Assessing the marine environmental quality of the coastal waters exposed to the Maghtab Solid Waste Disposal Site

FINAL REPORT

June 2004

SUBMITTED TO THE

ENVIRONMENT PROTECTION DIRECTORATE

Malta Environment and Planning Authority

By

Prof. Victor Axiak

CONTENTS

1. INTRODUCTION

In June 2003, the present consultant has been commissioned by the Environment Protection Directorate, (EPD) of the Malta Environment and Planning Authority (MEPA) to carry out an impact assessment of the Maghtab Solid Waste Disposal Site on the marine water quality of the inshore coastal waters.

1.1 Aim And Components of Study

The overall aim of the project was to contribute towards the assessment of how the Maghtab solid waste disposal site (SWDS) may be impacting on the marine environmental quality. This assessment is based on new information generated through surveys carried out over the period 2003-2004, as well as through archived data made available through surveys undertaken over the period 2001-2003.

The whole programme of investigations included three components, as follows:

a) Monitoring of water quality

Monitoring of basic water quality parameters was undertaken at 4 stations along the coastline in the vicinity of Maghtab. The parameters monitored included: water turbidity, chlorophyll a, and nutrients. Furthermore, microbiological monitoring was undertaken including total bacterial counts, faecal streptococci and organic carbon. These parameters were monitored before and after rainstorm periods.

b) Monitoring of sediment quality

Petroleum hydrocarbons as well as heavy metals were monitored in superficial marine sediments in the immediate vicinity of Maghtab, twice over the period 2003-2004.

c) Biomonitoring of Impact

The aim of this component was to provide a clearer and more comprehensive picture on the environmental impact that emissions and releases from the Maghtab landfill may be exerting on the state of health of marine organisms in the area. For this purpose, two biomarkers of stress were used: genotoxicity (a general biomarker for overall stress) and metallothionein induction (a specific biomarker of stress induced by heavy metals).

A First Progress Report was submitted to MEPA in July 2003, containing the results which had been obtained to date and a first assessment based on such preliminary results.

The present document is the Final Project Report. It includes a brief review of the Maghtab SWSD; the results of the three components of the present study as have been identified above, and a general assessment based on such results.

1.2 A brief overview of Maghtab SWDS

A substantial amount of literature has been published on the Maghtab SWDS, and therefore only a brief overview will be presented here.

The Maghtab SWDS (**Figure 1**) is located in the limits of Naxxar, on the northern coast of Malta. By 2000, it occupied a surface area of over 600,000 m^2, of which 64% had already been utilised and covered by waste. An outer boundary buffer zone exists around the landfill which is equivalent to 33% of the total area. The dimensions of the landfill are approximately 1500 m and 950 m from end to end. The height of the landfill is continuously increasing.

The site at the Maghtab area was never intended to be used as a landfill. The area, consisting mainly of a garigue environment, was considered as unproductive land. An agriculture rehabilitation scheme called the '*Izra' u Rabbi*' project proposed by the Department of Agriculture in the 1970s involved making the land more productive by placing layers of organic household waste and soil as a method of soil nutrient fertilisation. The project was never fulfilled, trees were never planted and instead the Maghtab area started to receive an increasing amount of waste. The area then started to be used as a landfill. Growing in size both laterally and vertically, the waste disposal site became the sole solid waste disposal location after Wied Fulija was closed down in 1996.

Until its closure in April 2004, the Maghtab site received a variety of waste categories including municipal solid waste, industrial waste (which contains a significant proportion of hazardous waste) and construction and demolition wastes. Although some separation at source may have occurred in some instances, this effort was fruitless once the waste was delivered to the site. **Table 1** shows the quantity of solid waste disposed at this site over 1998-2001.

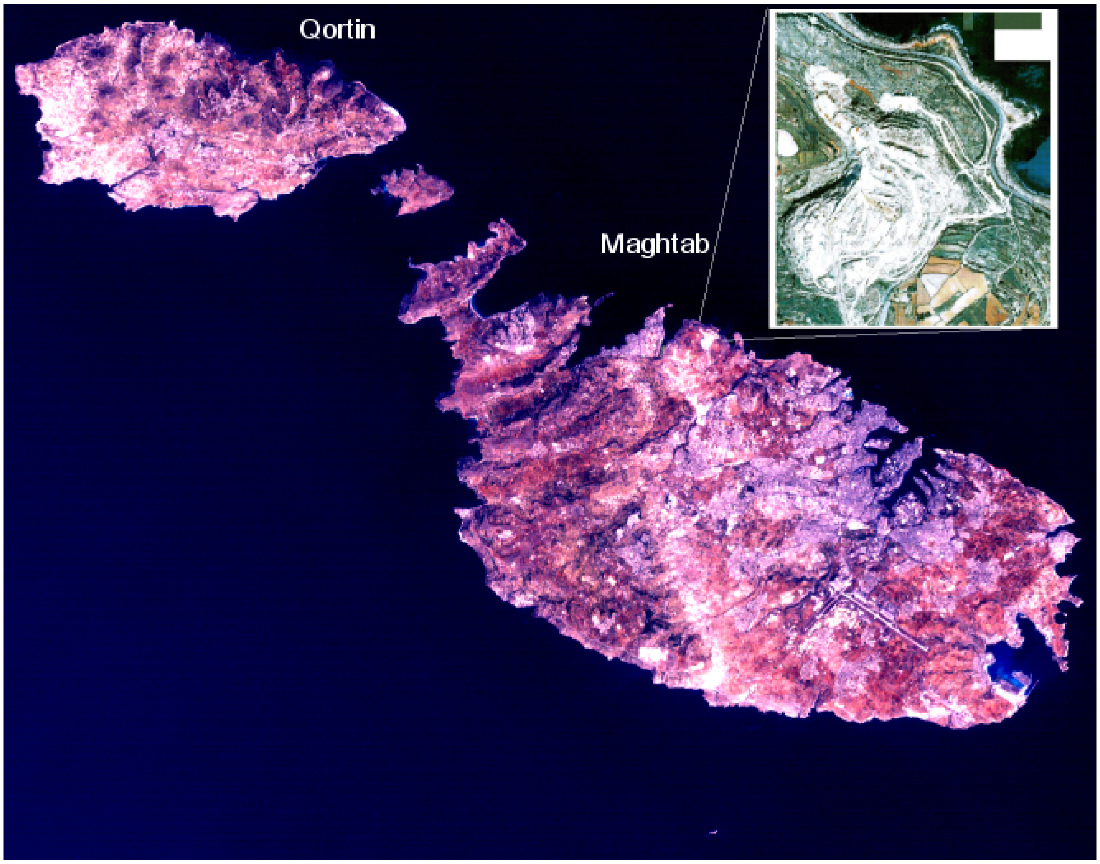

Figure 1. Location of the two main waste disposal sites: Il-Qortin in Gozo, and Maghtab in Malta. The insert shows an aerial overview of Maghtab.

Table 1. Quantities of waste deposited at the Maghtab waste deposit site

Year	**Municipal Solid Waste (tones/yr)**	**% by weight**	**Construction and Demolition tonnes/yr**	**% by weight**	**Industrial and other waste tonnes/yr**	**% by weight**	**Total tonnes/yr**
1998	113,510	12.70	692,053	77.40	88,540	9.90	894,103
1999	125,576	10.70	956,372	81.48	91,755	7.82	1,173,703
2000	167,230	11.86	1,198,971	85.05	43,441	3.08	1,409,642
2001	188,326	16.22	939,548	80.93	33,005	2.84	1,160,879

Throughout its history the Maghtab SWDS has never been properly managed and its immediate location to the shoreline has always given rise to concerns regarding its potential impact on the marine environment.

The research group of the present consultant produced the first preliminary assessment of the potential impact of the SWDS on the marine environment, in 1999 (Saliba, 1999). Since then, the same research group conducted a number of investigations with the aim of contributing further data and information for such an assessment.

In 2002, consultants Scott Wilson Kirkpatrick & CO. Ltd., were commissioned by the Government of Malta to undertake a scientific profile of Malta's landfills. Preliminary results as arising from this study and as reported in the local media (The Times, Nov 23. 2002) show that while potentially hazardous materials were found to be present at all landfills, there was no detectable seepage into the ground water, nor in the marine environment close to Maghtab. The final report has not yet been published, and was not available to the present consultant.

