Cayman Islands Government

Landfill Site Environmental Review

Task 2: Environmental Investigations Interpretative Report

3 August 2015

Amec Foster Wheeler Environment
& Infrastructure UK Limited

Report for

Jennifer Ahearn
Chief Officer
Ministry of Health
Government Administration Building
133 Elgin Avenue
Grand Cayman
Cayman Islands

Main contributors

Julian Bromhead
Simon Howard
Alun Mcintyre
Phil Scott

Issued by

....
Simon Howard

Approved by

pp ....
Phil Scott

Amec Foster Wheeler

Canon Court
Abbey Lawn
Abbey Foregate
Shrewsbury SY2 5DE
United Kingdom
Tel +44 (0) 1743 342 000

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1	Draft for client comment	21 July 2015
2	Second draft	3 August 2015

Executive summary

Background and Scope

This report has been produced as a deliverable associated with Phase 1 of the National Solid Waste Management Strategy (NSWMS) for the Cayman Islands. It comprises Task 2: Environmental investigations and updated risk assessments for the three operational landfill sites located on the islands. It follows on from Task 1 environmental review (February 2015) which was a review of existing environmental information and initial risk assessment. The Task 1 environmental review provided a series of recommendations for targeted risk based environmental sampling and monitoring which formed the basis of the Task 2 fieldwork, the factual data for which is reported separately. This report is an interpretation of data from both the recent environmental investigation and historical data where appropriate. Environmental risk assessments from the Task 1 environmental review have been updated based on the Task 2 investigation data.

The main landfill site is located at George Town on Grand Cayman and this is where the bulk of the Task 2 environmental investigation work took place. It included the monitoring of existing and new groundwater wells, surface water and sediment sampling in canals/dykes surrounding the site and in North Sound, and dust and landfill gas monitoring. Samples of vegetation surrounding the landfill and also from within North Sound were taken for analysis. Historical monitoring data for groundwater and surface waters has also been considered within the interpretation of environmental effects.

Groundwater boreholes were installed and sampled at Cayman Brac landfill together with sampling of surface waters and monitoring and sampling of landfill gas. At Little Cayman landfill, where wastes are set alight and burned, some soil and surface water sampling was undertaken. There is no significant pre-existing environmental monitoring data for the two sister island landfills.

This environmental data has been collated and screened, primarily against Florida state clean-up assessment criteria for waters and soils. Landfill gas monitoring and analysis was undertaken on the George Town and Cayman Brac sites and based on the collected data air quality modelling has been undertaken for the George Town site. Amenity related issues have also been considered for each site; these are hazards such as dust, landfill fires and nutrients in waters for which there are no direct assessment criteria.

Risk Assessment

Based on appraisal of environmental data and consideration of receptors a qualitative risk assessment has been undertaken for each of the sites. The outcome of the risk assessments in terms of identification of key[1] contamination and amenity risks associated with the landfills are as follows:

George Town:

- **Site users and visitors**: arsenic in soils as well as hydrogen sulphide and methane;
- **Adjacent residents:** nuisance from odour and landfill fires;
- **Adjacent commercial/industrial site users:** hydrogen sulphide from sediments contaminated by various sources including the landfill, as well as nuisance from odour and landfill fires;
- **Groundwater:** hydrocarbons from spills and overtopping of bunds;
- **Surface water:** hydrocarbons from spills and overtopping of bunds, ammonia and orthophosphates from groundwater; and
- **North Sound:** ammonia and metals from canal water.

[1] Key contamination risks are regarded as those that are assessed as moderate and above. For amenity risks, which are much more subjective in nature, key risks are defined as high risks only.

The landfill also has a significant visual impact from various viewpoints.

Cayman Brac

- **Site users and visitors**: methane from landfill gas;
- **Groundwater:** hydrocarbons from waste oil storage spills to ground; and
- **Surface water:** metals leaching from landfill.

Little Cayman

- **Groundwater:** hydrocarbons from illegal waste oil disposal pit.

Recommendations

Amec Foster Wheeler's recommendations resulting from assessment and interpretation of the data in this report and the resultant risk assessments are summarised in the following tables.

Recommendations for Environmental Improvements and Monitoring at George Town Landfill

Ref	Source/Risk	Proposed Work	Objective/Rationale
1	Fugitive gas emissions from the landfill surface	Progressive engineered capping of completed areas of the landfill to minimise landfill gas emission and enable gas collection for energy recovery Application of daily cover to landfilled wastes	Reduction in emission of odorous gas constituents and methane which is a significant greenhouse gas Prevent vermin accessing the landfilled wastes
2	Landfill gas	Repeat of flux box tests Bulk gas monitoring in existing gas probes at least every three months Gas pumping trials following first phase of capping	Better definition of landfill gas emission rates Ongoing evaluation of gas quality Recovery of landfill gas and use in electricity generation.
3	Incinerator emissions	Establish emissions monitoring programme	Provide quantitative assessment of emissions from incinerator and their likely impact
4	Landfill fires	Removal of stockpiled tyres which are a particular fire hazard Monitoring for airborne PAH's during waste fires	Burning tyres pose a significant risk in terms of combustion Evaluation of potential health impact to offsite receptors (note capping of the wastes will reduce the potential for fires).
5	Groundwater contamination	Progressive capping of the site Monitoring of existing groundwater wells on at least an annual basis	Reduce leaching potential from the wastes and impact on groundwater Continued evaluation of impacts
6	Surface water contamination	Monitoring in North Canal on at least a six monthly basis	Continued evaluation of impacts
7	Marine water contamination	Reinstate annual DoE sampling in North Sound	Continued evaluation of impacts

Recommendations for Environmental Improvements and Monitoring at Cayman Brac Landfill

Ref	Source/Risk	Proposed Work	Objective/Rationale
1	Clinical waste disposal in the landfill	Reinstate the incinerator to prevent direct disposal If continued landfill disposal in the short term then cover the disposal area daily	Cease landfill disposal of clinical waste Good practice and reduced risk of vermin nuisance or public health incident
2	Incinerator emissions	Establish emissions monitoring programme when incinerator is operational	Provide quantitative assessment of emissions from incinerator and their likely impact
3	Landfill gas as a greenhouse gas	Bulk gas monitoring in existing gas probes at least every three months Consideration of whether engineered capping and gas recovery for flaring is of cost benefit	Ongoing evaluation of gas quality Potential reduction in uncontrolled gas emission by may not be economically viable due to small size of landfill
4	Groundwater contamination	Monitoring of existing groundwater wells on at least an annual basis	Continued evaluation of impacts
5	Surface water contamination	Monitoring of shrimp pond on at least an annual basis	Continued evaluation of impacts

Recommendations for Environmental Improvements and Monitoring at Little Cayman Landfill

Ref	Source/Risk	Proposed Works	Objective/Rationale
1	Illegal oil disposal pit	Prevent access Further assessment and remediation	Potential health and safety hazard and prevent further disposal Assessment of remediation requirements
2	Continued uncontrolled landfill expansion	Management and restrictions to prevent further expansion of burning area	Limit on uncontrolled site expansion, especially in direction of Booby Pond.

Contents

1. Introduction

1.1 Background

Amec Foster Wheeler Environment & Infrastructure UK Ltd. (Amec Foster Wheeler) has been commissioned by the Cayman Islands Government (CIG) to prepare and assist in the delivery of a National Solid Waste Management Strategy (NSWMS) for the Cayman Islands. This work is being delivered in three main phases:

- Phase 1: The preparation of the NSWMS and the delivery of environmental investigations at the existing landfills on the islands;
- Phase 2: Preparation of an Outline Business Case to deliver the NSWMS; and
- Phase 3: The procurement of the new waste management services and infrastructure in line with the NSWMS.

1.2 Scope and Terms of Reference

This report has been prepared by Amec Foster Wheeler on behalf of the CIG as a deliverable from Phase 1. It comprises Task 2: Environmental investigations and updated risk assessments for the three operational landfill sites located on the islands. It follows on from Task 1 environmental review (February 2015) which was a review of existing environmental information and initial risk assessment. The Task 1 report provided a series of recommendations for targeted risk based environmental sampling and monitoring which formed the basis of the Task 2 fieldwork for which the factual data is reported separately. The Task 2 investigation draft factual report (Amec Foster Wheeler reference 36082rr008i1) is dated June 2015.

The scope of the targeted environmental investigations was agreed with CIG and was generally in line with the Task 1 environmental review recommendations, albeit with some minor variation and additions. The fieldwork was undertaken between 8 and 18 April 2015 and included the following work:

George Town Landfill

- Groundwater sampling and analysis in 5 existing wells (MW8, 9, 11, 13 and 14) as well as 4 new monitoring wells (MW15A, MW19, MW20 and MW21);
- Groundwater level monitoring of all of the above wells plus continuous level monitoring in wells MW8, MW9 and MW14 by data logger, which appears to show a tidal influence;
- Surface water sampling and analysis at 10 locations including within North Sound, the North Canal, nearby ponds and a sample of ponded leachate from within the landfill;
- Sediment sampling and analysis at 6 locations in perimeter canals/dykes and the North Sound;
- Sampling and analysis of plant samples from 4 locations around the landfill and 6 samples of marine vegetation/algae from North Sound;
- Installation of 6 gas probes (GP1-GP6) within the wastes and monitoring and analysis of landfill gas from each probe;
- Flux box monitoring of landfill gas surface emissions at three locations across the landfill, including one on a capped area and two on uncapped wastes;
- Dust sampling at 2 locations (DM1 and DM2);
- Dust deposition measurements at a total of 9 locations across the site during the investigation;
- Fugitive hydrogen sulphide surveys on and adjacent to the landfill on two occasions; and
- Sampling of soil from the Hurricane Ivan fill area for asbestos (17 samples).

Cayman Brac Landfill

- Groundwater sampling and analysis in 4 new monitoring wells (CB1-CB4);
- Surface water sampling and analysis at 3 locations (BSW1-BSW3) from surrounding ponds;
- Installation of 4 gas probes (GP21-GP24) within the wastes and monitoring and analysis of landfill gas;
- Dust deposition measurements at two locations during the investigation;
- Fugitive hydrogen sulphide surveys on the landfill (14 April 2015); and
- Sampling of soil from across the landfill, principally for asbestos although the soil sampled from an area of surface staining (BSS6) was also scheduled from diesel range organics (DRO) and polycyclic aromatic hydrocarbons (PAHs).

Little Cayman Landfill

- Sampling of soil (LSS1-LSS5) for analysis and leaching tests;
- Surface water sampling and analysis at 2 locations (LSW2 and 3); and
- Dust deposition measurements in one location during the investigation.

The sampling and monitoring was undertaken by Amec Foster Wheeler staff from the United Kingdom and United States (US). Laboratory analysis was undertaken in the US.

Amec Foster Wheeler were supported during the investigation work by personnel from a number of CIG departments including Department of Environmental Health (DEH), Department of Environment (DoE), Public Works Department (PWD) and Ministry of Home Affairs Health and Culture (MHAH&C). New monitoring wells were completed by Industrial Services & Equipment (ISE) Limited under contract to Amec Foster Wheeler.

This report is an interpretation of the investigation data, the detailed results for which are provided in a separate factual report. It also includes some reference to previous monitoring information, where it exists and which is mainly associated with the George Town site, which was reported in the Task 1 environmental review. Preliminary environmental risk assessments were reported in the Task 1 environmental review; these have been updated in this report based on the findings of the Task 2 investigations and monitoring.

The three landfill sites are all currently operational and receive the majority of waste that is generated on the islands. However, the development of the new NSWMS will be guided by the waste management hierarchy and will aim to significantly reduce the future dependency on landfilling as a waste management option. The current environmental condition of the landfills, nevertheless, remains a significant factor in considering both the short and long term waste management options for the islands and the potential environmental liability they pose now and in the future. These environmental liabilities are discussed in this report which provides some recommendations on further assessment and management of the sites.

1.3 Structure of the Report

The report is structured as follows:

- Section 1: Introduction
- Section 2: Assessment methodology
- Section 3: Environmental condition George Town Landfill;
- Section 4: Environmental condition Cayman Brac Landfill;
- Section 5: Environmental condition Little Cayman Landfill; and
- Section 6: Conclusions and recommendations.

