letourneuxi* present in the sediments. Significant species found in the pools include the calanoid copepod *Diaptomus* sp., the first record of this genus from the Maltese Islands and the conchostracan *Cyzicus tetracerus*, another RDB species.

The seasonal coastal wetland at Għadira s-Safra is also important for its faunal community, supporting locally rare species of crustaceans, including *Triops cancriformis* and *Branchipus visnyai.*

Faunal records for this area are limited, but it should be assumed that there are established faunal communities associated with the garrigue and steppe communities, as well as the woodlots and thickets, which would be impacted by changes to the vegetation community.

The only other community of note is an extensive bed of Lesser Reed (*Phragmites australis*) and stand of Greater Reed (*Arundo donax*), which is expected to support species such as Reed, Sedge and Marsh Warblers (*Acrocephalus* spp.).

Ecological value

Several areas near the landfill site at Magħtab have been recognised as having ecological value in the Malta Structure Plan (1992). The two major designations that are used in the Plan are Area of Ecological Importance (AEI) and Site of Scientific Importance (SSI).

The transitional coastal wetland at Għadira s-Safra has been recognised as qualifying to be both an AEI and SSI for its rare species. The maritime steppe/garrigue qualifies for AEI status for its freshwater pools, and the presence of garrigue assemblages within the rocky steppe community around the landfill site qualify it as an AEI also.

The coastal fringe at Għallis qualifies to be an SSI for its suitability for the Siculo-Maltese endemic woodlouse *Miktoniscus melitensis*, which is rare and has restricted Maltese Island distribution.

Several individual tree species have special protection under Maltese legislation, including Lentisk and Aleppo Pine (*Pinus halepensis*), which are “strictly protected trees” and Carob, Olive (*Olea europea* s.l.) and Mulberry (*Morus* spp.), which are “protected trees”. With some restrictions, trees over 50 years old are also listed as “protected trees”.

6.2 Qortin

6.2.1 Waste mass

The waste mound encroaches to within only one or two metres of the approximately 18 – 20m high, near vertical scarp formed by the Upper Coralline Limestone Formation. This overlies the Blue Clay, which makes up the 80m high, undulating, sparsely vegetated (1v:3h) slope down to sea level (Plates 6.8 and 6.9). The near horizontally bedded limestone strata comprise three layers (the Tal-Pitkal, Mtarfa and Għajn Melel Members), all of which are fractured to varying degrees. Locally the upper bed overhangs the lower ones (Plate 6.10). The underlying clay is significantly softer and is known to be prone to the effects of weathering and mass movement (slope instability) particularly when wetted. There are a number of minor seepages at the toe of the cliff (at the juncture where permeable limestone overlies the less permeable clay deposits). This is visible in Plate 6.9 in the form of the extensive vegetation developed along the course of Għajn Barrani spring from where it emerges from the base of the Upper Coralline Limestone to the sea.

There is much evidence of earlier minor shallow failures / movements of the clay slope and there are many blocks of limestone (some of significant size) on the clay slope that appear to have become detached from the cliff face. In addition there are open fissures on the surface of the limestone particularly around the western end of the waste mound and locally there are wide fractures in the face of the cliff, particularly in areas where blocks appear to have become detached (Plate 6.10). The extent of cambering of the limestone plateau in response to the gradual lateral movement of the underlying Blue Clay is shown on Plate 6.11.

The waste mass was fully penetrated in the hole drilled indicating a maximum thickness of 18 m at this time. This accords with the postulated thickness determined by a review of the survey data.

Evidence from the drilling suggests that the wastes are reasonably consistent throughout their depth comprising layers of conventional domestic and agricultural waste intermingled with construction debris.

The waste has not been subjected to any significant compaction during placement and is likely to be undergoing settlement as a result of self-weight consolidation (i.e. the newer layers of waste compressing the underlying materials) and general organic waste decomposition. There is evidence of some differential surface settlement probably occurring as a result of waste decomposition and the effects of subsurface combustion. There is also evidence of some tension cracks in areas showing either surface staining or direct evidence of combustion.

The waste mound has slope angles of typically 25^o but range up to around 35^o locally. Spalling of waste materials occurs around the entire site as the materials ‘regrade’ to angles of repose and some material has fallen over the limestone cliff to the northeast and onto the underlying clay slope. There is some evidence of waste instability in the form of cracking of the surface behind the top of the steep slopes on the western side of the landfill.

6.2.2 Surface Contamination

Samples of exposed waste contained concentrations of the following determinands at concentrations greater than the Maltese background samples (Table 6.5):

- chromium;
- copper;
- nickel;
- zinc;
- lead;
- cadmium;
- mercury;
- 2-methyl-naphthalene (burnt waste);
- dibenzofuran (burnt waste)

The areas immediately surrounding vents where combustion gases vent to the ground surface were stained with condensate. This typically contains a wide range of volatile and semi-volatile organic compounds resulting from combustion of wastes:

- chloroform
- benzene, toluene, ethylbenzene and xylene
- tetrachloroethene
- alkyl benzenes
- chloroalkanes
- chlorobenzenes

- PAHs;
- Total phenols;
- alkyl phenols;
- dioxins;
- other unresolved organic compounds.

Table 6.5: Comparison of Qortin Samples with Maltese Background Concentrations (all mg/kg except where noted)

	Maltese Background	*Soils on Adjacent Land*	*Waste*
Arsenic	5	3	<1
Chromium	34	24	62
Copper	21	6	374
Nickel	18	21	21
Lead	19	275	114
Sulphate	1787	6100	6540
Zinc	83	59	275
Acid Soluble Sulphide	<10	<10	33
Complex Cyanide	<2.5	<2.5	<2.5
Thiocyanate	3	3	3.6
Total PAH	3.8	<1.6	10.0
Total Phenols	<0.01	<0.01	0.81
Cadmium	0.5	<0.5	3.8
Mercury	<0.3	<0.3	<0.3
Selenium	2.8	<0.5	<0.5
Total Organic Matter	2.5	2.7	2.4
pH Value In Soil	7.8	7.8	8.5
Total Cyanide	<2.5	<2.5	<2.5
Free Cyanide Soil	<2.5	<2.5	<2.5
Total Dioxin ng/kg I-TEQ	<0.01	0.7	61

6.2.3 Heating / Combustion

The results of the thermographic imaging coupled with the results of the gas monitoring (notably the CO measurements) and the surface temperature monitoring indicate that only minor areas of the landfill mass are undergoing heating with localised combustion. The results are summarised on Figures 6.9 and 6.10.

Thermographic Imaging

Thermographic images of the landfill indicate that combustion is restricted to the uppermost layers of the landfill and concentrated around the rim of the upper waste surface (Figure 6.10, Plate 6.8).

Temperature Measurements

Surface measurements of elevated temperatures where gases and vapours are vent to surface correlated well with the heat distribution measured with the thermographic survey (Figure 6.11). Locally temperatures of venting gases were around 60 °C, temperatures potentially indicative of aerobic waste decomposition or possible combustion.

Borehole temperatures within the waste were generally constant between 43 and 46 °C, decreasing slightly to around 40 °C at the base of the landfill. Temperatures in this range are normal for landfills containing decomposing municipal solid wastes and indicate that significant combustion within the waste mass is unlikely to be occurring.

Gas Monitoring

The results of the surface gas monitoring are summarised as dot-density plots on Figures 6.12 – 6.14 for carbon monoxide, carbon dioxide and methane (no hydrogen sulphide was detected).

Elevated concentrations of carbon monoxide correlated well with surface temperature measurements and the thermographic survey being concentrated around the upper outer margins of the landfill and, to a lesser extent, in the centre of the landfill surface. In contrast, methane concentrations were elevated (up to 18% on the surface and 20% in the monitoring well). These concentrations indicate that anaerobic decomposition of waste is occurring within the depths of the landfill. Carbon dioxide concentrations were also generally high in those areas where elevated temperature and carbon monoxide concentrations were also recorded. These concentrations confirm that aerobic decomposition of waste (including but not necessarily restricted to combustion processes) is operating in the outer edges of the landfill where the supply of oxygen to the waste is greatest.

Interpretation

The combination of the thermographic survey, surface temperature and gas monitoring has allowed the following conclusions to be drawn regarding the extent of combustion at Qortin:

- there is evidence of limited combustion at Qortin towards the top and edges of all sides of the landfill where oxygen supply is greatest;
- there is no evidence of abnormal heating through the full depth of waste within the landfill;
- normal landfill waste decomposition processes appear to be active within the main waste mass.

6.2.4 Air Quality

Measurements of volatile organic compounds in Gresham tubes are summarised in Table 6.6 together with associated PID readings. Only a limited number of volatile organic compounds were identified in surface soil gas samples despite elevated concentrations of VOCs indicated by the PID readings (which may be affected either by gas temperature or moisture content). Individual VOCs were not detected in borehole samples. The reason for this difference in behaviour between borehole gas from deep within the landfill and surface gas sampling is not clear at present.

For reference the measured concentrations are compared to the UK maximum exposure limits (long term 8 hr TWA) or the occupational exposure limits (long term 8 hr TWA) in UK HSE document EH40/2002. Benzene and trichloroethane in soil gas both locally exceed the relevant MEL/OEL.

Table 6.6: Volatile Organic Compound Measurements at Qortin (ppm)

	Total VOCs (PID)	*trans-1,2-Dichloro-ethene*	*Carbon Disulphide*	*1,1,1-Trichloro-ethane*	*Benzene*	*All other VOCs*
UK OEL/MEL (8 hr TWA)		5	10	100	3	
QW1	0	<10	<10	<10	<10	<10
QGS1	2349	<100	<10	**275**	**25**	<10
QGS2	621					

MEL – maximum exposure limit
OEL – Occupational Exposure Limit
TWA – Time Weighted Average
PID – Photoionisation detector

6.2.5 Other Impacts

Soil

Impacts on the soils in the area surrounding Qortin have been assessed by comparing chemical analyses of these materials with background samples of soil from Malta. Soils around Qortin show concentrations of lead exceeding background in two locations:

- from the Blue Clay slope immediately below the waste; and
- from the garigue plateau to the west of the waste.

No other determinands were present in elevated concentrations. However, it should be noted that dioxins were detected in a single sample but not at concentrations considered elevated in agricultural soils.