Atmospheric emissions from Maghtab include dust as well as a range of chemicals (partly resulting from slow combustion within the landfill). A significant amount of these airborne pollutants may end up in the marine environment through atmospheric fallout and deposition.

The Maghtab SWDS is located on the periphery of the groundwater lens. According to the Water Services Corporation, groundwater flow under this site is in the direction of the sea, rather than inland. This seems to constitute a safeguard against pollution of groundwater by landfill leachate. Any possible contribution from the landfill would result in a marked increase in concentration from the inflow to the outflow region (Saliba, 1999). The SoER, 1998 reported the analyses of groundwater extracted from boreholes at the Fulija and Maghtab in 1995. These analyses did not indicate significant groundwater pollution by leachate from deposited waste. On the other hand, Saliba (1999) suggested that there was an increase in the concentration of potentially toxic metals of samples taken from the inflow and outflow regions of the water table in the immediate vicinity of Maghtab.

This same study (Saliba, 1999) also produced preliminary data indicating that the Maghtab site is a potential source of marine pollution, particularly heavy metals.

2. IMPACT ON WATER QUALITY

2.1 Nutrients, Primary Productivity and Water Transparency

2.1.1 Surveys and Methodology

Four surveys were carried out over the period 2003-2004: 25th June 2003, 8th January; 23rd March and 28th May 2004. Water parameters were monitored at surface, at four stations along the Maghtab coastline, as well as at four stations off Qawra Point and in St. Paul's Bay, which may serve as reference sites (being exposed to other anthropogenic pressures, but most likely not to be exposed to impact by Maghtab disposal site). The location of these monitoring stations is shown in **Figure 2**.

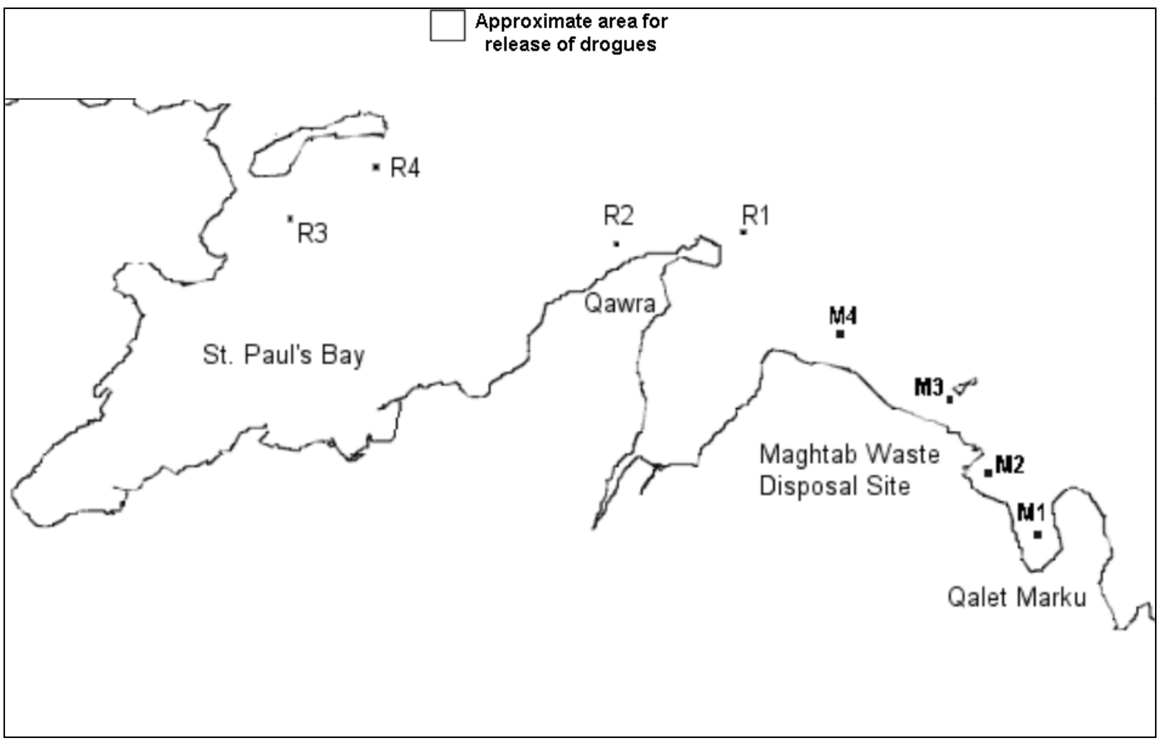

Figure 2: Location of water quality monitoring stations. Approximate area for release of drogues for surface and subsurface sea currents is also shown.

The various water parameters which were monitored include: temperature; salinity; water visibility and transparency; Chlorophyll a and dissolved nutrients.All surveys were undertaken between 09.00 and 11.00 hours.

Temperature, salinity, chlorophyll ***a,*** and water transparency were measured *in situ* by means of electronic probes as follows:

Temperature:	Eil Type M.C.5 Induction Meter
Salinity:	Eil Type M.C.5 Induction Meter
Chlorophyll ***a***:	Submersible Spectrofluorimeter (Minitracka)
Water Transparency:	Submersible Transmissometer, 660nm
Dissolved Oxygen	Oxygen Meter

All electronic probes were immediately calibrated prior use. The temperature/salinity meter was calibrated against standard seawater at room temperature. The spectrofluorimeter was calibrated against standard concentrations of chlorophyll ***a*** dissolved in acetone (Sigma).

The transmissometer used in this survey measures beam attenuation at 660 nm. It has an optical path of 25cm. Its calibration involves the measuring of its voltage output at 100% transmission, at 91.3% transmission (pure distilled water), and then at 0% transmission (blocked beam). The water transparency is then measured in terms of a beam attenuation coefficient.

For a monochromatic beam travelling through a water column containing suspended particles, light loss is either by absorption into other forms of energy, or by scatter outside of the collimated beam. The amount of light loss depends upon the length of water column (25cm in this case) and the coefficients of light absorption and light scatter by the particles suspended in the water. The beam attenuation coefficient includes both absorption and light scatter losses.

For nutrient analysis, water samples were collected from the surface by a 3-litre Van Dorn all plastic water sampler. Samples were stored in polycarbonate bottles and transported to the laboratory within a maximum period of 8 hours. They were then stored at -22^{o} C for a maximum period of 5 days. Dissolved nitrates (and nitrite) and phosphate levels were measured according to Parsons *et al*. (1984).

Furthermore, data on sea current velocities and directions in the area are being reported here. This information was obtained over the period September 2003 to February 2004 using the Lagrange Method. The drogues employed for this purpose had been described by Axiak (2003). Drogues were released at one site off St. Paul's Bay as indicated in **Figure 2**, at surface and at 5m depth. Their position was monitored by GPS (Global Positioning System) for a given time period..

2.1.2 Results

The results are presented in **Tables 2** to **5.**

Table 2: Water parameters as measured at surface at the different stations on the 25th June 2003.

Station	field coordinates		Temperature	Salinity	Chlorophyll A	Water Transparency	Dissolved Oxygen	Nitrates	Phosphates
		Units	*degree C*	*ppt*	*ug/L*	*BAC*	*% saturation*	*ug-at N/L*	*ug-atP/L*
M1	35.56.736	14.27.108	26.5	37.2	0.252	0.195	88.6	6.487	0
M2	35.56.963	14.26.852	25.3	38.3	0.229	0.247	97.0	49.995	0
M3	35.57.198	14.26.749	25.4	38.4	0.420	0.518	97.1	80.253	0
M4	35.57.272	14.26.508	25.6	38.2	0.185	0.231	89.9	5.272	0
R1	35.57.753	14.25.916	25.6	38.4	0.000	0.500	92.4	0.534	0
R2	35.57.682	14.25.376	25.8	38.2	0.172	0.252	93.4	0.088	0
R3	35.57.778	14.24.330	25.8	38.0	0.000	0.340	90.9	0.000	0
R4	35.57.833	14.24.390	25.9	38.1	0.261	0.397	93.2	na	0

0 = below detection limit
Locations of various stations are shown in Figure 2.
BAC = Beam attenuation Coefficient (m^{-1})

Table 3: Water parameters as measured at surface at the different stations on the 8th January 2004.