2. Assessment Methodology

2.1 Assessment Approaches

Three different assessment approaches have been used to evaluate the environmental condition of the landfill sites:

- Soil, surface water and groundwater water data has generally been screened against generic assessment criteria (GAC, i.e. a 'Tier 2' assessment) based on the Florida Administrative Code (FAC) contaminant clean up target levels[2]which are based on human health assessment;
- UK proposed standards under the Water Framework Directive (WFD) to protect the water environment have been used for nutrients and some metals within surface waters[3];
- Air quality data (including landfill gas and dust) have been assessed against UK Environment Agency (EA) and World Health Organisation (WHO) assessment criteria;
- Amenity risk, such as windblown litter, for which there are no quantitative assessment standards, has been evaluated in accordance with UK EA H1 Annex A guidance[4].

Further detail of the assessment methodologies is provided below.

2.2 Land and Water Contamination

Approach

The tiered approach to assessing risks from land and water contamination is set out in the UK Department for Environment, Food and Rural Affairs (DEFRA) and EA publication *Model Procedures for the Management of Land Contamination* CLR11[5]. This considers potential contamination sources at the landfill, pathways and receptors in order to identify potential contamination linkages.

Contaminants would include potentially harmful substances in the wastes, soils, sediments, surface waters and groundwater.

Amec Foster Wheeler's approach to undertaking land and water contamination risk assessment is based on a tiered framework in accordance with CLR11, as outlined in Table 2.1.

Table 2.1 CLR11 Tiered Framework

Tier	Description
Tier 1: Preliminary Risk Assessment	Development of a conceptual model; Preliminary Risk Assessment examining potential contaminants, pathways and receptors to identify the potential 'contaminant linkages'; Identification of further risk assessment requirements.
Tier 2: Generic Quantitative Risk Assessment (GQRA)	Screening of analytical results against GAC for soils and groundwater including Soil Guideline Values, Environmental Quality Standards, etc., to identify issues that require more detailed consideration; Identification of further risk assessment or risk management requirements.

[2] Chapter 62-777 contaminant clean-up target levels. Florida Department of State, 2005.
[3] DEFRA – Water Framework Directive Implementation in England and Wales: New and Updated Standards to Protect the Water Environment. May 2014.
[4] H1 Annex A – Amenity & accident risk from installations and waste activities. v 2.1, Environment Agency, December 2011
[5] Model Procedures for the Management of Land Contamination – Contaminated Land Report 11. Environment Agency, September 2004

Tier	Description
Tier 3: Detailed Quantitative Risk Assessment (DQRA)	Refinement of site conceptual model which may require the collection of additional data; Application of detailed quantitative risk assessment procedures in accordance with Environment Agency Guidance to further assess potential contaminant linkages: ➢ With respect to human receptors this may involve assessment of site specific exposure scenarios taking into account toxicological properties of substances to derive site specific assessment criteria (SSAC); ➢ With respect to controlled water receptors this may involve simple analytical calculations of groundwater and/or surface water flow and contaminant attenuation to derive remedial target concentrations. ➢ To undertake the assessment proprietary software such as the CLEA Software, RBCA or RAM may be used; ➢ Identification of further risk assessment or risk management requirements.

In general the application of increased tiers of analysis will result in less conservative remediation targets resulting in less costly remedial action. Therefore the cost for increased tiers of assessment is justified where remediation liabilities are potentially high and less costly solutions can be established as acceptable by detailed risk assessment.

The land and water contamination assessment for the landfills provided within this report is generally based upon a Tier 2 assessment. For the George Town Landfill some historic quantitative monitoring data is available, particularly for surface waters and groundwaters, in addition to that obtained from the recent investigation work. For Cayman Brac and Little Cayman landfills there is very little pre-existing monitoring data prior to the recent investigations.

The contaminant-pathway-receptor relationship allows an assessment of potential environmental risk to be determined based on the nature of the source, the degree of exposure of a receptor to a source and the sensitivity of the receptor. On this basis an assessment is made of the environmental liabilities associated with the risk. These can be expressed, for example, in terms of:

- Additional costs associated with site redevelopment or remedial measures;
- The potential for costs, fines or penalties imposed for breaches of environmental legislation or third party claims; and
- Loss of land value.

Assessment Standards

Florida Administrative Code

Within this report, as part of a Tier 2 risk assessment, chemical analysis data for soils and groundwater are compared with GAC, for determinands where values are available, in order to identify contaminants of concern and determine whether further assessment of risks is required.

The assessment criteria used depends upon the source media (soil, groundwater) and the receptor under consideration. The GAC used in this study are those produced under the FAC chapter 62-777 contaminant clean-up target levels from 2005, referenced on the previous page of this report and available at: http://www.dep.state.fl.us/waste/quick_topics/rules/documents/62-777/62-777_TableI_GroundwaterCTLs.pdf

These are derived based on human health receptors. They are considered to be those which are most directly relevant to the Cayman Islands considering geography, climate and given that the FACs also consider marine surface water criteria which is an important factor for the islands.

UK Proposed Standards to Protect the Water Environment

There are no Florida marine surface water assessment criteria for nutrients including ammonia, nitrate/nitrite and phosphorous. Ammonia is also toxic to fish at relatively low concentrations. The proposed UK standard[6] for unionised ammonia (NH3-N) in marine waters is 0.021 mg/l (long term mean value). There is no proposed equivalent standard for total ammonia (NH4-N) in marine waters but that for rivers is summarised in Table 2.2. The values are appropriate for 'Type 7' rivers which are those with alkalinity concentrations exceeding 200 mg/l $CaCO_3$ which correspond with those recorded in the North Canal during April 2015 monitoring.

Table 2.2 Ammonia Standards in Type 7 Rivers (UK)

Type of Standard	Total Ammonia (mg NH4-N/l)
High	0.7
Good	1.5
Moderate	2.6
Poor	6.0

UK proposed standards for orthophosphate (also known as reactive phosphorus) in rivers are summarised in Table 2.3. These standards are for lowland high alkalinity rivers (alkalinity >50mg/l $CaCO_3$).

Table 2.3 Reactive Phosphorus Standards in Lowland High Alkalinity Rivers (UK)

Type of Standard	Reactive Phosphorus/ Orthophosphate (mg/l)
High	0.0036
Good	0.069
Moderate	0.173
Poor	1.0

There are no specific water quality standards for UK rivers for nitrate but there are proposed assessment standards for groundwater contributions to wetlands. For a swamp/wet woodland the mean proposed annual threshold is 22mg/l.

Risk Assessment Criteria for Land and Water Contamination

The definitions of potential consequence and likelihood of a contamination linkage are defined in Table 2.4 together with the definition of the potential significance.

[6] Water Framework Directive implementation in England and Wales: new and updated standards to protect the water environment. DEFRA, May 2014

Table 2.4 Risk Assessment Criteria Land and Water Contamination

Potential Consequence of Contaminant Linkage	
Severe	Acute risks to human health. Short-term risk of pollution of sensitive water resource (e.g. major spillage into controlled waters). Impact on controlled waters e.g. large scale pollution or very high levels of contamination. Catastrophic damage to buildings or property (e.g. explosion causing building collapse). Ecological system effects – irreversible adverse changes to a protected location. Immediate risks.
Medium	Chronic risks to human health. Pollution of sensitive water resources (e.g. leaching of contaminants into controlled waters). Ecological system effects – substantial adverse changes to a protected location. Significant damage to buildings, structures and services (e.g. damage rendering a building unsafe to occupy, such as foundation damage).
Mild	Non-permanent health effects to human health. Pollution of non-sensitive water resources (e.g. pollution of non-classified groundwater). Damage to buildings, structures and services (e.g. damage rendering a building unsafe to occupy, such as foundation damage). Substantial damage to non-sensitive environments (unprotected ecosystems e.g. crops).
Minor/ Negligible	Non-permanent health effects to human health (easily prevented by appropriate use of PPE). Minor pollution to non-sensitive water resources. Minor damage to non-sensitive environments (unprotected ecosystems e.g. crops). Easily repairable effects of damage to buildings, structures, services or the environment (e.g. discoloration of concrete, loss of plants in a landscaping scheme).
Likelihood of Contaminant Linkage	
High likelihood	An event is very likely to occur in the short term, and is almost inevitable over the long term OR there is evidence at the receptor of harm or pollution.
Likely	It is probable than an event will occur. It is not inevitable, but possible in the short term and likely over the long term.
Low likelihood	Circumstances are possible under which an event could occur. It is by no means certain that even over a longer period such an event would take place, and less likely in the short term.
Unlikely	It is improbable that an event would occur even in the very long term.
Potential Significance	
Very High Risk	Severe harm to a receptor may already be occurring OR a high likelihood that severe harm will arise to a receptor, unless immediate remedial works/mitigation measures are undertaken.
High Risk	Harm is likely to arise to a receptor, and is likely to be severe, unless appropriate remedial actions/mitigation measures are undertaken. Remedial works may be required in the short term, but likely to be required over the long term.
Moderate Risk	Possible that harm could arise to a receptor, but low likelihood that such harm would be severe. Harm is likely to be medium. Some remedial works may be required in the long term.
Low Risk	Possible that harm could arise to a receptor. Such harm would at worse normally be mild.

The potential significance for each Contaminant Linkage is calculated from the following matrix (Table 2.5).

Table 2.5 Potential Significance of Contaminant-Receptor Linkage Matrix

		Likelihood			
		High Likelihood	Likely	Low Likelihood	Unlikely
Potential consequence	Severe	Very High	High	Moderate	Moderate/Low
	Medium	High	Moderate	Moderate/Low	Low
	Mild	Moderate	Moderate/Low	Low	Negligible
	Minor or Negligible	Moderate/Low	Low	Negligible	Negligible

It is generally accepted that risks identified as moderate or higher would require further investigation, assessment or remediation.

2.3 Air Quality Modelling

Surface emission rates of landfill gas (LFG) from the active George Town landfill area have been estimated from use of a GasSim (v2.5) model and these have been used in a dispersion model to estimate ambient concentrations of LFG at sensitive residential receptors (Lakeside Development and Parkside Close) downwind of the landfill. GasSim simulates the fate of landfill gas arising from managed or unmanaged landfill sites and was developed for the UK Environment Agency (EA). The model uses information on waste composition and quantity, landfill engineering, and landfill gas management techniques to enable assessment of the best combination of control measures for a particular design and rate of filling.

From a review of the data on trace components contained in the landfill gas (LFG), acquired by on-site measurements in April 2015, ambient concentrations of trace components, including, for example, hydrogen sulphide and a range of volatile organic compounds, some of which are halogenated, were also estimated at these receptor locations.

Estimates of the emission of odour from the active landfill surface were taken from a recent research study in the UK[7] and this was also applied in a dispersion model to assess the likelihood of odour nuisance being experienced at the above receptors as a result of surface emissions of LFG.

2.4 Amenity Risk

The amenity risk assessment approach is based on the identification of a hazard, receptor and pathway. It then considers risk management, probability of exposure and consequence, together with a summary of overall impact. Amenity risk is based on identification of a potential hazard or nuisance, for example landfill fires, for which there are no generic assessment criteria.

Risk Assessment Criteria for Amenity Risk

Table 2.6 summaries the headings for amenity risk assessment evaluation based on UK EA H1 Annex A guidance.

[7] SNIFFER (2013) Odour Monitoring and Control on landfill Sites. http://www.sniffer.org.uk/files/2813/7476/3982/ER31_Final_Report.pdf

Table 2.6 Assessment Approach for Amenity Risks

Hazard	Receptor	Pathway	Risk management	Probability of Exposure	Consequence	Overall Impact
E.g. landfill fires	Residents in Lakeside development	Air, receptor downwind of site	None currently	High likelihood	Waste or tyre combustion products in smoke	High

The risk matrix for amenity risks is presented as Table 2.7.

Table 2.7 Amenity Risk Matrix

Consequence → **↓ Probability**	**Very Low**	**Low**	**Medium**	**High**
Very Low	Low	Low	Low	Low
Low	Low	Low	Medium	Medium
Medium	Low	Medium	Medium	High
High	Medium	Medium	High	High

3. Environmental Condition George Town Landfill

3.1 Location and Setting

Location

The George Town landfill is located to the north of central George Town towards the western coast of Grand Cayman as shown on Figure 1. It is owned by Cayman Islands Government (CIG) and operated by the Department of Environmental Health (DEH). The total site area is approximately 73 acres (30 hectares) in extent and the site boundary is identified on Figure 1. The majority of the site has historically received inputs of waste materials, the exceptions being the western margin of the site, to the west of Esterley Tibbetts Highway and the north-west margin of the site, to the north of the dyke/canal.