The fact that recorded concentrations of lead exceeded the background concentration does not mean this substance is a risk to human health. Although, the presence of elevated lead does not indicate it is derived from the landfill, the samples affected may reflect either the impact of waste materials on adjacent land or the presence in soil of lead shot from shooting on land adjacent to the landfill.

Groundwater

The identification of potentially elevated concentrations of groundwater contaminants was assessed by comparison with EU Council Directive 98/83/EC on the quality of water intended for human consumption.

The following determinands were found to be elevated above the drinking water standards:

- iron (QBH1 and all agricultural wells);
- chloride (QBH1, all agricultural wells and spring);
- sodium (all agricultural wells);
- sulphate (one agricultural well – QOW2);
- total coliforms and *E.coli* and (QBH1 and all agricultural wells tested).

Elevated concentrations of iron are likely to relate to the ferruginous nature of the basal unit of the Upper Coralline Limestone Formation (the glauconitic limestones of the Għajn Melel Member). Chloride, sodium and sulphate concentrations were only slightly elevated. Sodium and sulphate could be naturally occurring. However, slightly elevated chloride concentrations could suggest an impact from the landfill.

Concentrations of metals in groundwater were not elevated when compared to the values in the drinking water directive. Bacteriological contamination of groundwater was identified near the landfill in both QBH1 and the agricultural wells where bacteriological determinands were measured. There are considered to be two possible sources:

a) the landfill; and

b) animal slurries at nearby animal husbandry units and spread on fields.

Both may potentially contribute to the presence of bacteriological contamination identified.

Marine Environment

The marine water sample contained slightly elevated concentrations of ammoniacal nitrogen only. This substance can be produced by landfill leachate or in sewage deposited in the sea. The latter seems more likely given that any leachate migration would have to occur by flow over the Blue Clay slope from springs at the base of the Upper Coralline Limestone scarp. A more likely source could be the sewage outfall in San Blas bay to the east. Given the lack of plausible hydraulic connections between the marine environment and the landfill at Qortin it is considered that this marine sample is the most representative of the samples taken of background water quality in the Maltese islands.

6.2.6 Ecology

*Vegetatio*n

Much of the area around Qortin is agricultural land, with non-agricultural communities mainly restricted to the southernmost portion of the scarp community at il-Mielħa and part of area at il-Qortin ta' Għajn Damma. To the west of the dump, between the landfill site and derelict agricultural land, there is a substantial area of garrigue, moving into rdum base vegetation and narrow band of clay steppe. To the north and east of the landfill, clay steppe dominates the landscape with a small area of rocky steppe adjacent to the tip on the northeast side.

A steppe/garrigue community exists at il-Qortin ta' Għajn Damma, adjacent to the landfill on the west. This is considered to be a previous maritime garrigue, which has been degraded by its proximity to the landfill and by encroachment. Dominant plants included the Red Data Book (RDB) (Schembri and Sultana, 1989) species Seaside Squill (*Urginea pancration*) and Mediterranean Thyme (*Thymbra capitata*), as well as Pitch Clover (*Psoralea bituminosa*), Branched Asphodel (*Asphodelus aestivus*), Olive-leaved Germander (*Teucrium fruticans*), Spiny Asparagus (*Asparagus aphyllus*), Caper (*Capparis orientalis*), Tree Spurge (*Euphorbia dendroides*), Mediterranean Heath (*Erica multiflora*) and Carob. In areas of severe disturbance around the periphery of the landfill, ruderal species such as Crown Daisy (*Chrysanthymum* coronarium) and Cape Sorrel (*Oxalis pes-caprae*) have become dominant.

The agricultural land to the west of the garrigue around il-Mielħa has been derelict for a long time and shows some characteristics of a steppe community. It comprises mainly late pioneer vegetation including Fennel (*Foeniculum vulgare*) and Giant Fennel (*Ferula communis*), with Cape Sorrel being the most abundant species throughout the area. Solitary Tamarisk (*Tamarix africana*), an RDB species which is rare and has restricted distribution in the Maltese Islands is present in scattered pockets throughout the derelict agricultural land in the west, north and east of the study area.

The west-facing scree in this derelict agricultural area is colonised by the endemic Maltese Salt-tree (*Darniella melitensis*), Caper and Golden Samphire (*Inula crithmoides*) on steep rock faces, with the base of the scree comprising dense Carob and Great Reed (*Arundo donax*) vegetation, with agricultural species such as Almond (*Prunus dulcis*), Fig (*Ficus carica*) and Pomegranate (*Punica granatum*). Thickets of Carob (*Ceratonia siliqua*) with associated development of pseudomaquis are scattered in various locations around the agricultural area, particularly to the south of the landfill site.

Throughout the clay steppe, to the north and east of the landfill, there are stands of individual shrub species, including Solitary Tamarisk, Maltese Salt-tree, Shrubby Orache (*Atriplex halimus*) and Great Reed in wetter areas. Some slopes to the north of the landfill site contain *Eucalyptus* sp. stands that were introduced for shooting purposes, and there are remnants of cultivated plots containing Prickly Pear (*Opuntia ficus-indica*), Almond and Fig trees.

The steep coastal slopes to the north and east of the area are colonised by species including Golden Samphire and Maltese Salt Tree. Several other ecologically valuable species, noted in the RDB, occur in the area, including Mediterranean Stocks (*Matthiola incana melitensis*), Carline Thistle (*Carlina involucrata*), Seaside Squill and Mediterranean Thyme. Along the shoreline and in the clay steppe community at Għajn Barrani, the rare Chaste Tree (*Vitax agnus-castus*), an RDB species with restricted distribution in the Maltese Islands is present, as are stands of Solitary Tamarisk.

Fauna

Faunal records from the area are restricted, but it is known from the literature (Schembri *et al*, 2002) that a small colony of Levantine Shearwater (*Puffinus yelkouan*) breeds in the locality and that Jackdaws (*Corvus monedula*) and Barn Owls (*Tyto alba*) previously lived in the area.

Despite the paucity of information, it must be assumed that there are established faunal communities associated with the different plant communities, which would be impacted by changes to the vegetation.

Ecological value

The Gozo and Comino Local Plan (2001) lists only a single site in the locality as an Area of Ecological Interest (AEI). This is the sand dune complex at Ramla-l-Hamra Bay, which was designated in 1995, for its dune ecology.

Notwithstanding the lack of designations, there are several features of ecological value around the landfill. The garrigue to the west of the landfill has important conservation potential, and the presence of several species with restricted distribution, such as Solitary Tamarisk and Levatine Shearwaters around the landfill site, should also make the area an important ecological resource.

6.3 Wied Fulija

6.3.1 Waste mass

The two waste mounds encroach to within a few metres of the crest of vertical or overhanging sea cliffs approximately 100m high. Waste also infills the line of the former Wied il-Ħallelin and forms a large, sloping, wedge-shaped face where this is exposed above the cliff (Plate 6.12). The near horizontally bedded rock in the cliffs comprises strata of the Lower Coralline Limestone Formation.

There is evidence of previous cliff failure where significant blocks have fallen into the sea beneath the eastern waste mound (Plate 6.13).

The waste mass was fully penetrated in both the holes drilled indicating a maximum thickness of around 20m. This accords with the postulated thickness determined by a review of the survey data. However, there is a significantly greater thickness locally where the former valley has been infilled (up to 37 m below the crest of the western waste mound).

Evidence from the drilling suggests that the wastes are reasonably consistent throughout their depth comprising layers of conventional domestic and industrial waste intermingled with some construction waste.

The waste is likely to be undergoing settlement as a result of self-weight consolidation (i.e. the newer layers of waste compressing the underlying materials) and general organic waste decomposition. There is evidence of some differential surface settlement probably occurring as a result of waste decomposition and the effects of subsurface combustion. There is also evidence of some tension cracks in areas showing either surface staining or direct evidence of combustion. There is evidence of spalling of material from the face of the valley infill but no evidence of any significant mass movement.

The waste mound has slope angles of typically 31° but range up to around 38° (locally) between the flat benches. Spalling of waste materials occurs around the entire site as the materials ‘regrade’ to angles of repose. There is some evidence of waste instability in the form of cracking of the surface and differential settlement at the western extremity of the landfill.

6.3.2 Surface Contamination

Samples of exposed waste contained elevated concentrations of the following determinands:

- chromium;
- copper;
- zinc;
- lead;
- cadmium;
- PAHs (burnt waste);
- Total phenols (burnt waste);
- dioxins (burnt waste);
- other unresolved organic compounds (burnt waste).

Condensate around venting combustion gases also contained elevated concentrations of toluene.

Visibly uncontaminated cover materials contained similar concentrations of determinands to background samples in Malta with the exception of the presence of detectable (but not elevated) concentrations of dioxins.

6.3.3 Heating / Combustion

The results of the thermographic imaging coupled with the results of the gas monitoring (notably the CO measurements) and the surface temperature monitoring indicate that areas of the western landfill mass are undergoing significant heating (with localised combustion). There is evidence of localised heating and combustion on the crest of the eastern waste mound. The results are summarised on Figures 6.15 and 6.16.

Thermographic Imaging

Thermographic images of the landfill indicate four main areas of interest (Figure 6.16):

- The western end of the east mound (Plate 6.13);
- southern and south-eastern face of the west mound (Plate 6.12b);
- the central face of the west mound (Plate 6.12c); and
- western end of the west mound (Plate 6.12d and e);

The southern and south-eastern face of the west mound is characterised by localised evidence of heating both along the crest and toward the base of the waste mound, particularly the corner between the southern and south-eastern sides. There is more widespread heating at the western end of the west mound. In contrast there is only limited evidence of localised heating of the crest of the south-western side of the east mound in approximately three locations. The remaining areas of the site showed no evidence of significant heating in the thermographic survey.

Temperature Measurements

Surface measurements of elevated temperatures where gases and vapours are vent to surface correlated reasonably well with the heat distribution measured with the thermographic survey (Figure 6.17). Typically temperatures of venting gases were between 50 and 80 °C, temperatures potentially indicative of active combustion in areas of the site where thermographic imaging had identified heating. In localised areas temperatures at the surface exceeded 140°C (peak 243°C). These very elevated temperatures were concentrated on the western end and south-eastern corner of the western mound and in one location on the crest of the eastern mound. In these areas at least, combustion is still likely to be occurring.