Station	Temperature	Salinity	Chlorophyll A	Water Transparency	Dissolved Oxygen	Nitrates	Phosphates
	degree C	*ppt*	*ug/L*	*BAC*	*% saturation*	*ug-at N/L*	*ug-atP/L*
M1	15.3	37	1.279	0.189	98.9	3.411	0.002
M2	15.4	37.5	0.658	0.166	100.6	7.544	0.012
M3	15.4	37	1.040	0.176	96.9	10.221	0.110
M4	15.8	37.4	1.113	0.183	97.3	15.112	0.002
R1	15.3	36.9	0.962	0.136	97.4	2.111	0.000
R2	15.3	37	0.876	0.170	99.52	1.145	0.001
R3	15.8	38.0	0.991	0.176	96.9	0.443	0.002
R4	15.8	38.1	0.561	0.132	96.8	0.132	0.001

Table 4: Water parameters as measured at surface at the different stations on the 23rd March 2004.

Station	Temperature	Salinity	Chlorophyll A	Water Transparency	Dissolved Oxygen	Nitrates	Phosphates
	degree C	*ppt*	*ug/L*	*BAC*	*% saturation*	*ug-at N/L*	*ug-atP/L*
M1	15.1	36.4	0.764	0.198	95.2	3.33	0.222
M2	15.1	36.3	0.499	0.199	98.3	0.28	0.000
M3	15.1	36.4	0.439	0.194	97.4	2.74	0.000
M4	15.1	36.4	0.377	0.197	95.4	0.69	0.000
R1	15.1	36.4	0.586	0.200	95.2	3.79	0.131
R2	15.1	36.4	0.370	0.208	95.6	2.19	0.000
R3	15.1	36.3	0.787	0.299	94.9	1.20	0.000
R4	15.1	36.3	0.479	0.293	96.7	0.25	0.013

Table 5: Water parameters as measured at surface at the different stations on the 28th May 2004.

Station	Temperature	Salinity	Chlorophyll A	Water Transparency	Dissolved Oxygen	Nitrates	Phosphates
	degree C	*ppt*	*ug/L*	*BAC*	*% saturation*	*ug-at N/L*	*ug-atP/L*
M1	19.7	37.4	0.152	0.215	98.6	4.347	0.001
M2	19	37.3	0.217	0.212	95.0	2.118	0.002
M3		37.4	0.230	0.218	95.1	1.221	0.101
M4	19.6	37.2	0.151	0.211	97.9	2.272	0.034
R1	19.9	37.4	0.120	0.250	95.4	1.534	0.011
R2		37.2	0.272	0.351	95.4	1.088	0.001
R3	19.4	37.0	0.100	0.340	93.9	1.020	0.022
R4	19.1	37.1	0.441	0.347	94.2	2.114	0.031

Figure 3 shows graphically the frequency distribution (percentage occurrences) of sea current directions over the period March 2003 to February 2004, in a locality off St. Paul's Bay. This data was compiled in connection with another water quality monitoring programme in this area. No current measurement has been performed in the immediate vicinity of the Maghtab coastline. Nonetheless, it may be expected that the data as indicated in **Figure 3**, is also applicable to this area, and if anything, the sea currents (both at surface and at subsurface) would be expected to flow along the shoreline in the general direction towards the E to SE.

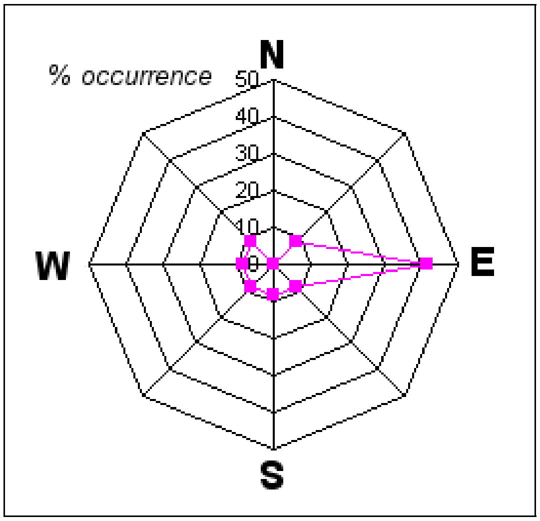

Figure 3: Frequency distribution of sea current directions towards the various geographical sectors, over the period March 2003 to February 2004.

Data presented in **Tables 2** to **5** suggest that no anomalies in the levels of chlorophyll A, water transparency, dissolved oxygen and dissolved phosphates could be detected in waters along the Maghtab coastline, when compared to reference stations.

With respect to the levels of dissolved nitrates (and nitrites), a single factor analysis of variance on the pooled data for all surveys showed that while the mean level along Maghtab coastline was 12 times as much as that recorded for the reference sites, this difference was not statistically significant (at $P = 0.059$). This was due to the high range of values being recorded off Maghtab especially during June 2003.

2.2 Effects on Microbiology of Inshore Waters

2.2.1 Surveys and Methodology

Microbiological levels of total marine bacteria and of faecal streptococci, as well as levels of particulate organic matter were monitored at 5 fixed stations along the Maghtab coastline, and at two reference sites (Salina Bay, and Cirkewwa) from the 5th February up till the 15th March 2003. The period coincided with occasional heavy rainfalls. Samples were collected from surface waters along the shoreline, approximately every 2 to 8 days. During this period, a total of 15 surveys were made.

Location of sampling stations is shown in **Figure 4**.

Total marine bacteria were monitored using Zobell 2216E marine agar as a medium for Total Bacterial Counts while Slanetz and Bartley medium was used for the enumeration of faecal streptococci. Determination of levels of particulate organic carbon was conducted using the wet oxidation with dichromate technique.

2.2.2 Results

Figures 5, 6, and **7**, which show the mean values for the respective parameters as measured at each station for the whole period.

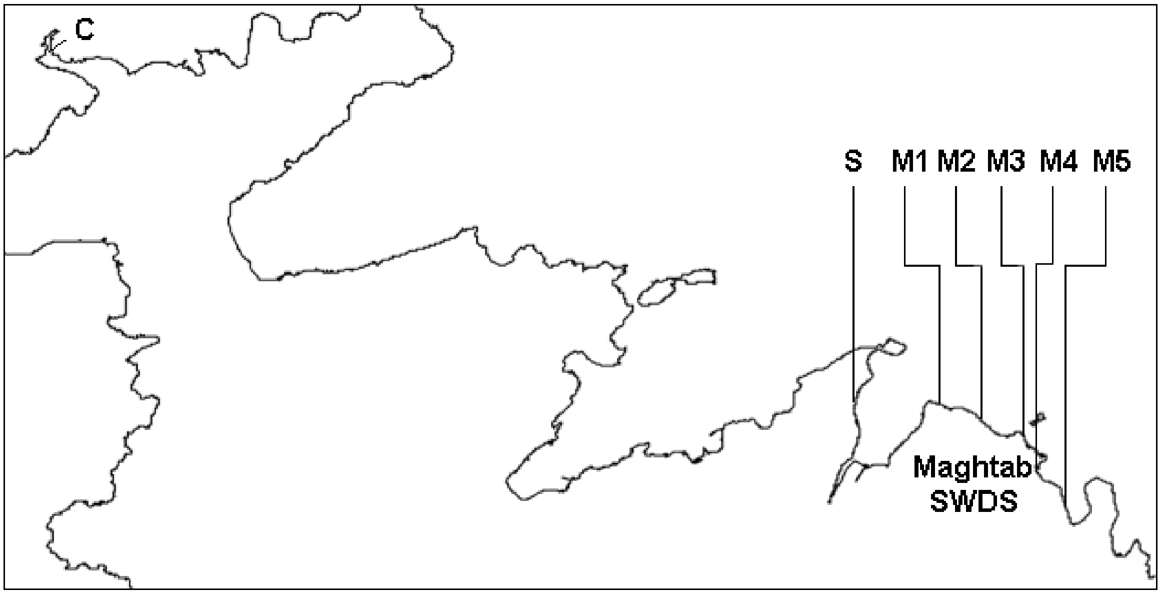

Figure 4: Location of monitoring stations for microbiological monitoring.