The landfill is predominantly a land raise formed by tipping over an area of former mangrove swamp which was partially excavated to recover the underlying marls (calcareous soils). The site has no formal engineered containment (i.e. a basal lining system). Part of the site is capped with a thin layer of soil materials and has re-vegetated in some areas.

Topography

The land surrounding the landfill is mainly flat lying and where developed is formed from reclamation of former mangrove swamp. The height of land surrounding the landfill varies between approximately 2 and 5 feet (0.6-1.5m) above mean sea level (MSL). The highest part of the landfill is at approximately 80 feet (24.4m) above MSL. An updated topographical survey has recently been completed at the site and the output was received shortly before issue of this report.

Surrounding Land Use

The land usage surrounding the landfill is summarised below, with reference to the Task 1 environmental review:

- Immediately to the north of the site is a tidal drainage channel which connects with North Sound to the east. The area immediately north of the drainage channel is mangrove swamp. The Cayman International School and Camana Bay development are located approximately 0.2 miles (325 m) and 0.55 miles (880 m) north of the landfill respectively.
- Beyond the eastern boundary of the site is land owned by Cayman Water Authority and comprises four large former wastewater treatment lagoons, two of which are still used for sludge storage. The lagoons are lined and variously sludge and water filled. To the south of the lagoons is the current wastewater treatment plant housed within a large building. Some 0.1-0.2 miles (160- 320m) east of the landfill site is land zoned for industrial use. This is mainly undeveloped or used for open storage. DEH lease some land to the east of the wastewater treatment lagoons which is used for storage of waste collection vehicles.
- To the south of the site is an area of mangrove with industrial and commercial development beyond. This land is occupied by a variety of businesses, including a concrete batching plant.
- Esterley Tibbetts Way (which is the main arterial road to West Bay) is immediately adjacent to the fence line forming the western boundary of the site. The Lakeside residential development is located west of the road and approximately 330 ft (100m) from the landfill boundary and a further 610 ft (185m) from the area currently used for active landfilling of waste. This development comprises a number three-storey residential apartments with car parking and leisure/landscape areas (including a small lake). The landfill is visible from the upper storeys of the lakeside buildings.

Site History and Infrastructure

The history of development of George Town landfill and a description of infrastructure at the site is described in the Task 1 environmental review.

Climatological Information

General climatological information for Grand Cayman is provided in the Task 1 environmental review and summarised in Table 3.1.

Table 3.1 Meteorological Summaries for Grand Cayman

Month	Average Rainfall (inches)[a]	Average Wind Speed (mph)[b]	Average Wind Direction [c]	Average Temperature (°F)
January	1.68	11.3	ENE	77.3
February	2.88	9.6	ENE	77.2
March	7.42	9.9	ENE	78.4
April	20.36	10.2	ENE	80.0
May	3.56	8.6	E	81.7
June	1.69	8.9	E	83.3
July	11.51	8.8	E	83.9
August	5.35	8.4	E	83.6
September	3.85	6.7	E	83.1
October	0.71	9.8	ENE	81.8
November	1.97	11.4	ENE	80.7
December	3.36	9.7	ENE	78.7

Sources:
a. Cayman Islands Government National Weather Service 30-year average for Georgetown, Grand Cayman Island.
b. Cayman Islands Government National Weather Service 21-year average for Georgetown, Grand Cayman Island.
c. Cayman Islands Guide www.caymanislands-guide/weather/wind

Some specific meteorological data was provided by the National Weather Service to cover the period of the Task 2 fieldwork and this is presented in the Task 2 factual report.

Waste Composition and Inputs

The 2011/12 waste composition and input data for the site is provided in the Task 1 environmental review. The waste input into the George Town site in the year ending June 2014 is estimated by DEH at 62,400T. Weighbridge data from March and April 2015 indicates that historical tonnage data reported from George Town landfill may underestimate the actual tonnages received. The projected input at George Town derived from the March and April weighbridge data indicate an increase to around 71,500T for 2015.

Geological Setting

The geology in the vicinity of the George Town site is described in the Task 1 environmental review and is summarised in Table 3.2.

Table 3.2 Geological Succession George Town Landfill Area

Elevation (ft) and (m)	Thickness (ft) and (m)	Period	Series	Formation
+1.5 to +4.0ft/ +0.45 to +1.2m	2.5ft/ 0.75m	Made ground	Made ground	Imported fill
0.0 to +1.5ft/ 0.0 to +0.45m	1.5ft/ 0.45m	Quaternary	Holocene	Peat (swamp deposits)
0.0 to -3.0ft/ 0.0 to -0.9m	3.0ft/ 0.9m	Quaternary	Pleistocene	Ironshore Formation (calcareous marl)
-3.0 to -7.5ft/ -0.9 to -2.3m	4.5ft/ 1.4m	Quaternary	Pleistocene	Ironshore Formation (very soft friable limestone)
-7.5 to -25ft/ -2.3 to -7.6m	17.5ft/ 5.3m	Quaternary	Pleistocene	Ironshore Formation (soft friable limestone and marl bands)
-25 to -45ft/ -7.6 to -13.7m	20ft/ 6.1m	Tertiary	Oligocene- Pliocene	Pedro Castle Formation (hard dolomite and limestone)
-45 to >-300ft/ -13.7 to >-91.4m	>250ft/ >76m		Oligocene- Pliocene	Cayman Formation (dolostone)

Four new groundwater monitoring wells were completed around the margin of the landfill site as part of the Task 2 investigation works. These were rotary drilled by open hole methods (i.e. no cores were recovered). As assessment of the strata was made by Amec Foster Wheeler based on the drilling rate and flush returns.

These wells proved the following:

- Made Ground (landfilled wastes of soil with varying amounts of wood, plastic, textile, rubber and metal) to depths of between 4 and 11.8 ft (1.2-3.6 m) below ground level (bgl); overlying
- A limestone bedrock, anticipated to form part of the Ironshore Formation, which was typically recovered as coarse sand to coarse gravel-sized grey/white fragments of limestone and coral. The full depth of the limestone was not determined, with all boreholes drilled to approximately 30 ft (9.1m) bgl.

3.2 Data Sources

Previous Environmental Reports

Post, Buckley, Schuh & Jernigan 1991

An environmental assessment of the Grand Cayman Sanitary Landfill (now known as the George Town Landfill) was undertaken in 1991 (reporting date uncertain) by Post, Buckley, Schuh & Jernigan (PBS&J)[8]. This included the installation of eight groundwater monitoring wells around the landfill site. The study included groundwater level monitoring and sampling with level data reviewed against tidal cycles. The sampling and analysis of waters was also undertaken in some of the ditches around the landfill (these are also known as 'canals') including the discharge from the northern canal into the North Sound. Some limited sediment sampling from the ditches and North Sound was also undertaken. Information from this study is summarised in the Task 1 environmental review.

[8] Environmental Assessment of Grand Cayman Sanitary Landfill, Grand Cayman Island, BWI. Post Buckley, Schuh & Jernigan Report for CIG, 1991? (Electronic copy with no cover/issue sheet).

Cardno ENTRIX 2013

In April 2013 Cardno ENTRIX submitted a draft Environmental Statement (ES) for a proposed alternative landfill site on Grand Cayman[9]. Although this is primarily concerned with a proposed new landfill site near Bodden Town it also contains some reference to the baseline or 'no action alternative' of the George Town Landfill (section 4.1.2 of the ES). The ES provides a summary of water quality in the vicinity of George Town Landfill based on information provided by DEH for the period 2006-2010. It also provides a summary of DoE sampling of water quality in North Sound for the period 2003-2012. Annex F6 of the ES includes a short marine environmental evaluation report for the George Town landfill.

Pre-Existing Environmental Monitoring Data

Department of Environmental Health

DEH has provided six sets of monitoring data for surface water and groundwater in the vicinity of the landfill for the period 2006 to 2013 which is when they last undertook the monitoring. Sampling is only undertaken once every one or two years. The position of sampling locations is shown on Figure 2. In addition to water samples some soil samples have previously been taken and analysed from the sides of some of the ditches and adjacent to some monitoring well locations.

Department of Environment

DoE has provided annual water quality data for North Sound for the period 2006 to 2013. It is noted that the marine water quality sampling has a limited suite of determinands and no sampling was undertaken in 2014 or 2015 to date.

Other Environmental Data

There is no known landfill gas or air quality monitoring data for the landfill site.

3.3 Hydrogeology

Regional Setting

A summary of the regional hydrogeology is provided in the Task 1 environmental review.

Abstractions

There are no known groundwater abstractions in the immediate vicinity (<1000 ft/ 300m) of the landfill. Water Authority Cayman operates two reverse osmosis plants at its Red Gate Road Water Works for municipal water supply. The works are located approximately 1.0 miles (1.6 km) south-east of the landfill. The plants take saline groundwater from feed water wells cased to 100 ft (30m) depth bgl, open zone from 100ft (30m) to 150ft (45m) or 160ft (48m) bgl. Brine disposal wells on the same site are cased to 210ft below ground level with an open zone from 210ft to 300ft (63m–90m).

Caribbean Utilities Company (CUC) abstract groundwater for cooling purposes at their site off North Sound Road/Sparkys Drive some 0.7miles (1.1km) south-east of the landfill.

Groundwater Levels

In 1991 PBS&J carried out monitoring of groundwater levels in wells located around the landfill site in relation to tidal cycles. A well within the central part of the site (Well 5) was shown to have a head difference of between 0.45ft (0.14m) and 0.68ft (0.2m) (mean 0.56ft/ 0.17m) above the corresponding tidal level in

[9] Grand Cayman Waste Management Facility – Draft Environmental Statement. Cardno ENTRIX report for Dart Cayman Islands, April 2013.

North Sound, the groundwater levels exhibiting a tidal lag. The amplitude of tidal fluctuations in North Sound were 1.2 times that at Well 5. PBS&J estimated a groundwater flow velocity of 12 feet (3.6m) per day from the landfill towards the North Sound.

As part of the Task 2 investigation data loggers were installed in monitoring wells MW8, MW9 and MW14 to record fluctuations in groundwater levels. In general, the data show groundwater variation on the order of 0.6 ft (0.18m) over a 24 hr period and are therefore similar to previous results obtained by PBS&J and indicative of tidal influence.

Groundwater Quality

1991 Investigation

In 1991 PBS&J carried out groundwater sampling and analysis from a number of wells around the landfill site. At that time only the eastern part of the current landfill was developed. Evidence of leachate contamination of groundwater was reported in Well MW3 located on the eastern boundary of the old landfill area (see Figure 2 for location). This was evidenced by elevated ammoniacal nitrogen (400 mg/l), total alkalinity and total organic carbon (TOC) with respect to other wells. Other wells recorded ammoniacal nitrogen concentrations of between 0.04 and 20 mg/l.

Sample analysis from Well MW3 also showed elevated lead, iron and chromium, as did MW5. Benzene, toluene, ethylbenzene and chlorobenzene were also present in MW3 at concentrations of 1.1 to 66 µg/l.

DEH Sampling 2006-2013

DEH undertake periodic sampling and analysis of the groundwater monitoring wells and up to a maximum of six data sets are available for this period. The groundwater monitoring network has been degraded as the landfill footprint has expanded with time and the number of effective monitoring wells has reduced. Wells MW 5, 8, 9, 13, 14, 15, 16 and 18 (see Figure 2 for location) were available for sampling by DEH during the last monitoring round in 2013. In total there are 34 data sets for the period. Wells 16, 17 and 18 were installed in December 2010.

Amec Foster Wheeler Sampling 2015

Amec Foster Wheeler undertook sampling from existing groundwater wells MW 8, 9, 11, 13 and 14 and new wells MW15A, 19, 20 and 21 installed as part of the Task 2 investigation work. Wells 5, 15 and 18 have been lost since the last DEH monitoring round. Well MW16 was not sampled as it contained free product hydrocarbons.

Assessment Criteria

The 2006-2015 sample data has been screened against Florida clean-up standard for poor yield/low quality groundwater. These assessment criteria have been selected due to the brackish nature of the underlying aquifer. The results and assessment criteria are summarised in Appendix A. The nature of the groundwater is summarised below.

General Chemistry 2006-2013

The pH range of the groundwater is typically 7.1-7.6. Specific conductance (laboratory measurements) ranges from 2,000-24,000 µmhos/cm indicating a saline influence.