Borehole temperatures in the east mound (WFW2) were typical of municipal waste landfills (45-52°C within waste) declining toward the base of the waste (40 °C). Higher temperatures would be expected closer to the limited zones of combustion in the west and south-west of this mound. In contrast, on the west mound, borehole temperatures in WFW1 were higher (77°C decreasing to 65°C at base) indicating the proximity of areas of combustion in the eastern face of the western mound.

Gas Monitoring

The results of the surface gas monitoring are summarised as dot-density plots on Figures 6.18 – 6.21 for carbon monoxide, carbon dioxide, methane and hydrogen sulphide respectively.

Elevated concentrations of carbon monoxide correlated well with surface temperature measurements and the thermographic survey. The most highly elevated concentrations (taken to be indicative of active combustion causing a low oxygen atmosphere) were observed at the base of the south-eastern corner of the western waste mound). Generally elevated concentrations were generally observed over the seaward faces of both mounds of the landfill. Low concentrations of carbon monoxide were restricted to areas where there was little other evidence of current heating.

Methane concentrations were generally low, indicating that the anaerobic waste decomposition processes typical of normal landfills are not occurring to a significant extent.

Carbon dioxide concentrations were generally high in those areas where elevated temperature and carbon monoxide concentrations were also recorded. These concentrations confirm that aerobic decomposition of waste (including but not necessarily restricted to combustion processes) predominate in the landfill. However, in contrast to carbon monoxide concentrations, the most elevated carbon dioxide measurements were restricted to the uppermost areas of the landfill. These are areas where the supply of oxygen to the waste (thus allowing complete combustion) would be greatest.

Interpretation

The combination of the thermographic survey, surface temperature and gas monitoring has allowed the following conclusions to be drawn regarding the extent of combustion at Wied Fulija:

- there is evidence of combustion (or at least active smouldering) on the landfill;
- the principal areas affected are the western end of the west mound, localised areas along the seaward crest and base of the west mound and localised areas on the south-western crest of the eastern mound;
- the distribution of heating and landfill and combustion gases suggests that actual combustion is restricted to the outer edges and upper surfaces of the landfill in general. The presence of heat at low levels on the seaward side of the western mound may resulting from upward oxygen penetration from cracks and fissures in the underlying limestone bedrock or funnelled up through permeable wastes in the infilled valley of the Wied Ħallelin;
- the presence of the most significant heating on the western end of the west mound is likely to relate to the narrow width of the waste mound in this area (thus allowing greater oxygen access) and its being located up-wind of the remainder of the site.

The extent of heating and possible combustion may reflect:

- the proportion of municipal solid waste in the original waste deposited;
- the retention of heat by inert waste within the landfill;
- the exposed situation of the landfill allowing oxygen migration both laterally and upward through underlying strata and into the open textured waste.

6.3.4 Air Quality

Measurements of volatile organic compounds in Gresham tubes are summarised in Table 6.7 together with associated PID readings. Only a limited number of volatile organic compounds were identified in surface soil gas samples despite elevated concentrations of VOCs indicated by the PID readings (which may be affected either by gas temperature or moisture content). At Wied Fulija, in contrast to the other sites VOCs were detected in both borehole and surface gas samples. The reason for this difference in behaviour is not clear at present.

For reference the measured concentrations are compared to the UK maximum exposure limits (long term 8 hr TWA) or the occupational exposure limits (long term 8 hr TWA) in UK HSE document EH40/2002. Benzene in soil gas is present consistently in greater concentrations than this guidance value whilst other VOCs detected locally exceed the relevant MEL/OEL.

Table 6.7: Volatile Organic Compound Measurements at Wied Fulija (ppm)

	Total VOCs by PID	*trans-1,2-Dichloro-ethene*	*Carbon Disulphide*	*1,1,1-Trichloro-ethane*	*Benzene*	*All other VOCs*
UK MEL /OEL (8 hr TWA)		5	10	100	3	
WFW1	0	<10	<10	<10	**80**	<10
WFW2	0	<10	<10	<10	**15**	<10
WFGS1	>9999	<10	<10	10	<10	<10
WFGS2	0	**370**	<10	**6675**	**20**	<10

MEL – maximum exposure limit
OEL – Occupational Exposure Limit
TWA – Time Weighted Average
PID – Photoionisation detector

6.3.5 Other Impacts

Soil

Impacts on the soils in the area surrounding Wied Fulija have been assessed by comparing chemical analyses of soil with analysis of background samples of soil from Malta.

Soils around Wied Fulija show concentrations of the following determinands exceeding the Target Value:

- copper;
- nickel;
- zinc;
- lead;
- cadmium; and
- PAHs.

In addition, dioxins were detected in the two off-site samples analysed, but not at concentrations considered significantly elevated in agricultural soils.

The fact that concentrations exceed the target value does not mean either that the presence of these substances is a risk to human health. However a preliminary assessment of the contaminants listed suggests that of the contaminants listed above only lead is likely to present in sufficient concentrations to represent any potential risk to human health.

It should also be emphasised that the presence of the potential contaminants listed above does not indicate that they derive from the landfill alone (although data from the high volume sampler at Magħtab suggests this is plausible). Other local potential sources of the contaminants that need to be considered are:

- lead shot (lead);
- steel shot (copper, nickel and zinc);
- pig slurry application to land (copper and zinc).

Groundwater

The identification of potentially elevated concentrations of potential groundwater contaminants was assessed by comparison with EU Council Directive 98/83/EC on the quality of water intended for human consumption.

The following determinands were found to be elevated above the drinking water standards:

- chloride, sodium and sulphate (all boreholes);
- ammoniacal nitrogen (WFBH1);
- total coliforms (WFBH3); and
- Bacillus *stearothermophilus* (present in WFBH1).

Elevated chloride, sodium and sulphate concentrations reflect the salinity of the mean sea level aquifer (Lower Coralline Limestone Formation) as the boreholes extend beyond the base of the fresh-water lens (measured salinity was lowest in WFBH3 the borehole furthest from the sea).

Trace concentrations of the volatile organic compounds cis-1,2-dichloroethene, chloroform and trichloroethene were identified in WFBH3. Although the presence of these are only likely to have an anthropogenic origin, at first glance a source within the landfill appears unlikely given the inland location of the sample, upgradient of the site. However, groundwater flow patterns in karstic aquifers are complex and it is plausible that water quality in WFBH3 could be impacted by contaminants deriving from the landfill travelling via fractures or solution features against the prevailing hydraulic gradient.

Concentrations of metals in groundwater are not elevated when compared to the values in the drinking water directive.

Bacteriological contamination of groundwater was identified near the landfill in both WFBH1 and WFBH3. There are considered to be two possible sources:

a) the landfill; and
b) animal slurries at nearby animal husbandry units and spread on fields.

Both may potentially contribute to the presence of bacteriological contamination identified.

Marine Environment

The marine water sample from Wied Fulija contained slightly elevated concentrations of ammoniacal nitrogen only in similar concentrations to those observed near both Magħtab and Qortin.

6.3.6 Ecology

Vegetation

Most of the Wied Fulija landfill itself is unconsolidated construction waste, interspersed with mounds of fragmented glass and compacted metal containers. The vegetation on the recently disturbed landfill is dominated by oportunistic species characteristic of disturbed ground, such as Crown Daisy (*Chrysanthymum* coronarium) and Cape Sorrel (*Oxalis pes-caprae*). Areas that have not been recently disturbed show species composition that includes the endemic Maltese Salt-tree (*Darniella melitensis*).

The narrow coastal fringe to the south of the landfill is an important ecological habitat, which shows the characteristics of a degraded maritime garrigue. Close to the landfill, opportunistic species are mixed with original garrigue species, such as the RDB species Egyptian St Johns Wort (*Hypericum aegyptiacum*), as well as Olive-leaved Germander (*Teucrium fruticans*) and other species indicative of regressive or progressive succession, such as Branched Asphodel (*Asphodelus aestivus*) and the RDB species Seaside Squill (*Urginea pancration*). Close to the cliff edge, the endemic, rare Maltese Rock Centaury (*Palaeocyanus crassifolius*) was present. Other RDB species encountered on the clifftop included the rare Crystal Plant (*Mesembryanthemum crystallinum*), whose distribution is restricted in the Maltese Islands, as well as African Wolfblane (*Periploca angustifolia*) and Carline Thistle (*Carlina involucrata*), which both have restricted distribution in Mediterranean. Two endemic species, namely

Maltese Fleabane (*Chiliadenus bocconei*) and Maltese Sea Lavender (*Limonium melitensis*) were also found in this area.

On the west face of the narrow ravine, Wied il-Ħallelin, that interrupts the cliff face, there is a similar assemblage of species to that described above. This site has a high density of African Wolfblane, but does not include the Crystal Plant. Given its similarity to the cliff top vegetation, it is also considered to be ecologically important.

Although there are no sources of permanent water at this site, there is a single, temporal freshwater pool in the karst slope on the coastal fringe. The pool vegetation is typically ephemeral and includes Maltese Waterwort (*Elatine gussonei*) and filamentous algae (*Spirogyra* sp. and *Zygnema* sp.).

Fauna

The only faunal information available is of a Fairy Shrimp (*Branchipus schaefferi*) population in the freshwater pool. However, it must be assumed that there are specialised faunal communities associated with the cliff top vegetation community, which would be impacted by changes to the vegetation.

The South Malta Local Plan indicates that several species of birds utilise the coastal cliffs around this area also (SMLP, 2001).

Ecological value

The cliff top and ravine is of high ecological value and the coastal fringe is recognised for its ecological value in the South Malta Local Plan for its coastal cliffs and for its freshwater pools. It also qualifies as a Site of Scientific Interest for its populations of Maltese Rock Centaury and Crystal Plant.

The Maltese Salt Tree, African Wolfblane and Lentisk found in the coastal fringe are listed as “Strictly Protected Trees” in the Trees and Woodlands (Protection) Regulations 2001.

7. RISK ASSESSMENTS

7.1 Impact Assessment Process

7.1.1 Introduction

A two-stage impact assessment has been undertaken to identify significant environmental risks at each site:

1. a generic risk assessment to identify key hazards and receptors at risk; and
2. detailed quantitative and qualitative risk assessments to identify the magnitude and significance of risks.

The selection of viable remedial technologies and the development of appropriate rehabilitation strategies for each site is based on the outcome of this risk assessment process.