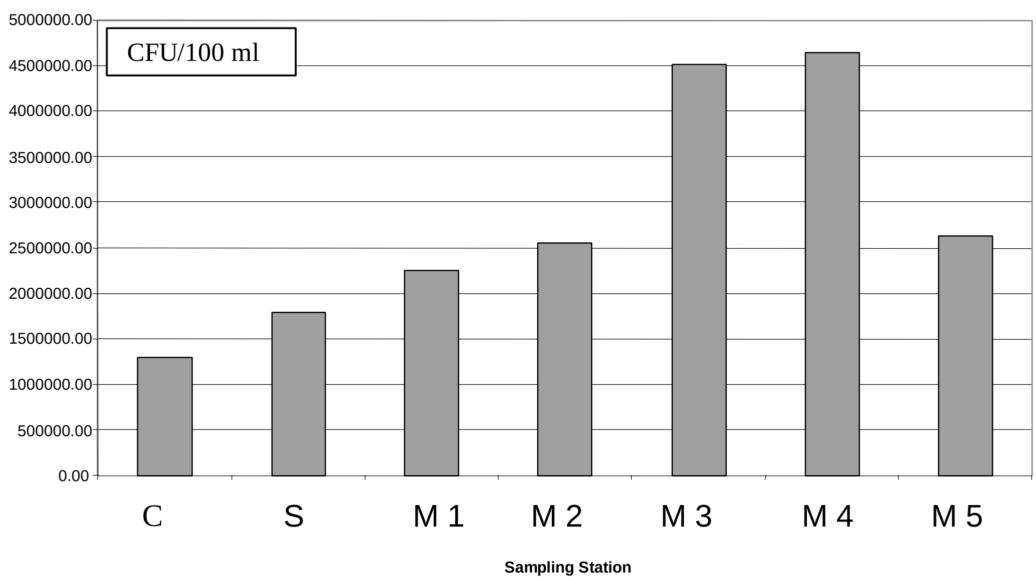

Figure 5: Mean levels of total marine bacteria as measured at each station over the period of investigation (C= Cirkewwa; S = Salini; M1 to M5 = Maghtab Stations)

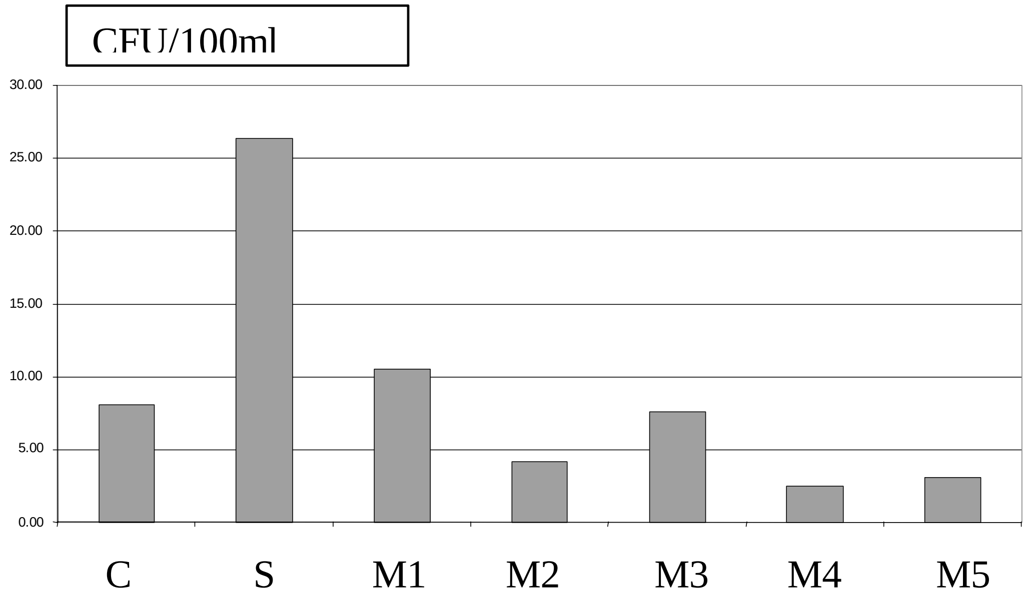

Figure 6: Mean levels of faecal streptococci as measured at each station over the period of investigation (C= Cirkewwa; S = Salini; M1 to M5 = Maghtab Stations)

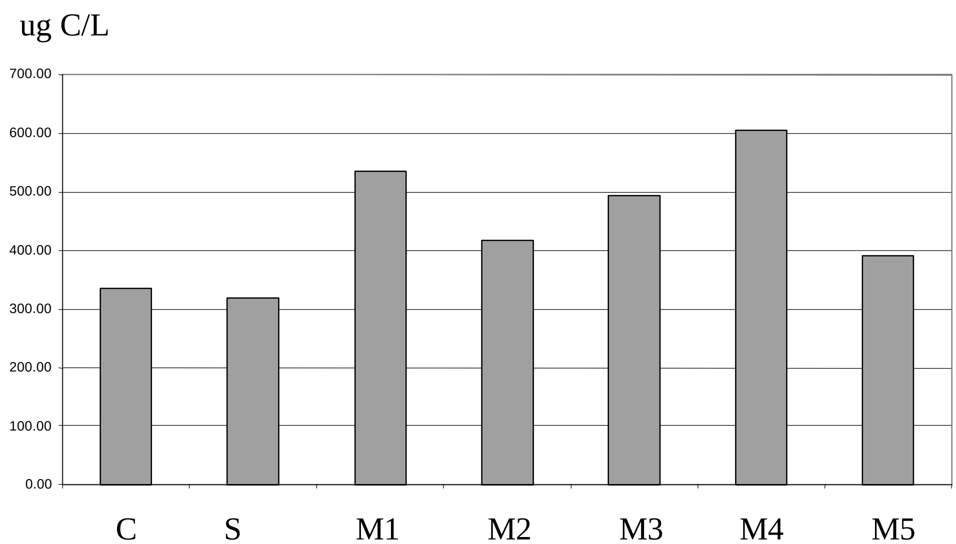

Figure 7: Mean levels of particulate organic carbon as measured at each station over the period of investigation (C= Cirkewwa; S = Salini; M1 to M5 = Maghtab Stations)

The results show that levels of Total Bacterial Counts (TBC) were consistently and considerably higher at the investigated sites at the Maghtab area that those obtained from the control sampling stations at Cirkewwa and Salina. The station at Cirkewwa had an average value of $1.30X10^6$ CFU ml^{-1} and the one at Salina with a value of $1.79X10^6$ CFU ml^{-1}. On the other hand the 5 sampling stations at the Maghtab area (M1 to M5) had values of $2.25X10^6$ CFU ml^{-1}, $2.55X10^6$ CFU ml^{-1}, $4.51X10^6$ CFU ml^{-1}, $5.0X10^6$ CFU ml^{-1}, and $3.0X10^6$ CFU ml^{-1} respectively.

The values were highest for the stations labeled M3 and M4. These are the two stations located closest to the contour of the landfill, with the coastline of the M4 sampling station being only approximately 50 metres away. The significance of the Maghtab stations in relation to TBC was also confirmed by the ANCOVA.

On the other hand, in the case of faecal streptococci (FS), counts as recorded along the Maghtab coastline were generally lower than those reported at Qawra. The station at Cirkewwa had an mean value of 8.09 CFU ml^{-1} and the one at Salina with a value of 26.36 CFU ml^{-1}. The 5 sampling stations at the Maghtab area (M1 to M5) had values of 10.49 CFU ml^{-1}, 4.21 CFU ml^{-1}, 7.64 CFU ml^{-1}, 2.51 CFU ml^{-1} and 3.08 CFU ml^{-1} respectively. One likely source of FS is agricultural water runoff (which often includes traces of animal manure), and the reference stations (particularly the station at Salina) are known to be exposed to this type of contamination.