Ammonia (NH_3) concentrations range from <1 to 150mg/l (MW11, 2011) but are generally <50mg/l. The Florida clean-up standard of 28mg/l has been exceeded on seven occasions. Orthophosphate concentrations range from <0.1 to 0.76 mg/l and nitrate (NO_3^-) plus nitrite (NO_2^-) up to 0.83mg/l. This data indicates the groundwater contains elevated nutrients.

Biochemical oxygen demand (BOD) concentrations are typically <40mg/l excepting one result of 1,800mg/l in MW15 in 2013. Chemical oxygen demand (COD) concentrations range up to 2,000mg/l. There are no assessment criteria for either determinand.

Total dissolved solids range up to 13,000 mg/l and are typically 5,000 to 10,000 mg/l. The assessment criteria is 5,000 mg/l.

General Chemistry 2015

The field measurements of pH were in the range 6.7 to 7.1 which is a slightly lower range than that recorded on previous laboratory samples. Conductance ranged from 4,800uS/cm in new monitoring well MW19 near the site entrance to 29,750 uS/cm in MW11 on the eastern margin of the site. Groundwater ammonia varied from 4.4 to 270 mg/l with results from individual wells detailed in Table 3.3 and shown on Figure 2.

Table 3.3 Ammonia in Groundwater 2015

	Monitoring Well								
	MW8	MW9	MW10	MW13	MW14	MW15A	MW19	MW20	MW21
Ammonia (mg/l)	28	8	41	9	16	14	4.4	6.6	270

Grey highlighting denotes exceedance of Florida clean-up standard

The Florida clean-up standard of 28 mg/l has been exceeded in MW10 and new monitoring well MW21 which had the highest result yet recorded at the site. Ammonia concentrations are shown on Figure 3. As the groundwater is considered to be in hydraulic conductivity with surface water, the groundwater from all monitoring wells would be regarded as ‘poor’ in respect of ammonia when compared to UK river quality standards (Table 2.2).

Orthophosphate concentrations are shown in Figure 4 and range up to 1.2 mg/l and in some wells exceed concentrations recorded previously. Nitrate (NO3-) plus nitrite (NO2-) concentrations were in all cases recorded below detection level (<0.2mg/l).

COD in groundwater in April 2015 monitoring was typically up to 250 mg/l but recorded at 1,000 mg/l in new monitoring well MW21.

Metals 2006-2013

The majority of metal analysis have returned results below laboratory limits of detection (LoD). Only iron has been detected above the clean-up level of 3 mg/l with results ranging up to 11 mg/l. Magnesium has been recorded at concentrations of up to 530 mg/l reflective of a saline influence.

Mercury has not been detected above the laboratory LoD of 0.02 mg/l in any of the samples. The maximum lead and chromium concentrations of 0.05 mg/l and 0.035 mg/l respectively are below the assessment standard.

Metals 2015

Results are similar to previous observations with the majority of metals present below LoD or at very low concentrations well below the assessment criteria.

Volatile Organic Compounds (VOC) 2006-2013

All VOC results have been less than the LoD excepting carbon disulphide (one sample) and 1,4 dichlorobenzene (two samples) at <3µg/l (LoD is 1µg/l). A concentration of 8.5 µg/l chlorobenzene was recorded in MW10 in 2011.

Volatile Organic Compounds (VOC) 2015

All VOC results from 2015 (5 samples) were less than the LoD.

PCBs 2006-2013

Polychlorinated Biphenyls (PCB) analysis has been undertaken on 19 groundwater samples. All results are less than the LoD.

PCBs 2015

All PCB analysis results (5 samples) were less than the LoD.

Pesticides/Herbicides 2006-2013

Analysis for a number of pesticide/herbicide compounds has been undertaken on 7 groundwater samples. All results are less than the LoD.

Pesticides/Herbicides 2015

Analysis of 5 samples gave results that were all less than the LoD

Hydrocarbons 2011-2013

Diesel range organics analysis (DRO) has been undertaken on 7 samples of groundwater from 2011 to 2013. Results range from <1 to 3.8mg/l in MW18 in 2013.

DEH has noted that significant hydrocarbon release occurred from the waste oil storage area in 2004 as a consequence of the tidal surge associated with Hurricane Ivan overtopping the containment bund. Oil contamination of the perimeter canals is understood to have occurred, which was subsequently remediated.

Hydrocarbons 2015

DRO was undertaken all samples of groundwater. Results were typically in the range 0.07 mg/l to 1.5 mg/l with an outlier of 18 mg/l in new monitoring well MW21. Gasoline range organic analysis (GRO) was also undertaken on all samples which recorded concentrations below the limit of detection with the exception of new monitoring well MW21 which recorded 0.3mg/l. There is no Florida state assessment standard.

For the purpose of data contextualisation, the WHO guidance[10] states that the application of the lowest WHO guideline value for (aliphatic) hydrocarbons (0.3 mg/l for carbon bands C12-C16, i.e. 'diesel range') to a total hydrocarbon measurement in water will provide a conservative level of protection. This guideline value has been exceeded in all of the 2015 samples except MW13.

Phenol and Tributyltin 2015

Two groundwater samples were tested for both phenol and tributyltin. Results for both compounds were recorded below the relevant LoD.

3.4 Hydrology

Drainage Network

There is a dyke or canal located along the western margin of the site which aerial photography and site observation would suggest connects with a similar channel located parallel to the northern boundary of the landfill. The northern canal is open to North Sound which is located approximately 2,000 ft (600m) beyond the eastern boundary of the landfill. The water level within these canals will fluctuate with the tide; the tidal variation in the North Sound recorded by PBS&J in 1991 was in the order of 0.8 ft (0.24m). Data from an IOC sea level monitoring station at George Town indicates the tidal variation in North Sound at the time of water sampling on 14 April 2015 was approximately 1 ft (0.3 m). The depth of the canals are such that they will be

[10] Petroleum Products in Drinking-water, Background document for development of WHO Guidelines for Drinking-water Quality, WHO (WHO/SDE/WSH/05.08/123).

in hydraulic conductivity with groundwater. The northern channel has a piped connection below Esterley Tibbetts Highway. The drainage channels are fringed with mangroves.

Historical maps and aerial photographs show that canals also once crossed the landfill site. These canals were created to allow tidal flooding as part of mosquito control practices. Parts of the western margin of the North Sound have previously been subject to marine dredging to supply marl for land reclamation purposes. This includes the area to the east of the landfill site.

A surface water runoff interception trench is constructed along the northern toe of slope of the main landfill area. This trench was constructed to intercept run-off during storm events and prevent any flow direct into the drainage canal just beyond the northern boundary of the site. It was dry during the site inspections in November 2014 and April 2015 but it contains water on occasions as it is included in the DEH monitoring programme.

Within the landfill site are some areas of standing water, mainly in the northern part of Hurricane Ivan fill area. This water was estimated at up to 1 ft (0.3 m) deep in April 2015 and there is visual evidence of contamination by leachate. A sample was taken for analysis and data is reported below. It is noted the amount of standing water had reduced significantly since the site inspection in November 2014; this is consistent with the April 2015 sampling being undertaken at the end of the dry season on the islands.

Surface Water Quality

1991 Investigation

PBS&J carried out some surface water quality monitoring of the canals within and adjacent to the landfill in 1991. The canals within the site have since been removed by sub-water table excavations to recover marl and limestone and the resultant void filled with waste materials.

The findings of the monitoring are summarised as follows:

- The surface water was brackish;
- Elevated levels of nutrients were detected, including ammoniacal nitrogen up to 5.5 mg/l but generally <1 mg/l;
- None of the metals tested were above laboratory LoDs;
- Organic constituents were similar to those recorded in groundwater; and
- Benzene and toluene were detected at one of the locations within the site.

DEH Monitoring Programme – Perimeter Canals 2006 to 2014

DEH has carried out monitoring of surface water quality at the following locations (as shown on Figure 5):

- SW12 on the western canal adjacent to the hazardous waste store;
- SW3 on the northern canal adjacent to Esterley Tibbetts Way,
- SW2 on the northern canal adjacent to the eastern margin of the landfill; and,
- SW1 on the northern canal near the intersection with North Sound.

SW1, SW2 and SW3 have each been monitored on 5 occasions between 2006 and 2013 and SW12 on 3 occasions between 2010 and 2013.

Amec Foster Wheeler Sampling 2015

Amec Foster Wheeler undertook surface water sampling in April 2015 at the same four locations historically sampled by DEH.

Additional samples were taken at:

- SW20 (in the north canal on the eastern boundary of the wastewater treatment works);
- Pond (a pond lying to the south of the track by the North Canal adjacent to North Sound); and
- Leachate (a shallow surface water pond on the landfill).

Locations are identified on Figure 5. Three further samples were taken in North Sound and are reported in the marine water quality section below.

Assessment Criteria

The data (excepting that for the leachate sample) has been screened against the Florida marine surface water clean-up targets as the canal surface water is in direct continuity with the North Sound. The data and screening criteria are summarised in Appendix B. Time series plots for BOD, COD and ammoniacal nitrogen are included in Appendix C.

The following summary can be drawn from inspection of the surface water quality results and associated graphical plots.

General Chemistry

The pH range of canal water recorded on lab samples up to 2013 is typically 7.3-8.2. The pH field monitoring in 2015 recorded values of between 6.9 and 7.8. Specific conductance on lab samples up to 2015 ranges from 22,000-130,000 µmhos/cm indicating saline conditions. Field conductivity values recorded in April 2015 range for 13,920 µS/cm at SW12 to 50,270 µS/cm at the canal mouth with North Sound reflecting increasingly saline conditions from west to east.

The BOD recorded in the canals during the 2015 sampling was in the range 10-15 mg/l. The spatial distribution including samples taken in North Sound is shown on Figure 6. Previously recorded (up to 2013) BOD concentrations were up to 30mg/l in the perimeter canals. COD concentrations have historically been recorded up to 11,000mg/l but did not exceed 270mg/l in the April 2015 sampling. Total dissolved solids typically range up to 30,000mg/l. There are no marine water assessment criteria for any of these determinands.

Historical ammonia concentrations up to 2013 range from 0.3 to 13 mg/l. The April 2015 sampling identified concentrations of between 2.0 and 6.5 mg/l in the perimeter canals. The spatial distribution of ammonia in surface water including samples taken in North Sound is shown on Figure 7. The observed ammonia concentrations in the perimeter canals reflect poor water quality based on UK guideline values.

Previously recorded orthophosphate concentrations range up to 0.44mg/l (SW1 in 2013). Concentrations recorded in April 2015 are shown on Figure 8 and were a maximum 0.12mg/l. On the basis of the recent round of data, the observed orthophosphate concentrations reflect moderate water quality based on UK guideline values. Nitrate plus nitrite concentrations were below the LoD in the canal samples.

These data indicates the canal water contains elevated ammonia and orthophosphate but to a lesser extent than in groundwater.

Turbidity is recorded for which there is a Florida marine water clean-up standard of 29 NTU. This has been exceeded on 6 occasions with 2 occasions each at SW1, SW2 and SW3. The maximum recorded value was found at SW1, the outfall to north Sound, where a value of 94 NTU was measured in 2010.

Metals

The majority of metal analyses have returned results below laboratory LoDs. Only iron has been detected above the clean-up level of 3 mg/l, on one occasion at SW1 in 2006 and at SW12 in 2010, when elevated chromium was also recorded. Magnesium has been recorded at concentrations of up to 1400 mg/l, which is representatives of a saline influence.

Mercury has not been detected above the laboratory LoD of 0.02 mg/l in any of the samples. The lead concentrations have not exceeded LoDs.

Dissolved Metals

Dissolved metals analysis was undertaken on samples from SW2, SW3 and SW20. These results have been compared against the total metals analysis and show fairly good agreement. This indicates that much of the concentration of individual metals within the samples is in a dissolved state. The sample from SW3 was analysed for dissolved metals only and recorded exceedences of the relevant clean-up levels for copper and lead.

Volatile Organic Compounds (VOC)

All VOC results have been less than the LoD excepting 13 µg/l of methyl ethyl ketone measured in the sample from SW12 in 2013. The relevant LoD is 10 µg/l.

PCBs

PCB analysis has been undertaken on 14 surface water samples. All results are less than the LoD.

Pesticides

Analysis for a number of pesticide compounds has been undertaken on 6 surface water samples. All results are less than the LoD.