7.1.2 Generic Risk Assessment

Hazards

The generic assessment identified that potential impacts requiring further detailed assessment are likely to be associated with the following hazards:

1. *The waste masses themselves:* particularly hazardous materials and the hazardous products produced as a result of decay or combustion of waste. In addition the size, height and the physical mass of the waste mounds may represent at hazard.
2. *Leachate* can potentially be produced as a result of the degradation of wastes, liquid wastes and sludges added to the waste mass and as a result of infiltration of rainfall into the waste mass. For this assessment this could potentially also include run-off produced by rainfall coming into contact with contaminated materials on the surface of the waste mass and flowing over the ground surface away from the landfills.
3. *Landfill gases* produced as a result of the decay of organic and other wastes.
4. *Aerial Emissions (including smoke and particulate matter)* produced as a result of the frequently incomplete combustion of waste and other site activities (such as vehicular movement and waste deposition on operational sites).
5. *Ground instability* potentially created as a result of voids caused by subterranean fires, which could collapse suddenly and the steep / high slopes of waste masses.

Receptors

The receptors likely to be at risk from hazards associated with the landfill sites were identified as:

1. *Air quality*: as a result of the direct emissions from the site (landfill and combustion gases, smoke/ dust). The quality of the air impacts on site workers and visitors (at Magħtab and Qortin) and those communities and visitors in the vicinity of the sites. The aerial emissions from the sites could also cause an impact on the surrounding land quality and ecology as a result of fallout / plume grounding. Additionally, some landfill gases (most notably methane and carbon dioxide) are greenhouse gases.
2. *Groundwater*: potentially impacted as a result of leachate generation and migration potentially impacting local groundwater abstractions (primarily agricultural) in the vicinity of Magħtab and Qortin.
3. The *marine environment*: ultimately the groundwater beneath the site and the run-off from the waste masses and surrounding land enters the sea either as sub-marine baseflow or overland flow generally along tracks and roadways.
4. *People*: essentially site workers and visitors to the sites at Magħtab and Qortin and those persons living and working in the immediate vicinity of the sites.
5. *Landscape*: due to the large size of the landfills they form dominant local visual features. At both Magħtab and Qortin the waste masses can be seen from a large surrounding area.
6. *Ecology*: The presence of the landfills has completely destroyed the existing ecology within the footprint of the waste mass but there is also the potential for the sites to have caused an impact on the surrounding ecology (particularly through generation of dust and the spalling of waste onto adjacent land).
7. *Archaeology*: at some sites the progressive development of the landfill mass has covered or encroached close to a number of sites of archaeological interest and had an impact on the accessibility of a number of other adjacent features.

7.1.3 Detailed Risk Assessments

A second tier detailed risk assessment has been undertaken for each site. This has involved quantitative risk assessments involving computer simulations (using commercial software) to model:

- potential leachate impacts on groundwater quality; and
- the effect of aerial emissions on local air quality.
- certain slope stability conditions.

The quantitative assessments of risks to groundwater quality and those associated with aerial emissions are summarised in more detail in the following section.

Probabilistic assessments based on direct observational evidence have been used to assess potential impacts associated with ground conditions (cliff stability) whilst judgemental (descriptive) assessments have been used to assess the impacts of landfill hazards on:

- the marine environment;
- people (incorporating the results of the air quality assessment);
- landscape;

- ecological receptors; and
- archaeological sites.

7.1.4 Impact Assessment Matrix

For each site, this assessment process has been summarised to produce a qualitative summary of the significance of impacts from each site assuming that no mitigation measures are in place. This qualitative assessment involves combining the magnitude of the identified hazards with an assessment of the sensitivity of the receptors. When combined (as indicated in the table below) a significance of impact has been determined:

		Sensitivity of Receptor		
		High	Moderate	Low
Magnitude of Hazard	High	SIGNIFICANT	SIGNIFICANT	SIGNIFICANT
	Moderate	SIGNIFICANT	SIGNIFICANT	NOT SIGNIFICANT
	Low	NOT SIGNIFICANT	NOT SIGNIFICANT	NOT SIGNIFICANT

These assessments are detailed for each site in the following sections and used to identify those hazards requiring mitigation as part of the rehabilitation works.

7.2 Summary of Detailed Risk Assessments

7.2.1 Groundwater

Outline Methodology

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 in any of the landfills during the Stage II 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 landfills (including the uppermost layers of Qortin) 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 (most likely 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 leachate migration through the base of the landfills is likely to be seasonal; albeit significantly limited by landfill heating and combustion. In the medium to long-term, as landfill combustion processes cease (either gradually or with intervention); 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 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).

This groundwater risk assessment therefore deals with assessing potential long-term impacts on groundwater quality rather than the current transient impacts (which are best assessed by monitoring). It is a baseline assessment to enable rehabilitation actions to be prioritised on the basis of demonstrable risk. It assumes that:

- the wastes will be left in place;
- significant heating or combustion within the landfills has ceased; and
- no measures to cap or otherwise restrict rainfall infiltration (and leachate production) are in place.

The methodology for the groundwater risk assessment consists of:

1. defining a conceptual model for the landfills including a description of the source of contamination, the receptors at risk and the pathways by which they might be linked;
2. choosing an appropriate modelling tool for 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.

Risks to the water environment were assessed 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 most appropriate risk reduction goals for the chosen receptor are standards for drinking water quality. As there are no appropriate Maltese standards the standards set out in EC Council Directive 98/83/EC on the Quality Of Water Intented For Human Consumption were used in the assessment.

Results

The results of the groundwater risks assessments show that if significant leachate generation within the landfill is possible then a wide range of contaminants (principally metals and inorganic ions but also some organic species) are leachable from the landfills in potentially significant concentrations. The potential impacts are greatest at Wied Fulija (due to the close proximity of the modelled receptor) and lowest for Qortin (where the contaminant source term was lowest) as might be anticipated.

It is important to stress that the modelled concentrations represent reasonable worst-case values because:

- the modelled source terms are considered conservative (worst case) estimates of leachate composition;
- contaminant mobility may be lower than modelled due to operation of adsorption processes within the landfilled wastes;
- biodegradation of organic contaminants and nitrification of ammoniacal nitrogen during transport may be of importance in limiting impacts;
- some (limited) retardation of contaminant transport is likely to occur (but was not modelled);
- volatile organic compounds may volatilise during transport.

However, the presence of detectable concentrations of contaminants in groundwater at Magħtab and Wied Fulija at the present time indicates that, where possible, the rehabilitation strategy should aim to reduce the production of leachate within each landfill by minimising infiltration.

7.2.2 Aerial Emissions

Outline Methodology

The emissions to atmosphere from the three landfills comprise a range of potential pollutants arising from a number of sources that include:

- dust (both contaminated and uncontaminated) generated by ongoing site activities (waste deposition, deposition of clean cover, vehicular movements);
- wind blown dust (both contaminated and uncontaminated);
- degradation of waste; and
- combustion or pyrolysis (starved air combustion) of waste.

The focus of this assessment is to quantify the environmental effects of emissions to atmosphere from the landfills at present. The following pollutants are considered.

- dioxins/furans (considered in terms of toxic equivalence);
- Volatile Organic Compounds (VOCs, benzene used as an indicator compound); and
- fine particulate matter (PM_{10}).

Whilst the Stage II site investigation works has shown that many more potential pollutants may be released to atmosphere than those listed above, it is considered that an assessment of the effects that the particular pollutants specified above may have on the environment around the landfills will provide a good indication of the overall impacts on air quality around the sites.

Odours were not considered in the risk assessment because they do not directly affect human health (other than being a manifestation of the presence of substances that may be hazardous). However, it is recognised that odour nuisance (particularly associated with Magħtab landfill) may impact on the quality of life in adjacent areas.

It is considered that the ongoing combustion of waste is of most concern with regards to the emissions to atmosphere from the landfills. Of the products of combustion being released to atmosphere, it is considered that the dioxins are of most concern to human health.

For each of the potential pollutants of concern emission rates were calculated based on measured concentrations in air, literature data, knowledge of the site size and likely composition of the waste mass. Modelling of the dispersion of current emissions was undertaken using the dispersion model AERMOD developed by the US Environmental Protection Agency. For dioxins, modelled off-site concentrations at ground level were compared with measured soil concentrations of dioxins.

Results

The following conclusions are drawn from the assessment of the effects on human health of emissions from the landfills currently:

- the soil survey provides evidence that aerial emissions from the landfills are the cause of increasing dioxin concentrations in the soil on immediately adjacent land;
- the measured concentrations of dioxins in soil are not currently higher than typical concentrations found in soil in other European counties and are not generally higher than available guideline concentrations appropriate for agricultural soil;
- estimates of emission rates of dioxins from the landfills are high (it should be noted that there is considerable uncertainty associated with the estimates of emissions);
- estimated dioxin deposition rates on land adjacent to Magħtab, derived from dispersion modelling predictions using the estimates of emissions, are in line with the measured concentrations in soil adjacent on adjacent land;
- modelling suggests that ongoing, uncontrolled, emissions of dioxins from the Magħtab landfill will continue to increase dioxin concentrations in soil on adjacent land and may eventually lead to concentrations that exceed guidelines and may impact on the food chain, giving rise to increased human exposure to dioxins;

- it is possible that concentrations of dioxins in air both on-site (and for a limited distance off-site) at Magħtab may represent a potential additional risk to human health above that associated with routine dietary exposure as a result of direct exposure via inhalation;

- the maximum predicted annual average concentration in air of benzene on-site at Magħtab would only be of concern if it was likely that people would be exposed to this concentration for a whole year;

- with the exception of the Magħtab site perimeter all the predicted annual average ground level concentration of benzene are below the assessment criteria;

- the predictions suggest that current emissions of fine particulate matter (PM_{10}) from both Magħtab and Qortin are leading to exceedences of the assessment criteria out to a distance of at least 1 km from the site; and

- current emissions from Wied Fulija are not predicted to be exceeding the assessment criteria for fine particulate matter.