With respect to total particulate organic carbon (POC), levels were higher along the Maghtab coastline, than at the control stations. The station at Cirkewwa had an average value of 334 mg Carbon m^{-3} and the one at Salina with a value of 318 mg Carbon m^{-3}. On the other hand the 5 sampling stations at the Maghtab area (M1 to M5) had values of 534 mg Carbon m^{-3}, 416 mg Carbon m^{-3}, 493 mg Carbon m^{-3}, 604 mg Carbon m^{-3} and 390 mg Carbon m^{-3} respectively. As in the case of TBC, the values are highest for the station M4, which is the station, located closest to the contour of the landfill and lowest for the two control sites at Cirkewwa and Salina.

On a number of occasions, the levels of TBC and of POC concentrations were observed to increase after rainfall. However this trend was not always evident after each rainfall event and hence the results obtained regarding affect by rainfall are inconclusive. ANCOVA confirmed that as a variable factor rainfall was not a highly significant element in the determination of TBC, FS and POC.

To conclude, the above results show that total bacterial counts in Maghtab stations were higher than those recorded at both reference sites. Furthermore such total bacterial counts increased somewhat immediately after rainfall periods. One explanation for such data is that leachates and/or surface runoff from the Maghtab solid waste disposal site are reaching the marine environment, enriching its organic carbon content, and this is leading to a general increase in total bacterial counts of the locality.

On the other hand, there is no evidence to suggest that water runoff is directly carrying any microorganisms into the marine environment, though this possibility may not be excluded.

3. IMPACT ON MARINE SEDIMENT QUALITY

3.1. Surveys and Methodology

For the purpose of this monitoring programme, superficial sediments rather than the water column were used as the environmental phase to be monitored to assess levels of pollution by heavy metals and petroleum hydrocarbons (PHC). This is because it is well known that monitoring of such contaminants in the water phase often yield unreliable results due to the heterogeneous distribution of this class of compounds in water as well as the rapid temporal fluctuations that may occur at the same site. On the other hand, superficial sediments are generally considered to be a most reliable environmental phase to monitor this form of pollution over time, since they are well known to act as sinks for these classes of marine contaminants. However, superficial sediments are also a significantly dynamic phase, due to natural forces, such as natural deposition or loss of sediments, biological perturbation, as well as dredging and other anthropogenic activities..

Furthermore, it may be argued that any increase loads of contaminants in the marine sediments along the Maghtab SWDS, may be due to other land-based pollution sources such as coastal road traffic and agricultural run-off.

All these factors will need to be taken into consideration in the following assessment.

For the purpose of the present investigation, the following marine sediment samples were collected:

Qalet Marku	4 samples	7th July 2003.
Qalet Marku	3 samples	December 2003
Balluta	1 sample	December 2003

Marine sediments along the Maghtab coastline were only available from Qalet Marku, since the rest of the near-shore sea bottom is rocky. On the other hand, much of the land-run off from the Maghtab SWDS (as well as from the adjacent valley and coastal road) may be expected to lead to Qalet Marku.

In each case, superficial sediments (top 3 to 5 cm) were collected by divers or by a grab sampler. Samples were stored at -22°C until analysed.

Furthermore, archived data available to the present consultant were also used to assess the likely impact of the Maghtab SWDS on the quality of marine sediments.

Heavy metal analysis was carried out on dried samples. Excess water was removed by filtration and the residue dried at 105 ^{o}C prior to weighing and analysis on AAS.

In comparing reported levels of petroleum hydrocarbons in the environment, it is important to note that different analytical methods often do not yield comparable quantitative data. In the present monitoring programme UV spectrofluorimetric analysis was used as the standard methodology. This methodology has been used for monitoring oil pollution in most Mediterranean states. Furthermore, it yields consistent and reliable data, and its minimum detection level is low (0.01 ug Chrysene Equivalents/ g Dry Weight).

On the other hand, this analytical methodology is sensitive to narrow range of PHC aromatic components, and its level of discrimination between different classes of hydrocarbons (e.g. hydrocarbons of recent biogenic or petroleum origins) is low. This latter limitation may however be satisfactory controlled through proper chromatographic clean-up of extracts. In any case, a significant amount of archived data is available for levels of PHC over a wide geographical extent of monitoring stations (which include relatively clean and pristine inshore areas, as well as port areas). This enabled the present consultant to establish background levels of hydrocarbons. Such background levels are most likely derived from recent biogenic sources, rather than from pollution by petroleum hydrocarbons. Concentrations, which exceed such background levels, are more likely to be of petroleum origin.

Prior to analysis, sediments were sieved through a 1mm mesh size. They were then refluxed in methanol and potassium hydroxide for 90 minutes. Hexane extraction of the methanol filtrate was then carried out, with the hexane extract being dried over anhydrous sodium sulphate, reduced in volume in a rotary evaporator and cleaned on 5% deactivated alumina. Elution of the clean-up column was carried out in three fractions: hexane, dichloromethane, and a mixture of both.

PHC were then quantified by measuring their fluorescence on a JASCO FP-750 spectrofluorimeter at 310 nm excitation and 360 nm emission wavelengths (band widths 10nm). Quantification was carried out against Chrysene standards, and levels of PHC expressed as ug Chrysene Equivalents per gramme dry weight of sediment. Reagent blank runs were periodically carried out.

3.2 Results

3.2.1 Heavy Metals

These are presented in **Table 6**, along with the levels of heavy metals as monitored in 1998/99 at the same site, as well as at a clean reference site (Ramla l-Hamra) using the same analytical method (AAS). In addition, this table shows the levels of heavy metals in marine sediments collected from near-shore sites exposed to significant coastal traffic. These sites are: MXett in front of Fortina Hotel; St. George's Bay, M"Xlokk; St. Julian's Bay. Sampling and analysis for such sites were carried out in October 2001.

These data confirm the findings in 1998-99 that the levels of most heavy metals as monitored in marine sediments exposed to leachates from the Maghtab waste disposal site are significantly higher than in the reference site. Furthermore, except for manganese and arsenic there is evidence that levels of heavy metals in marine sediments at Qalet Marku have increased significantly over the past 3 to 5 years.

It may be argued that marine sediments at Qalet Marku may be exposed to a range of land-based discharges and not only to leachates or surface run-off from the Maghtab SWDS. In particular, coastal traffic may be the source of a range of heavy metals due to road run-off as well as atmospheric fallout onto the marine environment. There is no doubt that the increased heavy metal loads in marine sediments may not be uniquely attributed to the Maghtab SWDS and it is quite reasonable to expect that such an inshore area as Qalet Marku would be exposed to a range of land-based sources.

However, for the purpose of assessing the environmental impact of this SWDS, we need to establish: (a) to what extent may this SWDS be contributing to these increased heavy metal loads; (b) to what extent are such loads causing an impact on the biological resources of the area. Evidently, the presence of multiple sources of pollution in a particular coastal area, is bound to increase the biological significance of any individual source, rather than reduce it.

In order to be able to quantify the contribution of the Maghtab SWDS to the increased heavy metal loads in the marine environment of the area, relative to other sources, a much more extensive and long-term monitoring programme would be required than the present investigation. Nonetheless, the data presented here may be used to reach some preliminary conclusions.

Table 6: Levels of heavy metals in marine sediments exposed to the Maghtab solid waste disposal site, and in reference site.

Station		Lead	Nickel	Copper	Chromium	Manganese	Cadmium	Arsenic	Mercury	Zinc
Qalet Marku 1998-1999	**mean**	**77**	**9**	**11**	**14**	**23**	**0**	**3**	**na**	**na**
	sd	44	1	4	2	2	0	1		
	n	3	3	3	3	3	3	3		
Qalet Marku July 2003	**mean**	**311.5**	**93.6**	**70.6**	**117.2**	**na**	**2.9**	**na**	**2.9**	**763.3**
	sd	118.9	23.2	23.7	36.4		0.8		1.5	167.1
	n	4	4	4	4		4		4	4
Qalet Marku Dec 2003	**mean**	**247.0**	**87.1**	**248.3**	**107.3**	**22.5**	**1.7**	**1.6**	**3.9**	**488.7**
	sd	152.5	26.5	140.4	30.1	10.5	1.6	0.6	2.9	156.2
	n	3	3	3	3	3	3	3	3	3
Balluta Dec 03		211	55.7	323	47	16.9	1.04	1.3	3.27	406
Coastal sites exposed to road traffic . [(a)]	mean	8.9	na	55.7	5.1	na	0.0	na	0.0	na
	max	35.4		157.0	20.3		0.0		0.0	
Ramla l-Hamra 1998-99		**5**	**7**	**4**	**14**	**43**	**0**	**9**	**na**	**na**

0 = below detection limit

(a) = Coastal sites (total 4) exposed to significant road traffic: MXett in front of Fortina Hotel; St. George's Bay, M"Xlokk; St. Julian's Bay. Sampling and analysis carried out in October 2001.