Hydrocarbons

DRO analysis has been undertaken on 7 samples of surface water. Results range from 0.33 to 0.84 mg/l measured in the sample from SW12 in 2013. Two samples for the April 2015 sampling were also tested for GRO and returned results below LoD.

For the purpose of data contextualisation, WHO guidance states that the application of the lowest WHO guideline value for (aliphatic) hydrocarbons (0.3 mg/l for carbon bands C12-C16, i.e. 'diesel range') to a total hydrocarbon measurement in water will provide a conservative level of protection. This guideline value has been exceeded in the samples from SW2 (2011 sample) and SW12 (2011, 2013 and 2015 samples). The results from the SW1, SW3 and SW20 (2015 samples) were all below this limit.

DEH Monitoring Programme – Landfill Drains

In addition to the surface water sampling described above sample SW7 is taken from the northern interception trench within the landfill area when this contains water. Samples have been taken at this location on 6 occasions during the period 2006-2013. The drain was dry during the sampling episode in April 2015. The reported results for ammonia concentrations range between 1.3 and 54 mg/l and are higher than those in the perimeter canals. Iron has been recorded above the marine water assessment criteria on one occasion. Other metal concentrations are below the assessment criteria. VOC concentrations have been less than detection with the exception of 5.2 µg/l carbon disulphide in 2007 (LoD is 2µg/l).

Marine Water Quality

Marine Ecology North Sound

A concise marine environmental evaluation report dated 2012[11] is included as an annex to the Task 1 environmental review. This reference notes dense turtle grass (Thallassia testudinum) observed three quarters of the way into the mouth of the northern canal with the grass blades showing moderate epiphyte growth. Nutrients affect the epiphyte density of the sea grasses. A plume of solids from the canal is apparent in an aerial photograph within the report.

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[11] Marine Environmental Evaluation Report for the George Town Landfill, MA Roessler & Associates, 25 May 2012 (Annex to Cardno ENTRIX draft Environmental Statement).

The evaluation report notes that approximately 60% of the North Sound is covered by well-developed beds of Thallassia testudinum.

DoE Sampling

DoE has carried out annual sampling of the water quality in the North Sound in the period 2006-2013 for a limited number of parameters. These are:

- Conductivity, temperature, pH;
- Salinity, dissolved oxygen, suspended solids;
- Nitrate-nitrite, reactive phosphate;
- Chlorophyll and faecal coliforms.

The following sample points are relevant to this study:

- Station 11 in the middle of North Sound which should be representative of background marine water quality;
- Station 14 near to the northern canal outfall with North Sound (similar to DEH sample point SW1 and Amec Foster Wheeler 2015 sampling point NS#1); and
- Station 13 in North Sound beyond the northern canal outfall.

These locations are shown in Figure 5.

Time series plots for the period 2006-2015 for suspended solids, nitrate-nitrite, reactive phosphorous and chlorophyll for each of these stations are included in Appendix C. The data shows:

- Suspended solid concentration at station 14 are variable from <10 to 60mg/l. Those at station 11 are <5mg/l and indicate that solids leaving the canal system are rapidly dissipated.
- Reactive phosphorous and nitrate concentrations at station 14 are several times those at stations 11 and 13. These data indicate that nutrients leaving the North Canal are rapidly dispersed.
- Chlorophyll levels at Station 14 are typically 5 to 60mg/m3, those at Station 13 <1 to 5 mg/m3 and those at Station 11 are <1 mg/m3. The data confirm that the nutrient loading of waters leaving the North Canal are being dispersed.

Amec Foster Wheeler Sampling 2015

Amec Foster Wheeler took water samples for analysis from four locations within North Sound on 13 April 2014. The locations are summarised in Table 3.4 and shown on Figure 5.

Table 3.4 Surface Water Sample Locations

Location Ref	Location Description	Note
NS#1	North Sound at outflow of North Canal	Equivalent to DEH monitoring point SW1
NS#2	North Sound approximately 400 ft (123 m) from North Canal outflow	
NS#3	North Sound approximately 640 ft (200 m) from North Canal outflow	
NS#4	North Sound approximately 1400 ft (427 m) from North Canal outflow	

Key analytical results are summarised in Table 3.5.

Table 3.5 North Sound Water Analysis April 2015 Key Parameters

	NS#1 (SW1)	NS#2	NS#3	NS#4	Trend NS#1 to NS#4
Alkalinity, Total - mg/l	200	160	140	120	Decrease
Ammonia - mg/l	2.5	1.1	0.51	<0.020	Decrease
BOD - mg/l	10	3.0	<2.0	<2.0	Decrease
COD - mg/l	260	200	200	200	Generally decrease
Chloride - mg/l	19,000	21,000	20,000	21,000	Similar
Nitrate Nitrite as N - mg/l	<0.018	0.044	0.087	0.059	Variable
Nitrogen, Kjeldahl - mg/l	3.7	1.7	1.0	0.38	Decrease
ortho-Phosphate - mg/l	0.10	0.052	0.025	<0.015	Decrease
Salinity – ppth	31	34	34	36	Increase
Sulphate - mg/l	2,600	2,900	2,800	2,900	Variable
Total Dissolved Solids - mg/l	39,000	39,000	43,000	40,000	Variable
Total Organic Carbon - mg/l	10	7.5	4.5	2.7	Decrease
Total Suspended Solids - mg/l	23	20	12	11	Decrease
Turbidity – NTU	3.6	4.1	2.0	0.8	Generally decrease
Faecal coliform CFU/100mL	220	-	6	-	Decrease
Dissolved Chromium – mg/l	0.014	0.017	0.012	-	Similar
Dissolved Copper – mg/l	0.057	0.066	0.046	-	Similar
Dissolved manganese mg/l	0.015	0.0094	0.0055	-	Decrease

The final column of the table shows the general trend in concentrations from NS#1 to NS#4 i.e. from the canal mouth out into North Sound. The data shows that the canal is a source of ammonia, orthophosphate, BOD and COD but there is relatively rapid dilution/dispersion of the canal discharge into North Sound. Dissolved metal concentrations are very low throughout, and with the exception of chromium, copper and manganese generally below the LoD. The data suggests low levels of dissolved manganese in canal water but this is rapidly diluted in samples further out into North Sound.

3.5 Soil and Biota Sampling

Sediment Sampling

1991 Sediment Investigation

PBS&J carried out some sediment sampling in 1991 within the canal to the north of the landfill and at a point in the North Sound approximately 2575 ft (785m) north of the canal discharge into the sound. The samples were tested for a limited suite of metals and PCBs, with the results summarised in Table 3.6.

Table 3.6 1991 Sediment Sample Results (4 samples)

Determinand	SS4 North Canal on east landfill boundary	SS3 North Canal east of water treatment works	SS2 North Canal Outfall to North Sound	SS1 North Sound
Chromium mg/kg	6.72	6.6	4.84	<4
Iron mg/kg	962	816	495	298
Mercury mg/kg	<0.02	<0.02	<0.02	<0.02
Lead mg/kg	<5	<5	<5	<5
PCB mg/kg	179	2.1	<2	<2

The contamination gradient, based on very limited data, indicates the origin of the canal sediment contamination to be the landfill site.

Amec Foster Wheeler 2015

Amec Foster Wheeler took three sediment samples from the North Canal (SW2, SW3 and Sediment #4), two (which includes a duplicate) at the outfall of the north canal to North Sound (Sediment #1), and two within North Sound (Sediment #2 and Sediment #3). Sediment sample locations are shown on Figure 9.

All samples were tested for metals and four for PCBs and pesticides. Metals results are recorded at less than the LoD with the exception of the following:

- Arsenic at 4.7 mg/kg at Sediment #2 in North Sound;
- Chromium 63 mg/kg at SW2, 15-20 mg/kg at Sediment #1/duplicate and 4.3-4.5 mg/kg at Sediment #2 and #3;
- Cobalt 2.4 mg/kg at SW2;
- Copper 16-21 mg/kg at Sediment #1/duplicate, <4mg/kg in all other samples;
- Lead 13-18 mg/kg at Sediment #1/duplicate and SW2, ≤5 mg/kg in all other samples;
- Mercury max 0.092 mg/kg at SW2;
- Nickel 6.4-10 mg/kg at Sediment #1/duplicate and SW2, <3 mg/kg in other samples;
- Selenium 7.2-10 mg/kg at Sediment #1/duplicate and SW2, <4mg/kg in other samples;
- Vanadium 33-44 mg/kg at Sediment #1/duplicate and SW2, <10 mg/kg in other samples; and
- Zinc 55-73 mg/kg at Sediment #1/duplicate, <12 mg/kg elsewhere.

No PCBs or pesticides were found above the LoD. Sulphate content was elevated at Sediment #1/duplicate at 8,100-9,300 mg/kg with the next highest reading being 3,800 mg/kg at SW2. The elevated sulphate could be a source of the hydrogen sulphide odour noted on occasion near the mouth of the north canal.

There are no definitive assessment standards for sediments. The values have been screened against the Florida soil clean up targets relating to leachability to marine water where assessment standards exist for chromium, mercury, nickel and selenium. The concentrations recorded for these metals area all less than the assessment levels with the exception of chromium where the standard was exceeded in SW2. However the standard is derived on the assumption that the chromium in in the hexavalent form, which is very unlikely. Hexavalent chromium was detected in canal surface water at SW2 but at a concentration several times below the Florida clean-up standard for marine surface water.

Biological Sampling

1991 Investigation

PBS&J in 1991 collected samples of mangrove from the sides of the canal, algae and sea grass from the north canal at the point of discharge in to the North Sound and Turtle grass from a site in the North Sound. The sampling methodology is unknown. Mercury is reported in two mangrove samples at 50mg/kg (MS-3 6/91) and 43.8mg/kg (MW-4 6/91) but these are believed to be erroneous results as it is the same result for iron in an adjacent column of the typed report table and was found at <0.02 mg/kg in a repeat sample MS-3 9/91 and in all other vegetation samples (MW-4 was not resampled). Chromium was detected in the algal sample (8.5 mg/kg) and iron in the Turtle grass sample SS-2 from the mouth of the north canal at 880 mg/kg which is above background.

PBS&J trapped some minnow-sized fish species within one of the canals north of the landfill area (this would have been relatively remote from the area of waste disposal at that time). Some mercury was detected (0.53mg/kg) which was above expected levels.

2015 Investigation

Amec Foster Wheeler collected four samples of mangrove and similar species leaf from trees fringing the canals/dykes around the western and northern perimeters of the site. The test suite was limited to selected metals, including mercury, and PCBs. The following were recorded above the relevant LoD:

- Iron: 10-58 mg/kg
- Chromium: up to 0.26 mg/kg
- Lead: up to 1.4 mg/kg
- Potassium: 370-3,500 mg/kg

All mercury and PCB test results were below the relevant LoD.

Five samples of marine vegetation were collected from the sea bed for analysis, two from the mouth of the north canal discharge to North South and four further samples (including one duplicate for sample ref: Manatee Grass #2) at locations further out into North Sound. The test suite was the same as that for the mangrove samples. The following were recorded above the relevant LoD:

- Iron: 38-180 mg/kg
- Chromium: up to 1.3 mg/kg
- Lead: up to 1.1 mg/kg
- Nickel: up to 0.71 mg/kg
- Potassium: 1,200-3,000 mg/kg

The higher chromium and nickel values were associated with algae at location NS#1 where the North Canal drains into North Sound. All mercury and PCB test results were below detection.

There are no specific assessment standards for metals in marine vegetation.

Soil Sampling

DEH Soil Sampling 2011-2013

DEH has carried out some sampling of soils from the banks of perimeter canals. Samples were collected above the normal water level adjacent to some of the surface water sample locations and also from surface soils adjacent to some of the MW monitoring point locations. Forty datasets are available for the period 2011-2013. Data has been screened (Appendix D) against the Florida soil clean-up standards for both:

- Direct exposure for commercial/industrial use and;
- Leachability based on groundwater of low yield/poor quality (assessment criteria are available for a limited number of metals).

Metal concentrations are below the assessment criteria with the exception of arsenic which exceeded the Florida direct exposure clean-up criteria of 12 mg/kg at locations SW7, MW5 and MW13 with a maximum concentration of 60 mg/kg. It is noted the Florida clean-up standard for arsenic is exceptionally low when compared to UK assessment criteria for the same commercial/industrial use scenario (which is 640 mg/kg). Concentrations of up to 40 mg/kg are typical of background in the UK for naturally occurring soils, but this is expected to be less for the limestone derived soils on the Cayman Islands. Another potential source of soil arsenic is from the past burning of treated timber.