The following conclusions are drawn from the assessment of the potential impact of landfill rehabilitation on particulate and gaseous emissions from the landfills:

- extinguishing the fires would ultimately reduce the emission of dioxins to close to zero and therefore stabilise the dioxin soil concentrations and minimise any risks to human health associated with inhalation;

- methods employed to extinguish the fires involving significant disturbance of landfilled materials are likely to lead to an increase in the emission rates of dioxins, organic vapours or particulates during the process;

- the possible use of controlled combustion has been demonstrated to have the potential to significant decrease the ongoing dioxin deposition rate whilst reducing the overall time the fires would burn without intervention;

- following the closure and rehabilitation of Magħtab and Qortin the predictions suggest that the contribution to ambient concentrations of fine particulate matter due to ongoing emissions from the site occurring as a consequence of the internal combustion will be similar to or less than the assessment criteria.

7.3 Magħtab

7.3.1 Hazard Identification

The following magnitudes have been ascribed to the various hazards identified earlier (Table 7.1):

Table 7.1: Hazards Identified at Magħtab

	Hazard	*Magnitude*	*Reason*
1	Waste mass	High	The Magħtab site contains hazardous wastes and is of significant size and height.
2	Leachate and runoff	Low-Moderate	Although no leachate was observed there is a potential for some leachate generation after periods of sustained rainfall. Leachate generation may increase as combustion processes cease and the landfill cools.
3	Landfill gases	Moderate	Little generation of conventional landfill gas (methane) but other hazardous gases are being produced as a result of site conditions (volatile organic compounds, dioxins).
4	Smoke/dusts	High	Significant quantities of potentially hazardous particulate emissions are being produced.
5	Ground stability	Moderate	The potential for undetected subterranean voids exists over most of the site. Slopes are locally very steep.

7.3.2 Receptors

The receptors around Magħtab have been assessed in terms of their sensitivity (Table 7.2) and based on the detailed assessments conducted significant impacts on these receptors have been identified (Table 7.3).

In general, the identified adverse impacts have been assessed based on existing conditions. However, recognition has also been taken of the likely changing nature of each site’s characteristics both as a result of ongoing natural processes and seasonal changes. The waste mass has buried specific local ecological and archaeological features and these cannot be recovered; for the purpose of these assessments it is the surrounding features that are considered.

Although concern has been raised on the impact of the landfill on the marine environment the initial results of a study commissioned by MEPA to review the state of the *Posidonia* (sea grass) meadows around the Maltese Islands has not identified any noticeable deterioration in the vicinity of Magħtab.

Table 7.2: Receptors near Magħtab

	Receptor	*Sensitivity*	*Reason*
1	Air quality	High	Although air quality in Malta is generally poor by western European standards there is a need to prevent its further deterioration. The air quality assessment has identified potentially significant elevations of some contaminants in air on and immediately adjacent to the site.
2	Groundwater	High	Local groundwater is abstracted for agricultural use near to the site and this resource is easily degraded.
3	Marine environment	High	The local coastline is an area of local importance for ecology and leisure. Additionally the marine habitats are potentially susceptible to degradation.
4	People	High	Ensuring the health and well-being of site workers and local populations is crucial.
5	Landscape	Moderate	Although the landfill is huge it is located within an area surrounded by other features of significant topographical scale (Victoria Lines, Wardija Ridge).
6	Ecology	Moderate	The site is located adjacent to areas of Ecological Importance and a Site of Scientific Importance (in terms of the Structure Plan). Ecological surveys have identified potential impacts on immediately adjacent land.
7	Archaeology	Low	The landfill has obliterated one site of antiquity and a number also exist in the local area which are potentially at risk if the landfill spreads beyond its existing footprint.

Table 7.3: Impact Assessment Matrix for Magħtab

		Receptor						
		Air quality	*Groundwater*	*Marine environment*	*People*	*Landscape*	*Ecology*	*Archaeology*
Hazard	Waste mass	NS	NS	NS	S	S	NS	NS
	Leachate / runoff	NS	NS/S*	NS/S*	NS	NS	NS	NS
	Landfill gases	S	NS	NS	S	NS	NS	NS
	Smoke/dusts	S	NS	NS	S	S	NS	NS
	Ground stability	NS	NS	NS	S	NS	NS	NS

S = Significant
NS = Not significant
* = There may be seasonal impacts that are significant and impacts may increase as the landfill cools.

7.3.3 Intervention

Where the assessment summarised in Table 7.3 indicates an impact as significant there is a requirement to undertake some form of positive intervention as part of the rehabilitation to mitigate any impacts as far as practically possible.

At Magħtab the effects of the surface and subterranean fires are considered to be having a significant detrimental impact on local air quality. This is compounded by the hazardous gases arising as a result of waste decomposition and other reactions. This subsequently impacts directly on the health and well-being of site operatives, visitors and those persons living and working immediately around the site. Smoke and fumes are also considered to impact adversely on the visual appearance of the site. This is considered to be the main impact necessitating mitigation.

The potential for ground movements due to surface collapse into voids or minor slope failure is considered to be a potential threat to the safety of those on site. There is not considered to be a major risk associated with a large-scale failure although this could be influenced by ongoing waste disposal activities during site completion. Ground stability would need to be addressed before the general public could be granted free access to the site (under recreational after uses for example).

The hazardous components of the wastes represent an unacceptable impact to those who may come into direct contact with these materials. However, in general these materials are well covered by inert material during disposal but this would become a significant risk should large volumes of waste be disturbed or moved.

Impacts on groundwater quality appear to be minimal at present but may be of transient significance seasonally. The groundwater risk assessment has identified potentially significant impacts on local groundwater quality should significant quantities of leachate be produced by the landfill in future.

Additionally the sheer size and shape of the waste mound is an imposing visual intrusion in the local settings, particularly in its un-vegetated state. The ever-expanding mass has also obliterated the pre-existing, now buried ecology and archaeological remains but is not considered to be a significant risk to the other surrounding features provided waste disposal activities are confined to the area within the existing footprint.

The rehabilitation strategy for Magħtab must therefore incorporate elements that:

- contain or control the emissions from the fires (and other landfill gases);
- reduce the potential for sudden ground movements to adversely affect plant or personnel;
- isolate or contain the hazardous waste materials;
- prevent the spread of waste materials over a larger footprint area;
- minimise risks of potential seasonal impacts on groundwater quality and
- reshape the waste mound and involves some re-vegetation of the surface.

7.4 Qortin

7.4.1 Hazards

The following magnitudes have been ascribed to the various hazards identified earlier (Table 7.4):

Table 7.4: Hazards Identified at Qortin

	Hazard	*Magnitude*	*Reason*
1	Waste mass	Low	There are not considered to be significant quantities of hazardous material in the waste.
2	Leachate and runoff	Low	No leachate was encountered although seasonally some may be produced and quantities may increase as combustion ceases and the landfill cools.
3	Landfill gases	Moderate	Decay of the waste appears to be producing landfill gas (methane) in significant quantities. This represents an explosive hazard and is a greenhouse gas.
4	Smoke/dusts	Low	Although near surface fires have existed at the site these appear to be under control and the low level of site activity does not appear to be producing much dust.
5	Ground stability	High	The waste mass is located immediately adjacent to a precipitous potentially unstable cliff above Għajn Barrani.

7.4.2 Receptors

The receptors around Qortin have been assessed in terms of their sensitivity (Table 7.5) and based on the detailed assessments conducted significant impacts have been identified (Table 7.6). In general the identified adverse impacts have been assessed based on existing conditions. However, recognition has also been taken of the likely changing nature of each site's characteristics both as a result of ongoing natural processes and seasonal changes.

7.4.3 Intervention

Where the assessment summarised in Table 7.6 indicates an impact as significant there is a requirement to undertake some form of positive intervention as part of the rehabilitation to mitigate any impacts as far as practically possible.

Due to the nature of the majority of the wastes at Qortin there is anaerobic decay producing quantities of landfill gas that are presently venting to atmosphere and may need to be controlled, particularly if the site is to have an after use involving public access. Such decomposition of waste may also be producing small quantities of leachate but this is not currently considered to be having a significant impact on water quality or the marine environment. However, there may be some adverse impact on water quality after periods of intense rainfall.

Table 7.5: Receptors near Qortin

	Receptor/Media	*Sensitivity*	*Reason*
1	Air quality	High	Although air quality in Malta as a whole is generally poor air quality in Gozo is better and there is a need to prevent its deterioration.
2	Groundwater	High	Local groundwater is abstracted for agricultural use to south of the site and this resource is easily degraded. Groundwater also provides the source of Għajn Barrani spring.
3	Marine environment	Moderate	The local coast-line is an area of local importance for ecology and leisure. Additionally the marine habitats are susceptible to degradation. Contamination of Għajn Barrani spring could potential lead to contaminant migration into the marine environment.
4	People	High	Ensuring the health and well-being of site workers and local populations is crucial.
5	Landscape	Moderate	Although the landfill is not large it is located on an elevated plateau and is highly visible.
6	Ecology	Moderate	Although there are no designated areas of Ecological Importance or Sites of Scientific Importance (in terms of the Local Plan) there are several features of value nearby.
7	Archaeology	Low	A number of features of antiquity exist in the near vicinity of the site and a number have been destroyed by the presence of the landfill.

Table 7.6: Impact Assessment Matrix for Qortin

		Receptor						
		Air quality	*Groundwater*	*Marine environment*	*People*	*Landscape*	*Ecology*	*Archaeology*
Hazard	Waste mass	NS	NS	NS	S	S	NS	NS
	Leachate / runoff	NS	NS/S*	NS/S*	NS	NS	NS	NS
	Landfill gases	S	NS	NS	S	NS	NS	NS
	Smoke/dusts	NS	NS	NS	NS	NS	NS	NS
	Ground stability	NS	NS	NS	S	S	S	NS

S = Significant
NS = Not significant
* = There may be seasonal impacts that are significant and impacts may increase as the landfill cools.

The steep waste slopes and close proximity of the waste mound to the edge of the Upper Coralline Limestone cliff present potentially significant risks to the surrounding land and personnel on the site should collapse occur. Currently the ever-expanding waste mass is encroaching nearer to the cliff edge and is increasing in height. This is reducing the factor of safety of the cliff, which could fail as a result of dislocation of a number of blocks of limestone from the main cliff face. Such a failure is considered likely within the timeframe before the waste constituents have completely stabilised. Thus there is a risk of waste materials being deposited onto the inaccessible Blue Clay slope causing adverse impacts to both the local ecology and visual appearance of this important coastal area.