A single sample of marine sediment from Balluta was collected in December 2003, and analysed on the suggestion of the PCCU itself. This area was considered to be exposed to heavy traffic density but not affected by a solid waste dump. However, it is worthwhile to note that this area is unfortunately also exposed to periodic and frequent discharges of raw sewage from coastal sewage pumping stations, which may also carry significant levels of heavy metals. Therefore, archived data for heavy metals from other inshore coastal areas, which are similarly exposed to heavy coastal traffic but less so to sewage pollution, have been included in **Table 6**.

Some observations and conclusions are now made with respect to the individual heavy metals analysed for.

Marine sediments from Qalet Marku evidently carry significantly high levels of lead, and usually such levels exceed normal Mediterranean background levels (UNEP, 1996) by at least a factor of 12. Local coastal sites exposed to significant coastal traffic exhibit levels of lead in the region of 9 mg/kg DW, with maximum levels reaching 35 mg/kg DW. The single sediment sample from Balluta exhibited a lead level of 211 mg/kg DW, while the marine sediments from Qalet Marku exhibited an overall mean level of 284 mg/kg DW for the period under review, with maximum levels reaching 442 mg/kg DW.

Similarly, sediments from Qalet Marku carry high loads of nickel, even with respect to sediments from Balluta.

A relatively high level of copper (323 mg/kgDW) was found in the single sediment sample from Balluta. Sediments from Qalet Marku had a mean copper level of 248 mg/kg DW with the highest recorded level being 403 mg/kg DW. All these reported levels were significantly higher that the mean level of copper from inshore coastal areas exposed to road traffic (mean: 55.7 mg/kgDW).

With respect to chromium, the mean levels from Qalet Marku were always higher than the level reported for Balluta or for the other areas.

Manganese levels from Qalet Marku were found to be higher than that reported for Balluta. However the relatively high levels of this metal from Ramla (Gozo) indicate that this may be due to natural occurrence. The same observations apply to arsenic.

Levels of the toxic metals cadmium and mercury from sediments collected from Qalet Marku were similar or slightly higher than that reported for Balluta. However, levels of cadmium and mercury from areas exposed to coastal road traffic were generally below detection limit.

The levels of zinc from Qalet Marku were quite high and at times exceeded the normal background levels for the Mediterranean (UNEP, 1996) by at least a factor of 15. The reported level of zinc from Balluta was also high but not as high as levels reported from Qalet Marku.

3.2.2 Petroleum Hydrocarbons

The mean level of PHC for the four sediment samples collected from Qalet Marku in June 2003, was estimated to be 16.1 ug CE/gDW (sd: 9 ug CE/gDW), while for the three samples collected in December 2003, this was estimated at 12.5 ug CE/gDW (sd: 10.1 ug CE/gDW). The level of PHC from Balluta in December 2003 was found to be 18 ug CE/gDW.

Figure 8 shows graphically a synopsis of results for the levels of PHC in sediments collected from Qalet Marku over the period 1998 (Saliba 1999) to 2003 (present study). It also shows PHC levels in other relevant areas. It is worth to note that all levels indicated have been reported by the research group of the present consultant using identical analytical methodology.

The overall mean PHC level of 20 ug CE/gDW for Qalet Marku was found to be statistically significantly higher than that recorded for clean reference areas ($P< 0.00001$) and that recorded for near-shore coastal areas exposed to road traffic ($P=0.0001$). Indeed the mean level for such near-shore areas (4.9 ug CE/gDW) was found to be at least twice as high as that reported for clean areas (2.1 ug CE/gDW), with this difference being statistically significant at $P = 0.04$). All statistical tests were carried out using single factor ANOVA.

These data suggest that while the levels of PHC in Qalet Marku show remarkable variations with time (as well as with location), they are significantly higher than those that would be expected in areas exposed only to road traffic.

Finally it is worthwhile to note that levels of PHC in harbour areas and semi-enclosed creeks in urban areas (usually exposed to heavy boat traffic as well as occasional sewage pollution) are usually quite higher than those reported at Qalet Marku and usually range in the region of 40 ug CE/gDW (with occasionally maximum levels exceeding 500 ug CE/gDW). Therefore, the reported single level of 18 ug CE/gDW for Balluta may be considered as quite typical of levels in similar semi-enclosed creeks in urban areas. However, in no way may Qalet Marku be considered as semi-enclosed and as lying in an urban area. Evidently, while traffic along the important coastal road of Maghtab is contributing to the high levels of PHC in marine sediments from Qalet Marku, the SWDS must also be contributing to such levels in significant amounts.