No metal values exceed the leachability criteria for groundwater of low yield/poor quality, but would exceed the criteria for leachability for marine surface water.

PCB test results (30 No) for soils are all below LoD. Pesticide suite test results (11 No) are also less than LoD with the exception of:

- 11 µg/kg 4.4,DDD at MW5 in 2013;
- 4.1 µg/l 4.4,DDE at MW5 in 2013, and
- 7.8 µg/l endrin aldehyde at MW15 in 2013.

These compounds are present at concentrations well below assessment standards for direct exposure or leachability to groundwater of poor quality.

Amec Foster Wheeler Sampling 2015

Seventeen samples of surface soil were collected from across the Hurricane Ivan fill area for asbestos analysis. No asbestos was detected in any of the samples.

3.6 Landfill Gas

The site receives municipal wastes including organic materials such as food and kitchen wastes, garden wastes, paper, cardboard and timber and can therefore be expected to be producing landfill gas. This is typically a mixture of methane and carbon dioxide together with trace components such as hydrogen, hydrogen sulphide and volatile organic compounds including halogenated organics, aromatic hydrocarbons, alkanes and ketones[12]. The trace compounds present in landfill gas give it an odour.

Site Inspection 2014

There has been no landfill gas monitoring carried out at the site historically. Amec Foster Wheeler undertook some initial measurements during the site inspection on 14 November 2014 by monitoring methane and

[12] Guidance on the Management of Landfill Gas. UK Environment Agency Landfill Technical Guidance Note (LFTGN) 03. September 2004.

carbon dioxide concentrations on the landfill surface. The data is reported in the Task 1 environmental review, but in summary, methane concentrations of up to 0.8%v/v were recorded in surface cracks and fissures in the waste which confirms the site is actively generating landfill gas.

Gas Probes 2015

Gas monitoring and sampling was undertaken on 10 April 2015 from gas probes (GP1 to GP6) which were installed within the waste mass in April 2015. The gas probe locations are shown on Figure 10.

Landfill gas monitoring data collected prior to the gas sampling using the portable infra-red gas analyser is presented in the Task 2 investigation factual report. The data shows methane and carbon dioxide concentrations indicative of landfill gas (~50-60% methane and ~25-45% carbon dioxide) with no or little (~2% or less) oxygen in all probes except GP1, located in the north-east of the site adjacent to a haul road. GP1 showed much lower concentrations of methane (1.8% v/v) and carbon dioxide (1.5% v/v) and oxygen around atmospheric concentration (21.5% v/v).

The gas analysis suite consisted of bulk gas constituents (C1-C4 hydrocarbons, carbon dioxide, nitrogen, oxygen, hydrogen and helium) as well as hydrogen sulphide, carbon monoxide and non-methane volatile organic compounds (NMVOCs).

Gas analysis results are included in the Task 2 investigation factual report and are summarised as follows:

- Carbon dioxide: 7.8 v/v (GP1) to 43% v/v (GP4) with all results above 30% v/v except GP1 and GP6;
- Methane: 11% v/v (GP1) to 59% v/v (GP2) with all results at, or above, 50% except GP1;
- Oxygen: 0.39% v/v (GP4) to 18% v/v (GP1) with all results <1% v/v except GP1 and GP6;
- Nitrogen: 5.5% v/v (GP2) to 68% v/v (GP1) with all results below 10% v/v except GP1 and GP6;
- Carbon monoxide, ethane, ethylene, helium, propane and propene: all results below relevant LoD;
- Hydrogen: all results below LoD except GP6 (0.012% v/v);
- Hydrogen sulphide: 0.46 ppm (GP1) to 2,300 ppm (GP3) with all results below 20 ppm except GP3 and GP5 (85 ppm);
- NMVOCs: below LoD except:
  - 1,2,4-Trimethylbenzene (16-850 ppb, all samples except GP6);
  - 1,2-Dichloroethane (27-57 ppb, GP2, 3 and 5);
  - 1,3,5-Trimethylbenzene (12-450 ppb, all samples except GP3);
  - 2-Butanone (MEK) (44-13,000 ppb, all samples);
  - 4-Methyl-2-pentanone (MIBK) 15-1,000 ppb, (GP1, 3 and 4);
  - Acetone (2,100-44,000 ppb, all samples);
  - Benzene (150-2,200 ppb, all samples);
  - Benzyl chloride (17-590 ppb, GP1, 4 and 5);
  - Carbon disulphide (78-1,200 ppb, all samples);
  - Chlorobenzene (37-38 ppb, GP5 and 6);
  - Chloromethane (780 ppb, GP4);
  - cis-1,2-Dichloroethene (62-110 ppb, GP2 and GP5);

- Dichlorodifluoromethane (38-460 ppb, GP4 and GP6);
- Ethylbenzene (82-1,300 ppb, all samples);
- m,p-Xylene (74-2,400 ppb, all samples);
- Methylene Chloride (14-4,600 ppb, all samples except GP2);
- o-Xylene (31-870 ppb, all samples);
- Styrene (16-570 ppb, all samples except GP2 and GP3);
- Tetrachloroethene (23 ppb, GP5);
- Toluene (150-3,300 ppb, all samples);
- Trichlorofluoromethane (40 ppb, GP6); and
- Vinyl chloride (110-2,400 ppb, GP2 and GP6).

Concentrations of bulk LFG (methane, carbon dioxide, oxygen and nitrogen) are largely consistent with the pre-sampling field data, although the concentrations of methane and carbon dioxide detected in GP1 and the laboratory analysis are substantially higher than the field results, whereas the oxygen concentration is lower. After the pre-sampling field data was taken, each probe was pumped for approximately 5 minutes until readings stabilised to allow sampling. Therefore, the results of the sample analysis are likely to be much more representative than the pre-sampling field data.

The low/below LoD hydrogen concentrations recorded are fairly typical of a landfill in the long methanogenic stage of landfill gas generation.

The hydrogen sulphide concentrations recorded are typical of those usually measured in landfills, although the result from GP3 is around two orders of magnitude higher than the other results. It is possible that the higher concentration recorded in GP3 is attributable to sulphate-based wastes (typically gypsum) landfilled within the vicinity of the probe.

With regard to the NMVOCs, those detected above the relevant LoD are all typical trace components within landfill gas. Some of the trace compounds detected, such as carbon disulphide, toluene and xylene, as well as hydrogen sulphide, are odorous components of landfill gas.

3.7 Fugitive Emissions

Flux Boxes 2015

Flux box monitoring was undertaken on 11 April 2015 in three locations on the landfill surface, including two uncapped areas (Flux Box 2 and 3) and one capped area (Flux Box 1). The flux box monitoring followed the methodology set out in the Task 2 investigation factual report. The flux box locations are shown on Figure 10.

The results of the flux box testing are summarised as follows:

- Flux box 1: No methane was detected during the test (<0.1%). Carbon dioxide concentrations began at 0.1% v/v and increased to 0.2% v/v after 30 minutes. Oxygen concentrations remained around 22% v/v (i.e. atmospheric concentrations) throughout the test.
- Flux box 2: No methane was detected during the test (<0.1%). Carbon dioxide concentrations began at 0.2% v/v and increased to 0.3% v/v after 5 minutes. Oxygen concentrations remained around 22% v/v throughout the test.
- Flux box 3: No methane was detected during the test (<0.1%). Carbon dioxide concentrations began at 0.0% v/v and increased to 0.1% v/v after 1 minute, 0.2% v/v after 8 minutes, 0.3% v/v after 20 minutes and 0.4% v/v after 25 minutes. Oxygen concentrations remained around 22%v/v throughout the test.

The results show that there are no detectable methane emissions from the landfill surface, although this is based on results obtained with an infra-red landfill gas analyser with a methane detection limit of 0.1% v/v (1,000 ppm). There is an intention to repeat the survey in future using a portable laser methane analyser, which is capable of being air freighted onto the island and can detect methane at a much lower 1 ppm, when a suitable opportunity arises.

For the purposed of air quality modelling gas emission rates have been assessed using GasSim as noted in section 2.3.

Hydrogen Sulphide Monitoring 2015

Fugitive hydrogen sulphide measurements in air were undertaken on and adjacent to the George Town landfill site on 11 April and 18 April 2015, following the methodology set out in the Task 2 investigation factual report. The weather conditions during the duration of each survey was as follows:

- 11 April wind direction from 70^0 to 90^0 at 5-8 knots, 25-27°C;
- 18 April wind direction from 120^0 at 6 knots, 28°C

The survey results for each day are presented on Figures 11 and 12. The results show the following:

- The first survey, on 11 April 2015, was undertaken across and around the landfill, at the site entrance, along the North Canal to North Sound and at other off-site locations including the Lakeside development to the west, the International School to the north and the AL Thompson store to the south. The highest result of 195 ppb was on the eastern landfill boundary adjacent to the water treatment works, with the next highest result of 179 ppb recorded at the mouth of the North Canal into North Sound.
- Of the 66 locations surveyed on 11 April, around one third (including the Lakeside Development and the International School) were 0 ppb and around half of the results were between 1 and 10 ppb (the AL Thompson store was 6.65 ppb). There were only 3 locations where >100 ppb hydrogen sulphide was detected, which were all either adjacent to the North Canal or the landfill boundary with the water treatment works.
- In general, the highest readings taken on the landfill were in the north-eastern part, which is adjacent to the water treatment works. The highest readings on the North Canal were away from the landfill, adjacent to the North Sound, and the concentrations fell sharply when moving away from the canal mouth back towards the landfill. The highest reading within the landfill, away from the boundaries, was 80.16 ppb, recorded near the top of the landfill adjacent to a large open pit used for disposal of animal carcasses and other difficult waste.
- The second survey, on 18 April 2015, was undertaken in fewer locations than the first survey, concentrating on areas where the higher results were recorded in the first survey, as well as the North Canal, Lakeside Development and International School. The highest result of 8.06ppb was recorded near GP1 in the north-east of the landfill, adjacent to the boundary with the water treatment works.
- Of the 23 locations surveyed on 18 April, some 14 locations (including the Lakeside Development, the International School and the AL Thompson store) were 0 ppb and the remainder of the results were between 1 and 10 ppb. At the mouth of the North Canal, a concentration of 5.7 ppb was recorded, with the only other two positive results along the north canal recorded north of the water treatment works to the north-east of the landfill.

By way of comparison, the WHO guideline value[13] for hydrogen sulphide for preventing odour nuisance is 7µg/m^3, which equates to 4.66 ppb. This value was exceeded in around two-thirds of the results from the first survey and three of the results from the second survey. The WHO long-term and short-term average guideline values are 140 µg/m^3 and 150 µg/m^3 respectively, which equate to 93.3 ppb and 100 ppb respectively. These guideline values were exceeded in three locations in the first survey, which were all

[13] Air Quality Guidelines for Europe. Second Edition. WHO, 2000

either adjacent to the North Canal or the landfill boundary with the water treatment works, but in no locations during the second survey.

Dust Sampling and Deposition Monitoring 2015

The landfill is a potential source of fugitive dust emissions. Some areas of waste are covered but there are large areas of exposed waste.

Dust sampling was undertaken in two locations (DM1 and DM2) in accordance with the methodology set out in the Task 2 investigation factual report. In each location, and as before, the sampling apparatus were run twice on subsequent days; once with a sampling cartridge for asbestos analysis and once with a sampling cartridge for metal analysis.

The results of the sampling are provided in the Task 2 investigation factual report and show the following:

- Asbestos fibres were not detected above the LoD in either sample; and
- The suite of metals analysed (antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, nickel, selenium, silver, thallium, vanadium and zinc) were not detected above the relevant LoD in either sample.

Dust deposition monitoring was undertaken in accordance with the methodology set out in in the Task 2 investigation factual report. The dust deposition measurement locations described in Table 3.7 and are shown on Figure 10.