Therefore, it is considered that the rehabilitation strategy for Qortin should include:

- reshaping of the waste mass to reduce slope angles and thus minimise the potential for deposition of wastes on the clay slope beneath the cliff should collapse occur in this area;
- recontouring the site to ensure all near surface fires are extinguished and produce a landform suitable for vegetation development and an afteruse and
- covering the potentially hazardous waste materials and landscaping the surface in addition to installing some form of gas management system.

7.5 Wied Fulija

7.5.1 Hazards

The following magnitudes have been ascribed to the various hazards identified earlier (Table 7.7):

Table 7.7: Hazards Identified at Wied Fulija

	Hazard	*Magnitude*	*Reason*
1	Waste mass	Moderate	There may be quantities of hazardous material in the waste in addition to the generation of hazardous wastes by degradation and combustion processes.
2	Leachate and runoff	Low	No leachate was encountered although seasonally some may be produced.
3	Landfill gases	Moderate	Little generation of conventional landfill gas but other hazardous gases are still being produced by combustion and degradation.
4	Smoke/dusts	Moderate	Small quantities of potentially hazardous particulate emissions are being produced by combustion
5	Ground stability	High	The potential for undetected subterranean voids exists over most of the site. Slopes are locally very steep. Additionally the waste mass is located immediately adjacent to a precipitous potentially unstable sea cliff.

7.5.2 Receptors

The receptors around Wied Fulija have been assessed in terms of their sensitivity (Table 7.8) and based on the detailed assessments conducted significant impacts have been identified (Table 7.9). In general the identified adverse impacts have been assessed based on existing conditions. However, recognition has also been taken of the likely changing nature of each site's characteristics as a result of ongoing processes.

7.5.3 Intervention

Where the assessment summarised in Table 7.9 indicates an impact as significant there is a requirement to undertake some form of positive intervention as part of the rehabilitation to mitigate any impacts as far as practically possible.

The isolated location of the Wied Fulija landfill effectively limits the significance of most environmental impacts caused by the wastes and the emissions resulting from the continuing fires.

However, the steep waste slope angles and the proximity of the landfill to the edge of a high sea cliff could have a significant impact on those persons on site at the time of a sudden collapse. Additionally, the consequential accidental deposit of spilled waste could have an adverse impact on both the local marine environment and the visual appearance of the locality. However, any such impact may be minor and short-lived as strong sea currents in the area would dilute and disperse much of the debris.

Although cliff failure has occurred in the past there is little to suggest that such collapses are frequent and it is difficult to identify the potential size of any such collapse. However, the potential for localised spalling of waste from the surface of the mounds is high.

Potential current and future transient impacts on groundwater quality are limited by the lack of local receptors and the close proximity to the coast.

The restoration strategy for Wied Fulija therefore concentrates on:

- reducing the potential impacts of any collapse of the wastes and
- controlling the aerial emissions from the combusting waste.

Table 7.8: Receptors near Wied Fulija

	Receptor/Media	*Sensitivity*	*Reason*
1	Air quality	High	Although air quality in Malta is generally poor there is a need to prevent its further deterioration.
2	Groundwater	Low	Although any leachate may reach the groundwater there is no utilisation of this resource, which is essentially seawater due to its immediate proximity to the coast.
3	Marine environment	Moderate	The local coast-line is an area of local importance for ecology and leisure. Additionally the marine habitats are susceptible to degradation.
4	People	High	Ensuring the health and well-being of site workers (associated compost processing and storage) with and local populations is crucial.
5	Landscape	Low	Although the landfill is not large it is located on an elevated plateau but is only visible from a small area.
6	Ecology	Moderate	The coastal cliffs are of ecological value and certain sections qualify as Sites of Scientific Interest (in terms of the Local Plan). There is the potential for emissions from the sites to have caused an impact on the surrounding ecology
7	Archaeology	Low	There are no sites of antiquity within 500m of the landfill.

Table 7.9: Impact Assessment Matrix for Wied Fulija

		Receptor						
		Air quality	*Groundwater*	*Marine environment*	*People*	*Landscape*	*Ecology*	*Archaeology*
Hazard	Waste mass	NS	NS	NS	S	NS	NS	NS
	Leachate / runoff	NS	NS*	NS	NS	NS	NS	NS
	Landfill gases	S	NS	NS	S	NS	NS	NS
	Smoke/dusts	S	NS	NS	S	NS	NS	NS
	Ground stability	NS	NS	S	S	S	NS	NS

S = Significant
NS = Not significant
* no identified groundwater receptor at risk (groundwater saline).

8. REHABILITATION CONSIDERATIONS

8.1 Introduction

The choice of potential rehabilitation options for each landfill is constrained by a number of key factors, namely:

- the characteristics of the site;
- external influences (statutory, strategic, planning, commercial and community);
- after use requirements; and
- the applicability of available remedial technologies.

8.2 Site Characterisation

Each site has been characterised by the development of site-specific conceptual models and the risk assessments outlined in previous sections. These have been used to assess the impact that each landfill is having on the surrounding environment currently and potentially in the future without rehabilitation. This process has identified key risks that require mitigation during the development of rehabilitation strategies for each site.

8.3 External Influences

There are a number of external (some intangible) influences on the determination of viable strategies for the rehabilitation of the landfills. These include:

- statutory requirements related to health, safety and environmental compliance (incorporated into the strategy development in the form of risk reduction goals or desirable environmental performance targets);
- strategic policies and aspirational planning objectives such as those identified by MEPA with respect to land use development and waste management as well as the goals identified in the National Solid Waste Management Plan; and
- commercial and community interests - essentially the interests of the business and local communities with respect to land and resources development. These are less straightforward to quantify in terms of assessing their impact on viable rehabilitation schemes. For the purpose of this study such influences have been considered in general terms only.

8.4 After uses

Potential after uses for each site identified in Section 4 have been assessed against:

- technical feasibility: both under existing conditions and following restoration (particularly in relation to landform);
- the scope and practicality of installation of additional environmental and safety control measures above those required to enable basic environmental management of the sites to be achieved; and
- the general “alue” of the after use relative to the additional restoration works required to achieve it.

These assessments have identified only a very limited range of feasible and potentially viable after uses, especially in the short and medium term. It is anticipated that for each of the sites a beneficial after use would be achievable only after a (prolonged) period of stabilisation, possibly involving an interim restoration period. This is essential to ensure the safety of people visiting the sites.

8.5 Rehabilitation Technologies

8.5.1 Available Techniques

A range of landfill management technologies are available, a number of which may be appropriate for utilisation at any of the three sites:

- natural stabilisation;
- engineered capping;
- combustion control;
- aerial emissions control;
- leachate management;
- landfill mining; and
- institutional controls.

These (and their sub-options) have been assessed by considering their:

- feasibility/practicality;
- efficacy;
- environmental impacts during implementation; and
- costs,

in terms of their applicability to the local situations at each site. This assessment is summarised in the remainder of this section.

8.5.2 Natural Stabilisation

Natural stabilisation would essentially involve sealing off the sites (which would require provision of security and fencing) and allowing natural process to complete the ongoing combustion and for waste degradation to continue and the landfill contents to progressively stabilise. This would lead to a gradual reduction in aerial and groundwater impacts to acceptable levels in the long-term.

Although natural stabilisation is relatively easy to implement it does not reduce environmental impacts in the short to medium term and it could take many decades for the waste masses to stabilise sufficiently to minimise all environmental impacts. Furthermore, adopting such a strategy is unlikely to be acceptable, either within the local community surrounding the sites or within the Maltese islands as a whole.

8.5.3 Engineered Capping

Capping the landfills would potentially be beneficial. Ideally a capping system would:

- reduce rainfall infiltration, minimise leachate production and consequent impacts on groundwater quality;
- prevent contact with and aerial mobilisation of contaminated materials; and
- limit air ingress into wastes thus reducing the extent of combustion over time.

A number of alternative capping techniques are available.

Clay Cap

A conventional layered landfill cap comprises a compacted clay liner (CCL) overlain restoration soils and containing gas collection and drainage layers. Such a cap would be effective in the short to medium term if designed and installed properly. However, there are no usable local sources of clay to construct the CCL and material imported from overseas would attract a very high cost. There are question marks against the effectiveness of CCL caps in the longer term when they are used in arid or semi-arid environments as the clay dries out and fissures develop allowing water and air in and emissions out. Construction of a clay cap would require significant reduction in side slope angles (and consequent removal of significant quantities of material) on any of the sites to be constructible.

Synthetic Cap

Generally installed as a clay cap but with clay replaced with either a geosynthetic clay liner (GCL) or a flexible (plastic) membrane liner (FML). This would have the same mitigating impacts as a clay cap. However, the effectiveness of GCL is also likely to be compromised by the semi-arid climate and it would not be possible to install an FML on the landfills until near surface heating has dissipated.

In addition, the steep slopes at all three sites would prevent the establishment of a restoration surface (essentially soil and planting) above the capping system. The cap would appear ‘bare’, which would be visually unacceptable. Alternatively, restoration capping could be deployed subject to reducing side slope angles involving the removal of large volumes of material.

BES Cap

The use of bentonite-enhanced soils (BES) to produce a low permeability cap is common but requires the use of a substrate to form the bulk of the capping (the bentonite typically comprises only a few percent of the volume of the material). There is limited suitable clay available locally (limestone fines are not suitable for this purpose). Installation requirements and performance are likely to be similar to a clay cap.

Compacted Cap

The formation of a lower permeability more geotechnically stable ‘crust’ to the waste masses utilising existing site materials could require excavation, waste processing and replacement resulting in the consequential environmental difficulties such activities would cause with regard to aerial emissions and safety implications (see comments on landfill mining below). Alternative methods of crust formation could involve in-situ compaction using heavy mobile plant. The efficacy of such measures to reduce air and rain ingress into the waste mass is uncertain but it would be unlikely (as with all capping techniques) to completely eliminate subterranean combustion or leachate production. Such techniques would, however, close up any potential voids created by the combustion process and render potentially unstable ground more stable provided there was no chance of continued or reactivated subterranean combustion. It would require construction suitable level working platforms throughout the waste masses to be implemented; this would involve the removal and temporary storage of large quantities of waste.

Evapotranspiration (ET) Cap

The deployment of a thick restoration soil layer with abundant planting would control infiltration (and the potential for leachate generation) by soil moisture storage and evapotranspiration. Such restoration surfaces work in arid-semi-arid environments over long periods and are generally low maintenance. However, it would not limit air ingress as much as other cap designs and would require the production of significant quantities of restoration soils. It would also require a reduction in side slope angle to enable effective deployment over the entire site. Such caps would be effective in oxidising some of the methane emanating from the waste mass (particularly at Qortin) before this is released to the atmosphere.