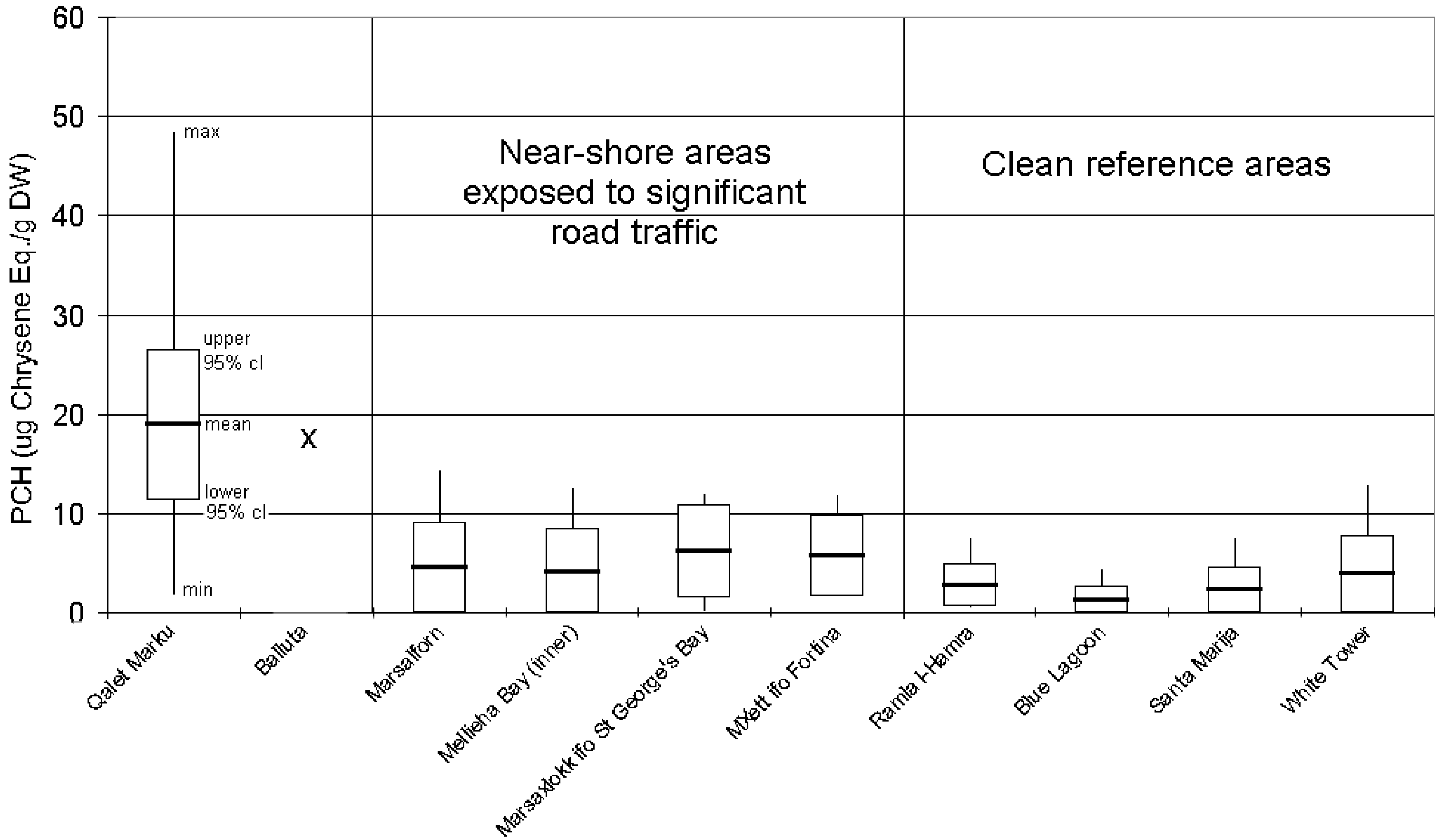

Figure 8: Levels of petroleum hydrocarbons or hydrocarbons as measured in marine sediments collected from Qalet Marku over the period 1998-2003. Also shown is the level of PHC from Balluta (Dec 03), and for other coastal sites (2000-2003).

To conclude, sediment quality in Qalet Marku is relatively low due to increased levels of certain heavy metals as well as of petroleum hydrocarbons. This is quite unlike similar open inshore areas located in non-urban areas. The data presented in the present study suggest that the Maghtab SWDS is one important land-based source contributing to such marine pollution, though coastal road traffic (and possibly other sources) may also possibly contribute to this situation. Of the heavy metals, lead and zinc in particular appear to reach relatively high levels, but other metals such as copper, nickel, cadmium and mercury also feature quite prominently.

4. BIOMONITORING OF IMPACT

As already indicate in **Section 3**, for the purpose of assessing the environmental impact of this SWDS, we need to establish: (a) to what extent may this SWDS be contributing to these increased heavy metal loads; (b) to what extent are such loads causing an impact on the biological resources of the area. The level of stress of marine contamination on marine organisms may be assessed through a variety of biomonitoring indicators. For the purpose of the present study, two bioindicators of stress have been used, namely genotoxicity in chitons, and metallothionein induction in limpets.

4.1 Genotoxicity in Chitons

4.1.1 Background and Methodology

Various marine contaminants including some heavy metals and certain components of petroleum hydrocarbons are known to exert a negative impact on the integrity of the genetic material of certain marine organisms. This impact may be considered to be extremely significant since it may lead to long-term changes in populations, which would reduce their chances of survival. Therefore genotoxicity is considered to be a very important and general index of biological stress.

For the purpose of the present investigation, specimens of the chiton, *Lepodochitona corrugata* were collected from the Maghtab coastal area, as well as from Ghar Lapsi (to serve as a reference site) during the period February-April 2003. The level of DNA integrity was determined using single strand breaks in chiton muscular tissue through the standard alkaline elution methodology (UNEP/RAMOGE, 1999). The method determines the degree of DNA breakages through the percentage retention of DNA as it flows through a filter paper in a properly buffered solution. DNA content was measured using spectrofluorimetry. Whenever possible, replicate runs from control and impacted sites were employed at the same time so as to limit systematic errors due to the experimental protocol.

4.1.2 Results

The results as expressed in % retention of DNA on filter, are shown in **Table 7**.

Table 7: Percentage retention of DNA (as an index of DNA damage) for muscular foot tissue of *Lepodochitona corrugata* populations from Maghtab area and from Ghar Lapsi (reference site).

	GHAR LAPSI	MAGHTAB
mean	62.70	61.21
replicates	15	6
standard deviation	9.8	11.2
max	74.5	71.2
min	37.8	40.8
95% confidence intervals	4.9	9.0

It is to be noted that the lower the % retention of DNA on the elution filter, the more numerous would be the DNA breakages.

These data show that at least for this chiton bioindicator species, there is no statistically significant (ANOVA) difference in the genetic integrity of the population from Maghtab and that from Ghar Lapsi.

4.2 Metallothionein (MT) Induction

To date, the Marine Ecotoxicology Laboratory has undertaken investigations on MT induction on limpets (*Patella rustica*) and chitons (*Lepodochitona corrugata)* collected from the Maghtab coastline.

4.2.1 Background and Methodology

Metallothioneins (MT) are specific body proteins found in a range of organisms (from unicellular organisms to humans) whose body production is often induced by the presence of heavy metals such as cadmium, zinc, copper or mercury. Other stressors may also induce their production. MT induction has been successfully used in the Mediterranean as well as in Malta as a specific biomonitoring tool for heavy metal pollution.

In the present study, total MT induction in the limpet *Patella rustica* , was determined by collection of specimens from 5 stations along the Bahar c-Caghaq coastline in the immediate vicinity of the Maghtab SWDS and along the same stretch of shoreline as sampled for water quality monitoring (**see Figure 2**). MT content was determined using the spectrophotometric assay of Viarengo *et al*., (1997). Furthermore, the levels of zinc, copper, lead and cadmium in the tissues of the muscular foot of this species were determined using differential pulse anodic stripping voltammetry (DPASV). Specimens of *P.rustica* were also collected from Qawra which served as the clean reference site. Samples were collected over the period 2000-2002.

Full methodological details for this component of the present investigation may be found in Debono, 2002).

4.2.2 Results

A synopsis of results of MT determinations is presented in **Table 8**. This table shows the estimated mean levels of MT as determined in different seasons as well as the associated induction factors. The induction factor is the ration between MT induction in the impacted site to that in the reference site. MT induction is known to be influenced by a number of natural biological factors including the reproductive state of the organism. Several local studies (e.g. Debono, 1999) suggest that during winter, MT induction is enhanced, and that it is during the winter months that MT induction (at least for the present test species) is most effective as a biomonitoring tool.

Table 8: Levels of metallothionein (as ugMT/g fresh weight) as determined in *Patella rustica* (muscular foot) collected from Maghtab coastline and Qawra (Reference) over the period 2000-2002. Estimated Induction Factor is also shown.

		Mean	Standard Deviation	number of replicates	Induction Factor
winter 2000	Maghtab	**199.31**	63.40	15	**1.4**
	Reference	**142.17**	19.05	2	
summer 2000	Maghtab	**167.87**	40.01	11	**0.8**
	Reference	**213.77**	61.82	3	
winter 2001	Maghtab	**147.43**	38.90	13	**1.5**
	Reference	**100.08**	23.76	3	
spring 2001	Maghtab	**199.56**	144.10	7	**0.6**
	Reference	**322.14**	97.20	2	
summer 2001	Maghtab	**362.34**	116.78	15	**1.1**
	Reference	**343.74**	33.85	3	
winter 2002	Maghtab	**362.21**	91.76	6	**3.6**
	Reference	**100.08**	23.76	3	

Clear evidence of MT induction along the Maghtab coastline in *Patella rustica* was available from these data, especially during winter. This may be related to natural MT fluctuations (as identified above) as well as to the increased heavy metal releases into the marine environment related to increased land-runoff.

Similar results were reported by Scerri (2001) in another test species, *Lepodochitona corrugata* (chiton) who showed that the highest level of MT induction occurred in specimens collected along the Maghtab coastline (during summer of 2000).

Results of tissue analysis for heavy metals in *Patella rustica* are given in **Table 9**.

Except for zinc, the body burden of other heavy metals, namely copper cadmium and lead was found to be higher in specimens collected along the Maghtab coastline that that in animals from the control site. This was especially evident for copper.

Table 9: Levels of heavy metals (as mg/kg FW) as determined in *Patella rustica* (muscular foot) collected from Maghtab coastline and Qawra (Reference) over the period 2000-2002.