Table 3.7 Dust Deposition Monitoring Locations - George Town Landfill

Monitoring Run	Location	Run time (mins)	Date and comments
Unit 001886 Serial 4442			
Run 2	Adjacent to MW14	25	Run on 8 April 2015 during groundwater sampling of MW14 as suitable location downwind of landfill site. Three separate runs (2, 4 and 5) as instrument turned off during rain showers.
Run 4	Adjacent to MW14	44	Run on 8 April during groundwater sampling of MW14 as suitable location downwind of landfill site. Three separate runs (2, 4 and 5) as instrument turned off during rain showers.
Run 5	Adjacent to MW14	228	Run on 8 April during groundwater sampling of MW14 as suitable location downwind of landfill site. Three separate runs (2, 4 and 5) as instrument turned off during rain showers.
Run 6	Adjacent to Gas Probe 1	49	Run 10 April during gas sampling of Gas Probe 1 within landfill.
Run 7	Adjacent to Gas Probe 2	32	Run 10 April during gas sampling of Gas Probe 2 within landfill.
Run 8	Adjacent to Gas Probe 3	45	Run 10 April during gas sampling of Gas Probe 3 within landfill.
Unit R10256 Serial 6709			
Run 1	Adjacent to MW19	33	Run on 8 April during drilling of MW19. Location downwind of landfill.
Run 2	In waste drop off area at site entrance	16	Run on 8 April during drilling of MW19. Location downwind of landfill.
Run 3	Adjacent to MW14	145	Run on 9 April as suitable location downwind of landfill site.
Run 4	Adjacent to MW8	84	Run on 9 April during groundwater sampling of MW8. Location generally upwind of landfill.
Run 5	Adjacent to MW11	77	Run on 9 April during groundwater sampling of MW11. Two separate runs (5 and 6) as instrument turned off during rain showers. Location generally upwind of landfill.
Run 6	Adjacent to MW11	58	Run on 9 April during groundwater sampling of MW11. Two separate runs (5 and 6) as instrument turned off during rain showers. Location generally upwind of landfill.
Run 7	Adjacent to DM2	129	Run on 11 April. Location downwind of landfill.

Runs 1 and 3 on unit 001886 were aborted and re-run as runs 2 and 4 respectively.

Dust deposition measurement data are included in the Task 2 investigation factual report. In summary, the overall average concentration of dust measured on each run ranged between 0.01 mg/m^3 and 0.036 mg/m^3 with the highest concentration recorded adjacent to monitoring well MW14 on 8 April 2015. Note that this location is downwind of the main landfill area of the site.

The particle size range of maximum response for the dust deposition monitor is 0.1 to 10 µm (i.e. 'PM_{10}'). By way of comparison, the EC/UK Air Quality Standard[14] for PM_{10} is 50 µg/m^3 (0.05 mg/m^3) based on a 24 hour mean, which was not breached in any of the locations monitored.

[14] The Air Quality Standards Regulations 2010

Other Vapour Sources

The waste oils storage area and hazardous waste storage areas are a potential source of vapours. No vapour monitoring is undertaken at the site.

Fires

A number of fires have been reported at the George Town landfill. These have caused particular problems and concerns when they have spread to stockpiled waste tyres.

The local press (Cayman Compass) reported a fourth fire at the landfill in 2014 on 18 August, see: http://www.compasscayman.com/caycompass/2014/08/18/Fire-ignites-again-at-landfill/ and a further fire reported on 1 March 2015 http://www.compasscayman.com/caycompass/2015/03/03/Firefighters-monitor-landfill/

Smoke and combustion products from landfill fires is a potential contaminant source. It is recommended that air monitoring for PAHs be undertaken on the downwind boundary of the landfill during any further fires.

3.8 Air Quality Modelling

Estimation of LFG Surface Emissions

A GasSim model of the Grand Cayman landfill site active tipping area was compiled, based upon the available data supplied on the level and composition of waste inputs. A copy of the output graphs for the model is included in Figure 13.

The peak gas generation rate was estimated to be 595 m^3/h across the 6.25 ha of active main landfill surface (see Figure 1 for location, this excludes the old landfill area and Hurricane Ivan fill area). On that basis, the equivalent areal emission rate of landfill gas is calculated to be 0.00952 $m^3/m^2/h$. This equates to 3.3 mg LFG/m^2/s. Figure 6.7 in the EA technical guidance document LFTGN 03 shows that this would be at the upper end rate for sites with a soil cap. Similarly, this figure also equates to 285 g LFG/m^2/day, which, in Figure 6.6 of the above document, is appropriate for sites without active gas controls, which is the case for George Town landfill.

Estimation of Odour Emission Rates

Whilst it would be theoretically possible, using the predicted surface LFG emissions above, to calculate an odour emission rate due to landfill gas emissions, this would be a potential inaccurate under-estimate for two reasons: firstly, it would ignore the odour component arising from the landfilled wastes themselves and, secondly, the odour concentration of the landfill gas is not known. Accordingly, an emission rate was sourced from a recent research report[15], where measured odour emission rates from active deposition areas on UK landfills are reported (Table 7 on page 28 of the report). Taking an average of the reported values yielded an odour emission rates from the landfill surface of 0.55 $ou_E/m^2/s$, where 'ou_E' is a European Odour Unit. This emission rate was applied uniformly across the active landfill area.

Dispersion Model Set-up

The dispersion model used in this assessment is the ADMS 5 (Service Pack 1) code[16]. For near field (up to 100 km from emission sources) modelling studies, ADMS is one of two preferred "new generation" dispersion models in wide use internationally, the other being AERMOD.

The ADMS model was configured as indicated in Table 3.8.

[15] SNIFFER (2013) Odour Monitoring and Control on landfill Sites. http://www.sniffer.org.uk/files/2813/7476/3982/ER31_Final_Report.pdf
[16] http://www.cerc.co.uk/environmental-software/ADMS-model.html

Table 3.8 ADMS Model Configuration

Parameter	Value	Comments
Emission Source	Polygonal ground-level area source with UTM vertices: 460801, 2135402 460747, 2135421 460476, 2135324 460463, 2135257 460559, 2135139 460689, 2135109 460765, 2135119 460832, 2135183	Emission Source
Receptors	A regular Cartesian grid of receptors spaced at 72.5 metre intervals. Discrete receptors with UTM co-ordinates: 460320, 2134932 460284, 2134992 460262, 2135025 460216, 2134997 460167, 2134913 460004, 2135267 459996, 2135336 459982, 2135440 459956, 2135534 459962, 2135606	Parkside Close and the Lakeside Development
Emission rates	Odour - 0.55 $ouE/m^2/s$	Uniform across active landfill area
	Trace Pollutants – Unit emission rate	Individual pollutant emission rates calculated from LFG analytical data and factored by dispersion co-efficient in model
Surface roughness	0.5 m	Typical for parkland & open suburbia
Meteorological data	3330 hours of non-sequential hourly average wind speed, direction, temperature, relative humidity, cloud cover from Owen Roberts International Airport between April 2013 and May 2015.	Although not a full year of data, considered to cover a representative spread of typical meteorological conditions
Output data	Odour - 98^{th} percentile of hourly average concentrations	To allow assessment against typical odour annoyance criteria
	Trace pollutants – annual (period) average and maximum hourly average	To allow comparison with air quality standards & guidelines

Figure 14 shows a schematic of the model domain, identifying the emission source and discrete receptors and Figure 15 shows a wind rose, constructed from the supplied meteorological data.

Data Processing and Outputs

Odour

Concentrations of odour at discrete receptors and on the receptor grid were calculated as the 98^{th} percentile of hourly averages over the period of meteorological data and are supplied as numerical values and an isopleth (contour) plot, respectively. These values are generated automatically by the ADMS dispersion model.

Trace Pollutants

In order to calculate the ambient concentrations of trace pollutants contained in the emission of LFG from the landfill surface, the ADMS model was set up with a unit emission rate, from which it was then possible to derive a dispersion factor from the source to each of the discrete receptors. This dispersion factor for each of the receptors was then multiplied by the calculated emission rate of each individual trace pollutant from the landfill surface, which itself had been calculated from the analysis of LFG samples.

Period (annual) average and maximum hourly average concentrations were derived and compared with relevant assessment criteria (see below).

Assessment Criteria

Odour

Odours are not generally additive in the same way as other annoyance parameters such as decibels for noise[17]. This reflects the way in which the brain responds to odour. The human brain has a tendency to screen out those odours which are always present or those that are in context to their surroundings. For example, an individual is more likely to be tolerant of an odour from a factory in an industrial area than in the countryside. The human brain will also develop a form of acceptance to a constant background of local odours.

Odour assessments in the UK, EU and some locations outside the EU use the odour unit as the standard reference figure. A European Odour Unit (ou_E/m^3) is a term used to describe the amount of odour that, when evaporated into a cubic metre of clean air, is sufficient to reach the detection threshold of a panel of screened and selected human subjects. The process of measuring odour is called olfactometry.

Limited research is available into what constitutes an appropriate and workable odour standard for sewage treatment. The Concise Guide[18] considers that an odour at five times its detection threshold (effectively 5 ou_E/m^3) can be considered as having the potential to cause annoyance. Although this is not directly aimed at the waste industry, it provides for a common guideline as to the historical approaches that have been adopted.

Research in the Netherlands[19] has highlighted the complexity of the assessment of odours. It states that situations exist where 5 ou_E/m^3 has been achieved and no complaints have been received, yet cases also exist where 1 ou_E/m^3 has been achieved and complaints were still received. Here, the Netherlands Emission Guidelines for Air considers that the exposure concentration where complaints escalate is at concentrations above 2.5 ou_E/m^3 as the 98th percentile of hourly averages.

The conclusion is that an appropriate criterion could lie anywhere between 1 ou_E/m^3 and 10 ou_E/m^3 as the 98th percentile of hourly averages at a critical receptor[20].

In 2002, the EA published a draft copy of its Horizontal Guidance Document H4 and, in 2011, a final version. This includes a graduated scale of "indicative odour thresholds", depending upon the perceived offensiveness of the odour, as follows:

- 1.5 ou_E/m^3 (98th percentile) for the most offensive odours;
- 3.0 ou_E/m^3 (98th percentile) for less offensive odours; and
- 6.0 ou_E/m^3 (98th percentile) for the least offensive odours.

These were derived from studies in Holland on the offensiveness of odours from intensive pig farming in rural areas. It is generally considered that sewage treatment works odours fall into the middle category (3.0 ou_E/m^3), unless there are septic wastewater or sludges on the site, in which case the most stringent criterion would apply.

[17] Environment Agency (2002) DRAFT Horizontal Guidance for Odour Part 1 - Regulation and Permitting.
[18] Valentin, F.H.H and North, A.A. (1980). Odour Control - A Concise Guide. Department of the Environment.
[19] Information Centre for the Environment (2001). *Netherlands Emission Guidelines for Air.* InfoMil.
[20] Hall, D. L., McIntyre, A. E., (2004). The Derivation of Odour Standards and their Role and the Foundation of Odour Management Plans for Planning Regulation. *In Proceedings of the Second National Conference Volume Two September 2004. Ed N. J. Horan.*

For landfill odours, typically a criterion of 3 ou_E/m^3 as a 98th percentile concentration, has been adopted as an appropriate annoyance metric.

Trace Pollutants

The list of trace pollutants for which some form of assessment criteria (air quality standards/guidelines) are available are contained in Table 3.9.

Table 3.9 Trace Pollutants and Assessment Criteria

Pollutant	Criteria, µg/m³		Source
	Long Term	Short Term	
Hydrogen sulphide	140	150[1], 7[2]	UK EA H1; WHO
1,2,4-Trimethylbenzene		37,500	UK EA H1
1,2-Dichloroethane		700	UK EA H1
1,3,5-Trimethylbenzene	1,250	37,500	UK EA H1
2-Butanone (MEK)	6,000	89,900	UK EA H1
4-Methyl-2-pentanone (MIBK)		362,000	UK EA H1
Acetone	18	100	UK EA H1
Benzene	5		UK Air quality standard
Benzyl chloride	5.2	158	UK EA H1
Carbon disulphide	64	100	UK EA H1
Chlorobenzene		158	UK EA H1
Chloromethane	1,050	21,000	UK EA H1
Ethylbenzene	4,410	55,200	UK EA H1
Methylene Chloride	700	3,000	UK EA H1
Vinyl chloride	159	1,851	UK EA H1

1 for the protection of human health
2 for the prevention of odour nuisance

Results of the Assessment

Odour

The results of the dispersion modelling exercise for odour at the discrete receptor locations are contained in Table 3.10.