8.5.4 Combustion Control

A number of techniques have been utilised elsewhere in the world to control and extinguish fires at landfills. However there is a degree of uncertainty over the effectiveness of these techniques, which would also be very costly. It also may be necessary to repeat the application of any particular technique as waste materials continue to decay aerobically and thus attain elevated temperatures. This would particularly be the case at Magħtab where there are significant volumes of organic materials present within the waste.

Dig and Expose / Cool

Whilst effective in isolating burning waste it would be difficult to initiate such a process at the larger sites (Magħtab and Wied Fulija) due to the very large volumes of waste to be removed, the large flat areas required for waste placement during cooling and the dangers involved for those undertaking the work. It will be difficult to prevent off-site impacts in terms of aerial emissions (particularly the risk of fires breaking out at the waste surface as oxygen is introduced into the exposed waste mass) or uncontrolled run-off of contaminated water used for cooling. However, it may be possible to accomplish at Qortin where much smaller quantities of waste materials are thought likely to be undergoing active combustion.

Water or Foam Injection

The efficacy of injecting water or foam to extinguish landfill fires is limited to sites where combustion is occurring at shallow depths and where the water or foam can readily be targeted at the combusting areas. The hot areas within the landfills (particularly Magħtab) are extensive and deep. Huge volumes of water or foam would be required and consequently large quantities of highly polluted leachate are likely to be produced within the waste mass. This would require collection and treatment before discharge which would not be possible at any of the sites due to the lack of a basal seal and there presence of highly permeable ground beneath the wastes.

Inert Gas Injection

Targeted injection of inert gas (usually in the form of liquid Nitrogen or sometimes carbon dioxide) into relatively shallow waste masses (if sealed) would reduce temperatures and limit oxygen ingress. However, sealing of the base of the waste masses would be necessary to allow a build up of the gas within the waste mass. Although this could theoretically be achieved by grouting, it would be very costly in such permeable ground. Alternatively water could be co-injected with the gas, which may freeze at the landfill base and form a seal. However, continued injection from an on-site liquid nitrogen production plant over a prolonged period (certainly in excess of one year) would be required to effectively extinguish fires.

Smothering

The effective limitation of oxygen from entering the landfills would necessitate the construction of some form of low permeability capping system in addition to providing some basal seal, particularly at those sites (Qortin and Wied Fulija) where there is likely to be a significant updraft of air through the underlying bedrock strata. An in-ground barrier system around the site perimeter would be required and the practicality of successfully installing such a system in fractured ground would incur exceptionally high cost. There would be significant difficulties associated with the successful deployment of effective capping systems due to the sites' geometry, size, available materials and cost (as detailed previously).

8.5.5 Aerial emission control

The active extraction, collection and treatment of landfill and combustion gases would minimise the negative impacts of these gases on air quality and consequently minimise the potential negative health impacts. The deployment of such systems would include shallow wells, surface pipework and gas treatment plant. The treatment plant could entail high temperature flaring (although a support fuel would be required) or proprietary gas / emissions treatment systems. The operational and maintenance requirements of such a system would be quite intensive.

The deployment and active management of such systems may (if properly monitored and controlled) accelerate the combustion process leading to a more rapid stabilisation of the wastes than would be achieved by natural stabilisation alone. However, for the largest site (Magħtab) it may be necessary to operate such a control system for over 20 years to achieve the necessary degree of stabilisation.

8.5.6 Leachate Management

The active extraction, collection and treatment of landfill leachate would minimise leachate production (or the potential for leachate production) and consequent impacts on groundwater quality. Such systems would be difficult to retro-fit to existing landfills and, as the leachate in Maltese landfills is likely to be transient following rainfall events and rapidly removed by downward percolation through bedrock, it is unlikely to be practicable to install such systems at any of the sites.

8.5.7 Landfill mining

The excavation, sorting (grading) and, where necessary, decontamination of waste for beneficial re-use, recycling or disposal would remove some of the volume of the waste mass for improved landscaping and stability purposes and also minimise some of the environmental impacts. Taken to the fullest extent, such processes could reduce landfill volumes significantly whilst ensuring control of combustion thorough exposure and cooling of landfilled wastes.

Coarse construction and demolition (especially excavation) waste could potentially be separated for re-use (such as for land reclamation from the sea if there was a predetermined requirement for this). However, such waste is likely to be contaminated and require cleaning (by soil washing for example) before beneficial re-use without containment. The fine fraction of the excavated and processed material is likely to be contaminated (some of which would be potentially classified as hazardous waste) and would require disposal within a lined landfill which would be capped on completion.

Some materials (albeit a small percentage) such as ferrous metals may be separated for recycling. It is estimated that the overall volume reduction for Magħtab (where much of the landfill comprises construction and demolition waste) may be in the region of 30% (i.e. about half of the volume of the C&D waste). Smaller volume reductions would be possible at Wied Fulija and Qortin.

There are extreme safety and environmental risks associated with such activities, primarily related to aerial emissions and control of cooling or washing waters associated with exposing, cooling and processing hot and combusting materials.

There would also be significant visual impact during the works (which could take many years, particularly at Magħtab) and there would be a need to utilise large areas of land close to the existing sites to act as process and storage areas during the works.

Although landfill mining is likely to have the best long-term benefits (as wastes are either re-used or disposed of in a controlled manner) these are unlikely to be compensated for by the significant negative short and medium term impacts caused by the works. Additionally, the cost of such operations may be prohibitively expensive particularly as:

- the potentially usable recovered products (essentially construction and demolition materials) currently have very little or no commercial value;
- there would be a need to place the remaining material in a fully engineered disposal facility (which could have impacts on Malta's waste management strategy); and
- unless surplus waste was translocated to a new disposal site, the sites would not be clean and the final landform would still be a 'landraise' (albeit of smaller dimensions than originally) with restricted afteruse potential.

8.5.8 Institutional Controls

A series of institutional controls could be implemented to ensure adequate health and environmental standards in conjunction with physical environmental controls or reclamation techniques deployed. Such measures may include statutory restrictions on groundwater abstractions to limit potential risks associated with drinking or irrigation using locally abstracted water. This would minimise any requirements for leachate control (by capping for example) but might be politically unacceptable particularly as the case is not proven (current impacts are low) and would require further monitoring and assessment.

Other institutional controls that could be implemented would include limitations on agricultural activity in the areas currently affected by aerial emissions and leachate pollution of groundwater (where this is used for agricultural purposes).

Such impositions would be difficult to enforce, probably socially unacceptable and would not alone address the key environmental hazards. However, as a minimum safety precaution it is suggested that the general public be denied open access to any of the sites in without a full restoration.

9. RESTORATION STRATEGIES

9.1 Guiding Principles

The guiding principles adopted in the selection of appropriate restoration strategies for each of the sites have been:

- to achieve improved environmental performance in the short, medium and long term;
- to address the most significant hazards (particularly those with health and safety implications) immediately;
- to ensure that no (significant) environmental deterioration is caused during restoration works;
- that restoration works are confined within existing site boundaries where possible with no significant demand for large tracts of adjacent land as temporary or permanent working areas or for long term storage / disposal unless essential for environmental control or for a viable after use;
- the selection of after uses that can be incorporated into the restoration process and can be achieved safely;
- the utilisation of generally proven or readily (regionally / locally) available technologies;
- adoption of cost effective techniques.

All the sites present significant challenges to the successful implementation of remedial strategies. It is considered essential that any techniques are subjected to pilot scale trials before full-scale deployment. If successful, such trials could readily be expanded and incorporated into the overall reclamation scheme.

In general, for each of the landfill sites the two key rehabilitation considerations of ensuring environmental control and providing a viable after use have proved to be incompatible. Options for each site have been devised; one a minimalist approach based on providing necessary environmental and safety control and the others identifying the additional works and resources required to enable the site to be beneficially used in the future.

Essentially, the restoration of all sites is based on a controlled stabilisation process followed by progressive restoration and revegetation to achieve a restoration landform suitable for recreational land-uses in the long term. The rehabilitiation process aims to minimise negative environmental impacts associated with:

- excavation of large quantities of potentially combusting and/or contaminated material;
- off-site transport of large quantities of excavated materials;
- import of significant quantities of restoration materials (e.g. for capping);
- use of scarce local resources (e.g. Blue Clay for capping).

At all three sites, options for the rehabilitation are limited due to the extensive overfilling that has necessarily taken place years to accommodate waste. The size of the sites and the fact that outer surfaces are sloped (mostly at steep angles) make large areas of the sites inaccessible to plant or equipment. This severely limits the potential for the installation of effective environmental controls and restricts significantly the range of potential after uses. In addition, the waste masses at Qortin and Wied Fulija are both located close to cliff edges restricting access for rehabilitation works in those areas.

The rehabilitation at each of the three sites will broadly involve:

- installation and maintenance of gas / emission control systems;
- minor reprofiling of the waste mass;
- gradual installation of a restoration cover; and
- development deployment of passive recreational afteruses on secured parts of the site.

It is envisaged that it may be many years (perhaps as much as 30 years in the case of Magħtab) before the full rehabilitation of each site is accomplished.

9.2 Magħtab

9.2.1 Site Constraints

Based on the development history Magħtab can be divided into four zones (Figure 9.1):

A the northern, seaward face;

B the main bulk of the central section of the landfill;

C the southern spur nearest to the reception area; and

D the formerly restored area to the west of the reception area, now handed back to the original owners and used for agricultural purposes

Zones A and B are undergoing extensive subterranean combustion and it is in these areas that the bulk of the incoming waste is likely to be placed over the period to site closure in 2004. Based on the large volume of waste likely to require accommodation at the site before closure an anticipated final landform has been devised increasing overall heights significantly (Figure 9.2). This further confirms that the potential for installing appropriate environmental control measures and adopting beneficial after uses at the site is very severely limited.

The stabilised waste in Zone C has already been excavated and screened to produce clean material for re-use as daily cover during the final phases of waste filling at the site. Zone D is former landfilled materials that have been restored for agricultural use. No additional rehabilitation works are proposed in these areas.