		Mean	Standard Deviation	95% confidence limits (+/-)	Number of replicates
zinc	Maghtab	56.25	21.08	9.00	24
	Reference	58.37	45.81	13.27	5
copper	Maghtab	2.10	1.80	2.63	24
	Reference	0.92	0.36	1.18	5
cadmium	Maghtab	5.44	3.85	3.85	24
	Reference	4.17	1.76	2.60	5
lead	Maghtab	2.83	3.09	3.44	24
	Reference	1.13	0.50	1.39	5

5. CONCLUSIONS

The Maghtab SWDS is located in the immediate vicinity of the coastline. As such it may be a source of contaminants into the marine environment through leachates, land-runoff and/or atmospheric fallout of gases as well as of particulates.

The present study had three component investigations: monitoring of water quality along the Maghtab near-shore coastal waters; monitoring of sediment quality, especially at Qalet Marku and biomonitoring using molluscan bioindicators.

5.1 Impact on Water Quality

Water quality monitoring did not indicate any anomalies in the levels of chlorophyll A, water transparency, dissolved oxygen and dissolved phosphates in the area. With respect to dissolved nitrates (and nitrites), statistical analysis on the pooled data for all surveys showed that while the mean level along Maghtab coastline was 12 times as much as that recorded for the reference sites, this difference was not statistically significant. This was due to the high range of values being recorded off Maghtab especially during June 2003. In fact during June, high levels of dissolved nitrates were found not only in Qalet Marku but also at various stations along the Maghtab coastline. However, in spite of these high levels of nitrates, no signs of eutrophic conditions are evident in the area.

Various land-based sources may lead to high nitrate levels in inshore waters including: pollution by sewage, and agricultural run-off. In the case of Maghtab, the high levels of nitrates reported in summer 2003 may not be due to sewage pollution since no coastal sewage pumping stations are present in the area. Furthermore, during the same period, levels of dissolved nitrates in the nearest urban area (St. Paul’s Bay and Qawra) were reported to be normal. Therefore, while inputs from agricultural run-off may not be ruled out, it is quite likely that the SWDS was the main source for these occasional high levels of dissolved nitrates.

Total bacterial counts as well as levels of organic carbon along the Maghtab coastline were higher than those recorded at both reference sites. Furthermore such total bacterial counts increased somewhat immediately after rainfall periods. One explanation for such data is that leachates from the Maghtab SWDSe are reaching the marine environment, enriching its organic carbon content, and this is leading to a general increase in total bacterial counts of the locality under the impact of such runoff waters. On the other hand, there is no evidence to suggest that water runoff is directly carrying any significant levels of microorganisms into the marine environment, though this possibility may not be excluded.

5.2 Impact on Sediment Quality

Sediment quality may be considered as a better index of the general level of pollution in the marine environment Subsequently, for the purpose of assessing the likely releases of heavy metals and of petroleum hydrocarbons from the Maghtab SWDS, superficial sediments from Qalet Marku rather than the water column were used as the environmental phase to be monitored. This is because it is well known that monitoring of heavy metals and PHC in the water phase often yield unreliable results due to the heterogeneous distribution of this class of compounds in water as well as the rapid temporal fluctuations which may occur. On the other hand, superficial sediments are generally considered to be a most reliable environmental phase to monitor this form of pollution over time, since they are well known to act as sinks for these classes of marine contaminants.

It may be argued that marine sediments at Qalet Marku may be exposed to a range of land-based discharges and not only from leachates or surface run-off from the Maghtab SWDS. In particular, coastal traffic may be the source of a range of heavy metals due to road run-off as well as atmospheric fallout onto the marine environment. There is no doubt that the increased heavy metal loads in marine sediments may not be uniquely attributed to the Maghtab SWDS and it is quite reasonable to expect that such an inshore area as Qalet Marku would be exposed to a range of land-based sources.

The present study has shown that marine sediments from Qalet Marku exhibit significantly high levels of lead, nickel and to a lesser extent, copper, mercury and cadmium, chromium and zinc. Furthermore, the overall mean PHC level was found to be at least twice as high as that reported for clean areas.

These data suggest that while the levels of PHC in Qalet Marku show remarkable variations with time (as well as with location), they are significantly higher than those that would be expected in areas exposed only to road traffic. A review of levels of heavy metals and of PHC in near-shore coastal areas exposed to significant road traffic suggested that the marine pollution load in sediments in the vicinity of Maghtab may not be explained only as a result of exposure to such road traffic along the coastal road in this locality. Evidently, while coastal road traffic is contributing to the high levels of contaminants in marine sediments from Qalet Marku, the Maghtab SWDS must also be contributing to such levels in significant amounts. Furthermore, the presence of multiple sources of pollution in this (or any other) coastal area, is bound to increase the biological significance of any individual source, rather than reduce it.

5.3 Biomonitoring

The level of stress of marine contamination on marine organisms may be assessed through a variety of biomonitoring indicators. For the purpose of the present study, two bioindicators of stress have been used, namely genotoxicity in chitons, and metallothionein induction in the limpet, *Patella rustica*.

Any genotoxic impact may be considered to be extremely significant since it may lead to long-term changes in populations which would reduce their chances of survival. The present study showed that at least for the chiton bioindicator species used, there was no evidence of any reduced integrity of the genetic material in natural populations along the Maghtab coastline.

On the other hand, there was clear evidence of metallothionein induction along the Maghtab coastline in *Patella rustica.* This is indicative of increased loads of heavy metals in the marine environment of this locality. Similar results were reported in another bioindicator test species, *Lepodochitona corrugata* (chiton) which exhibited the highest level of MT induction along the Maghtab coastline, during the Summer of 2000.

Finally, determination of body burdens of heavy metals in the limpet, also suggested increased loads in natural populations along the Maghtab coastline, at least during certain times of the year.

5.4 General Conclusion

To conclude, all the various components of the present study supported the idea that the Maghtab SWDS has indeed led to a reduction in environmental quality in the inshore coastal waters in the immediate vicinity. This reduction is also likely to be due to other land-based sources, especially coastal road traffic. Nonetheless, the findings of this study show that releases from the Maghtab SWDS may be considered to be significant with respect to other sources. Furthermore, the presence of other land-based sources of marine pollution in the area is bound to render the releases from the Maghtab SWDS as more significant and therefore to increase the degree of expected biological impact.

6. ACKNOWLEDGEMENTS

The data presented in the present report were collected through the efforts of various people working within the Marine Ecotoxicology Laboratory under the direct supervision of the present consultant. These include:

Jason Aquilina
Ingrid Borg
Henriette Debono
Michelle Ellul
Marie Therese Gambin
Ruth Guillaumier
Lisa Pace
Mario Saliba
Ramona Scerri
Charmaine Vassallo

Furthermore, George Peplow from the Department of Chemistry conducted heavy metal analysis using AAS.

7. REFERENCES

Axiak, V. 2003. Monitoring of Aquaculture Operations Water Quality off Sikka l-Bajda (March –August 2003) Report *Version: 27 October 2003.*

Debono, H., 1999. The assessment of heavy metal pollution in Malta. B.Sc. Dissertation. Biology Department, Faculty of Science, University of Malta, (Unpublished), Malta.

Debono, H. 2002. Chemical and biological monitoring of heavy metals pollution in the marine environment in the vicinity of the Maghtab landfill. M.Sc. Dissertation. Biology Department, Faculty of Science, University of Malta, (Unpublished), Malta

Parsons T. R., Maita Y., and Lalli C. M. 1984. A manual of chemical and biological methods for seawater analysis. Pergamon Press. Oxford.

Saliba M. 1999. *Environmental Impact Assessment of the Maghtab landfill on the marine environment*. B.Sc. Dissertation. Biology Department, Faculty of Science, University of Malta, (Unpublished), Malta.

Scerri, R. 2001. A chiton as a bioindicator of heavy metal pollution: An assessment. B.Sc. Dissertation. Biology Department, Faculty of Science, University of Malta, (Unpublished), Malta.

UNEP. 1996. State of the marine and coastal environment in the Mediterranean region. MAP Technical Reports Series. No. 100. UNEP. Athens.

UNEP/RAMOGE. 1999. Manual on the biomarkers recommended for the MEDPOL biomonitoring programme. UNEP. Athens.

Viarengo A., Ponzano E., Dondero, F., and Fabbri, R. 1997. A simple spectrophotometric method for metallothionein evaluation in marine organisms: An application to Mediterranean and Antartic Molluscs. Marine Environmental Research. 44 (1) 69-84.