9.2.2 Outline of Rehabilitation Strategy

Emissions Control

It is not considered either safe or effective to attempt any significant rehabilitation works at the site in areas undergoing combustion until the subterranean fires have been extinguished or at least been brought under demonstrable control. It is also not considered practicable to attempt to extinguish the fires by conventional landfill fire fighting techniques because of:

- associated health and safety risks to on-site personnel;
- potential off-site impacts (associated with use of water as an extinguishing medium for example); and
- the likely limited efficacy of such techniques on such a large site with numerous hot / burning areas.

Instead, a system incorporating aerial emission control will be implemented in Zones A and B. This will involve a positive gas abstraction system involving a flexible modular system of wells, connecting pipework and gas treatment units (either flares and/or high temperature oxidation units). Such a system would limit emissions of landfill gases and gaseous, volatile and semi-volatile combustion products. The system would need to be maintained in effective working order for some considerable time (perhaps around 20 years) whilst combustion ceases naturally and the waste mass progressively cools.

Reprofiling

In order to install an effective system (targeted at the combusting areas) and to undertake surface treatments, it may be necessary to provide vehicular access routes around the waste mass. This will require the excavation, removal and re-deposition of waste. In addition, it will be necessary to re-profile the steep western and eastern slopes of the site to reduce the risk of slope instability in these areas. It will also be necessary to remove some material from the base of the northern face (Zone A) to accommodate the proposed realignment of the coast road through this area.

Waste materials excavated will be redeposited in a controlled fashion in Zone A, as this flank of the landfill is currently at a shallower angle than waste slopes elsewhere and there is therefore room for additional waste deposition (Figure 9.3). Excavated wastes that are excessively hot will be cooled before placement and it may be necessary to reprocess some of the excavated waste to generate a clean restoration layer.

Restoration

At the same time as the installation and management of an emission control system the treatment, covering and planting of the lower waste slopes will commence. The entire covering of the outer surface of the waste mass utilising locally produced restoration soils and indigenous species will take many years to achieve (perhaps 10 – 15 years assuming a restoration rate of 3 - 4 hectares per year). A programme to produce such soils (from compost) and the provision of nurseries to provide the necessary quantity of plants required to revegetate the site has already been initiated using internal government resources.

In the longer term, the western flank of Zone B may abut the proposed new engineered landfill at Għallis. In this event there is little merit in attempting a high-grade restoration for this area. Instead it is suggested that this area be stabilised and made available in future years for the deposition of waste (as part of the proposed Għallis development) after the installation of the appropriate barrier systems.

Institutional Controls

There is a potential threat to the quality of local groundwater resources in the wet season. This could be mitigated by the implementation of institutional controls restricting the abstraction of groundwater from the agricultural wells immediately to the east of the landfill. An assessment of the results of groundwater monitoring would enable such a decision to be taken. Ongoing long term monitoring would effectively identify whether the rehabilitation had successfully ameliorated any leachate generation that may be occurring (as the waste mass stabilises).

9.2.3 After Use

Before any consideration could be given to the deployment of an afteruse on the site, particularly any activity that allowed public access, there would need to be a degree of certainty that noxious emissions were controlled, there was no potential for fires to break out at the surface or that the ground may collapse suddenly due to voids closing up. This could only be achieved after a long, carefully monitored, rehabilitation period.

The northern flank may be suited to the development of passive recreational activities, such as walking, horse riding and the like (even a ski slope) and a track layout for this could be incorporated into the reprofiling required here although it may be many years before the trackways could be used.

9.3 Qortin

9.3.1 Outline of Rehabilitation Strategy

Reprofiling

A final landform for Qortin to encompass all the existing waste and further input up to site closure is proposed (Figure 9.4). Achieving this landform involves the removal of waste from within approximately 6 - 8m of the cliff edge, the slackening of side slopes and the limitation of the final height of the waste mound. These measures are considered necessary to ensure stability of the seaward face and to provide a visually acceptable land-form capable of sustaining restoration capping and planting.

The excess material produced by these recontouring works (in addition to the waste input from the next couple of years) would be deposited in a controlled manner in the area between the existing waste mound and the site entrance (i.e. over the previously restored wastes in this area). There may be a need to tackle the small near surface fires that currently exist if these have not burnt out before closure. This could be accomplished during the recontouring works when material is exposed and allowed to cool.

The completed landform would be covered with a locally processed inert waste and the near surface layer composed of soil forming materials and planted with indigenous species tolerant of local conditions.

Emissions Control

Due to the high organic waste inputs at Qortin landfill the site will produce landfill gases (principally methane and carbon dioxide but also some combustion gases) after waste filling ceases but the quantities produced are not considered to be sufficient to allow beneficial utilisation (e.g. energy production) or requiring the installation of a capping / sealing system for environmental protection. Instead, these will be controlled using a positive gas abstraction system involving a flexible modular system of wells, connecting pipework and gas treatment units (either flares and/or high temperature oxidation units). Such a system would limit emissions of landfill gases and gaseous, volatile and semi-volatile combustion products.

Institutional Controls

The potential threat to the groundwater quality during and immediately after periods of intense rainfall could be mitigated by the implementation of institutional controls restricting the abstraction of groundwater from the agricultural wells immediately to the south and south-east of the landfill. An assessment of the results of the all-year groundwater monitoring currently proposed would enable such a decision to be taken. Ongoing long term monitoring would effectively identify whether the rehabilitation had successfully ameliorated any leachate generation that may be occurring.

9.3.2 After Use

There are potential after uses for this site and alternative landforms have been devised to incorporate passive recreational uses (Figure 9.5). The recontoured waste mound would be reshaped with lower slope angles to encourage more extensive revegetation. The adoption of such a strategy would necessitate the movement of a significant portion of waste material to adjacent areas; the disused quarry to the south-west of the existing site being the optimal location.

Whichever restoration option is adopted it will take a number of years for covering and planting to be installed and become established sufficiently for the site to be used or become accessible to the public. During this period of interim restoration the gas generating potential of the waste would have also declined.

9.4 Wied Fulija

9.4.1 Outline of Rehabilitation Strategy

A phased approach to the rehabilitation of Wied Fulija is proposed. Firstly, the continuing fires and the emissions from these should be brought under control followed by restoration.

The use of an emission control system using wells, pipework and gas treatment similar to those at Magħtab is proposed to control the off-gases associated with on-going combustion at the site. This may take up to 10 years to ensure complete cessation of burning (Figure 9.6). It is considered to be too dangerous to undertake extensive rehabilitation works with heavy plant and machinery on the seaward site of the two waste mounds, although some minor excavation works and covering may be possible in this area provided appropriate plant is deployed.

As the combustion appears to be confined predominantly to the seaward waste slopes it is possible that some minor recontouring, covering and landscaping of the landward slopes could be achieved, which would enhance the appearance of the site and assist in its long term restoration although it would be difficult to incorporate any beneficial after use into this scheme. There is little scope for re-deposition of excavated materials within the site boundary. These materials would have to be taken off-site and redeposited as part of the restoration of Magħtab.

9.4.2 After Use

There are known to be many aspirational after uses for the site but it is not considered to be an ideal location to sustain a tourist or local passive recreational activity (there being more desirable locations in the near vicinity). Trackways could be constructed using processed inert waste ensuring adequate cover above the waste materials and the intervening areas could be covered and planted using local species.

Although it may be possible to include the development of the afteruse landform during the period when combustion management is active it would be safer to await cessation of burning before allowing public access to any part of the site.

9.5 Scheme Implementation

Before the restoration works are commenced environmental monitoring will be initiated to collect data relating to baseline conditions before restoration works and to monitor the impact of the works. It is proposed that the following are monitored:

- aerial emissions from gas control systems;
- surface gas emissions from waste;
- off-site groundwater quality;
- groundwater level;
- noise;
- off-site air quality (dust); and
- meteorological data.

Consideration needs to be given to the manner in which the rehabilitation works are to be implemented. The rehabilitation of each of the sites will take many years to complete and will comprise a series of measures and components (some occurring simultaneously, others sequentially) to be fully realised. A summary of the principal activities associated with rehabilitation works is presented in Table 9.1 together with an outline summary of the mitigation measures to minimise potential detrimental environmental impacts associated with the works. The rehabilitation process will require long-term commitment and management.

Table 9.1: Rehabilitation Process, Potential Impacts and Mitigating Measures

Site Activity	Potential Impacts									Mitigating Measures to be adopted
	Dust Generation	Landfill Gas Release	Combustion Gas Release	Combustion of Waste	Exposure of Contaminated Materials	Odour Generation	Litter	Noise	Slope Instability	
Site Reprofiling										
Excavation, processing and sorting of Waste	●	●	●	●	●	●	●	●	●	Temperature probing in advance of excavations to identify potentially areas affected by heating. Trial pitting in advance of works to identify potentially contaminated materials No excavation in areas of active combustion unless fires put out. Minimise size and depth of excavated areas (i.e. exposed waste) at any one time. Use of litter screens during excavation. Cover exposed working face in waste at the end of each day Monitor on-site and off-site air quality and off-site noise levels
Transportation of Waste	●		●	●	●	●		●		Only on-site haulage vehicles to be used Monitor on-site and off-site air quality Monitor off-site noise levels
Placement/Deposition of Waste	●				●	●	●	●	●	Minimise area of filling to less than 0.5 ha Only cooled waste shall be deposited. Placement of waste in thin (0.5 m) layers Waste to be compacted after filling Use of litter screens during waste placement Monitor on-site and off-site air quality and off-site noise levels
Gas Control System										
System Installation	●	●	●	●		●		●		Use of impact wells or rotary water flush drilling to install wells Limit penetration of wells to 5 m below ground surface Leak testing of all pipework and manifolds Monitor on-site and off-site air quality Monitor off-site noise levels
Operation		●	●	●		●				Balance system to optimise gas extraction and control Monitor system efficiency Control emissions of landfill/combustion gases with thermal destruction by flaring or use of thermal destructors to achieve set emission targets consistently. Use of granular activated carbon filters to remove combustion products from thermal treatment exhausts Monitor gas emissions from waste Monitor on-site and off-site air quality

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Figures

Plates

Appendix A

Gas/Temperature Monitoring

Appendix B

Soil Analyses

Appendix C

Water Analyses

Appendix D

Air Monitoring Analyses

Appendix E

Laboratory Gas Analysis

Appendix F

Ecological Surveys