Table 3.10 Odour Results at Discrete Receptors

Receptor name	X(m)	Y(m)	98th percentile odour concentration, ouE/m3	Maximum average hour concentration, ouE/m3
Lakeside 1	460320	2134932	1.4	23.7
Lakeside 2	460284	2134992	1.5	19.9
Lakeside 3	460262	2135025	2.0	17.8
Lakeside 4	460216	2134997	1.5	15.9
Lakeside 5	460167	2134913	1.0	13.0
Parkside Close 1	460004	2135267	6.7	17.0
Parkside Close 2	459996	2135336	8.0	16.6
Parkside Close 3	459982	2135440	6.1	15.2
Parkside Close 4	459956	2135534	3.6	13.5
Parkside Close 5	459962	2135606	2.6	12.9

As can be seen, there are four receptor locations at which the odour annoyance criterion of 3 ou_E/m^3, 98th percentile, is forecast to be exceeded and it is understood that this is consistent with anecdotal reports of detected odours in these locations. In addition, the maximum hourly average odour concentrations forecast to occur would certainly be noticeable, varying between 12.9 and 23.7 ou_E/m^3.

Figure 16 shows a contour plot of odour dispersion from the landfill site generated by the ADMS dispersion model, incorporating the 98th percentile odour concentrations.

This shows that many of the receptors in Parkside Close are within the 3 ou_E/m^3 contour and are likely to experience odour at levels that could generate annoyance, whilst most of the Lakeside development sits just outside the same contour level.

Trace Pollutants

The results of the dispersion modelling assessment for the maximum hourly average concentrations of trace pollutants listed in Table 3.9 above are contained in Table 3.11.

Table 3.11 Trace Pollutant Results at Discrete Receptors – Short Term Averages

Pollutant	Lakeside, µg/m3		Parkside, µg/m3		Assessment Criterion, µg/m3
	Maximum	Minimum	Maximum	Minimum	
Hydrogen sulphide	64.3	35.3	46.12	35.09	1501, 72
1,2,4-Trimethylbenzene	0.13	0.05	0.09	0.07	37500
1,2-Dichloroethane	0.02	0.01	0.01	0.01	700
1,3,5-Trimethylbenzene	0.07	0.03	0.05	0.04	37500
2-Butanone (MEK)	0.77	0.29	0.55	0.42	89900
4-Methyl-2-pentanone (MIBK)	0.17	0.06	0.12	0.09	362000
Benzyl chloride	0.14	0.05	0.10	0.07	158
Carbon disulphide	0.15	0.06	0.11	0.08	100
Chlorobenzene	0.02	0.01	0.01	0.01	158
Chloromethane	0.19	0.07	0.13	0.10	21000
Ethylbenzene	0.39	0.15	0.28	0.21	55200
Methylene Chloride	0.39	0.15	0.28	0.21	3000
Vinyl chloride	0.37	0.14	0.27	0.20	1851

1 for the protection of human health
2 for the prevention of odour nuisance

It can be seen that maximum hourly average predicted concentrations of all trace pollutants are well within the specified health-related assessment criteria. However, for hydrogen sulphide, the maximum hourly average concentrations at all of the receptors exceed the WHO guideline value of 7 µg/m^3 as a 30-minute average value, proposed to avoid creating an odour nuisance. The minimum hourly average concentration forecast at a receptor is 35 µg/m^3, some five times the guideline value.

Table 3.12 contains the results of the assessment in respect of long term average trace pollutant concentrations predicted by the ADMS dispersion model. Usually, these relate to averages over a calendar year. In this case, as a result of the met data period considered, these are termed long term period averages.

Table 3.12 Trace Pollutant Results at Discrete Receptors – Long Term Averages

Pollutant	Lakeside, µg/m3		Parkside, µg/m3		Assessment Criterion, µg/m3
	Maximum	Minimum	Maximum	Minimum	
Hydrogen sulphide	1.02	0.54	1.48	0.69	140
1,3,5-Trimethylbenzene	0.0011	0.0006	0.0016	0.0007	1250
2-Butanone (MEK)	0.0123	0.0066	0.0179	0.0083	6000
Acetone	0.0476	0.0254	0.0691	0.0320	18
Benzyl chloride	0.0022	0.0012	0.0032	0.0015	5.2
Carbon disulphide	0.0023	0.0013	0.0034	0.0016	64
Chloromethane	0.0030	0.0016	0.0043	0.0020	1050
Ethylbenzene	0.0062	0.0033	0.0090	0.0041	4410
Methylene Chloride	0.0062	0.0033	0.0090	0.0042	700
Vinyl chloride	0.0059	0.0032	0.0086	0.0040	159
Benzene	0.0048	0.0025	0.0069	0.0032	5

In the case of the long term average modelled concentrations, there are no exceedences of the assessment criteria, by some considerable margin, in most cases.

Conclusions

Estimation of the surface emissions of landfill gas from the Grand Cayman landfill site using a GasSim model has enabled a quantitative modelling assessment of the likely emissions of odour, hydrogen sulphide and airborne trace organic micro-pollutants to be undertaken. The latter quantification of emissions was undertaken using analyses conducted on samples of the landfill gas on the site.

The results of the modelling exercise revealed that detectable ambient concentrations of odour are likely to be experienced off-site at the nearest residential developments downwind of the landfill site. In addition, modelling of hydrogen sulphide emissions showed that short-term (hourly) average concentrations at the nearest residential receptors were likely to exceed the WHO odour nuisance guideline concentration by a significant margin. These model predictions accord well with recent anecdotal reports of odour annoyance.

For the remaining trace organic micro-pollutants, none of these was forecast to exceed relevant assessment criteria as a result of surface emissions from the landfill site.

3.9 Other Issues

The main landfill area is the highest point on Grand Cayman and is visible from a considerable distance. The landfill is also visible to cruise ships moored offshore.

The main landfill area is not capped or restored and therefore is a significant visual intrusion. The visual impact cannot be considered using the risk assessment approach outlined for contamination sources or hazards.

3.10 Risk Assessment

Approach

The risk assessment approach is described in Chapter 2.

Conceptual Model

A conceptual model has been prepared for the landfill site which identifies potential contaminants and amenity related hazards, potential pathways and receptors. The conceptual model considers both onsite and offsite sources. The conceptual model is summarised in Figure 17.

Summary of Potential Contamination and Hazards

On-Site Sources

From the assessment of historical and current activities and the environmental monitoring data (which has been screened, where appropriate, against generic assessment criteria) the potential onsite sources are identified in Table 3.13. These include contaminants and amenity related hazards.

Table 3.13 Summary of Onsite Potential Contamination and Hazards

Location	Source	Contaminant (C) or Hazard (H)	Type	Source Quantitative Data Y= yes N= no	Comment
Soils around waste area	Unknown, could be from former waste burning	C	Arsenic	Y	Exceeds Florida soil clean-up assessment criteria but generally below UK assessment criteria. Noted at three locations. Arsenic containment pit onsite
Waste Oils storage area	Hydrocarbons	C	Hydrocarbons	Y	Oil contamination noted by Amec Foster Wheeler within well MW16. 0.84mg/l DRO in surface water at SW12
Groundwater	Leaching from wastes	C	Ammonia	Y	The Florida clean-up standard of 28 mg/l has been exceeded in MW10 and new monitoring well MW21 which had the highest result yet recorded at the site in 2015
Groundwater	Leaching from wastes	C	Iron	Y	Detected above the clean-up level of 3 mg/l with results ranging up to 11 mg/l
Groundwater	Leaching from wastes	H	Orthophosphate	Y	Found at reduced concentrations in surface waters
Surface water canal	Leaching from waste and groundwater base flow	C	Ammonia	Y	The April 2015 sampling identified concentrations of between 2.0 and 6.5 mg/l in the perimeter canals
Surface water canal	Leaching from waste and groundwater base flow	C/H	Metals	Y	The sample from SW3 recorded exceedences of the relevant clean-up levels for copper and lead.

Location	Source	Contaminant (C) or Hazard (H)	Type	Source Quantitative Data Y= yes N= no	Comment
Surface water canal	Runoff	H	Turbidity/dissolved solids	Y	Some historical issues noted
Sediment at canal mouth to North Sound	Historical run-off	C	Sulphate	Y	Potentially associated with hydrogen sulphide generation
Incinerator	Stack emission	C/H	Combustion products	N	No emission test data
Landfill area	Landfill gas	C	Methane and carbon dioxide	Y	Methane potentially explosive and carbon dioxide an asphyxiant
Landfill area	Landfill gas	C/H	Hydrogen sulphide	Y	Hydrogen sulphide elevated in one of the gas probes
Landfill area	Landfill gas	C/H	Trace gas components	Y	Trace gases are a source of odour and a potential hazard within the landfill
Landfill area	Municipal waste	H	Dusts	Y	Measured deposition rate less than guideline value but limited data
Landfill area	Municipal waste	H	Smoke from fires	N	Combustion products
Landfill area	Municipal waste	H	Vermin attracted to the wastes	N	Spread of food scraps and bones
Landfill area	Municipal waste	H	Flies and insects	N	Pest control carried out

Off-Site Sources

From the assessment of historical and current activities a number of contaminative activities or, hazards have been identified and are associated with off-site activities. These are set out in Table 3.14.

Table 3.14 Summary of Offsite Potential Contamination and Hazards

Location	Source	Contaminant (C) or Hazard (H)	Type	Quantitative Data Y= yes N= no	Comment
Wastewater sludge lagoons	Sludge decomposition	C	Hydrogen sulphide	N	Hydrogen sulphide generation from former/active sludge lagoons indicated by monitoring
Wastewater sludge lagoons	Sludge decomposition	H	Odour	N	Odour generation from former/active sludge lagoons
Various Industrial Premises	Soil and aggregate storage	H	Dusts	N	Various sources of dust generation on industrial premises to the south east and south of the site

Receptors and Pathways

Receptor groups have been identified in Table 3.15 together with some notes on their status.

Table 3.15 Receptors

Receptor Groups	Comments
Site workers and visitors	Site has open access and members of the public can access out of hours
Adjacent residents	Lakeside development and Parkside Close located approximately 330ft (100m) from site boundary and downwind of the site
Adjacent commercial/industrial premises	Industrial and commercial premises to the south and east of the site
Groundwater	Groundwater is brackish and in continuity with perimeter canals. There are public water supply (PWS) abstractions approximately 1 mile from the site; this water is treated.
Surface water in canals around the landfill	The canals are tidal and brackish water. There is no recreational use.
Marine water in North Sound	There is no specific water quality designation for the area of western part of North Sound adjacent to the landfill.
Ecological receptors	Some birds were noted in the 'leachate' ponds onsite. The canals are fringed by mangroves which are a roost for birds. Iguanas swim in the canals and were also seen on the landfill. Some large fish were observed in the eastern part of the North Canal during the April 2015 water sampling.

Potential pathways are considered in Table 3.16.

Table 3.16 Potential Receptors and Pathways

Receptor	Pathway
Site workers and visitors	Dermal contact, direct contact, ingestion, inhalation
Adjacent residents	Ingestion of dusts, inhalation
Adjacent commercial/industrial premises	Ingestion of dusts, inhalation
Groundwater (including PWS extraction)	Leaching and migration
Surface Water (canals and North Sound)	Run-off, migration and groundwater base flow
Ecological receptors offsite	Ingestion and bioaccumulation from contaminated waters/sediments

Risk Assessment Methodology

The development of the conceptual models have identified a number of potential contaminant and hazard linkages (contaminant/hazard-pathway-receptor linkages) between receptors and the landfill site. These are tabulated in Appendix E.

Each contaminant linkage has been qualitatively assessed using the following criteria:

i) Potential consequence of contaminant/hazard linkage;

ii) Likelihood of contaminant/hazard linkage; and

iii) Risk classification.

The risk assessment criteria assessment methodology is provided within Chapter 2 of this report.

The updated environmental risk assessment for the site is included in Appendix E. This comprises an analysis of potential contaminant/hazard linkages (contaminant/hazard-pathway-receptor) between potential receptors and the landfill site.

3.11 Risk Assessment Outcomes

The outcomes from the risk tables in Appendix E are summarised below. The first paragraph summary for each receptor considers contaminants and the second amenity hazards.

Site Workers and Visitors

Potential risks to site workers and visitors from arsenic in soils are assessed as moderate. The potential risks from hydrogen sulphide, other landfill gas trace components and methane (as a potentially explosive gas) are also all assessed as moderate. The risks to site workers/visitors from hydrocarbons from the waste storage area is assessed as moderate/low, assuming appropriate PPE is worn.

Adjacent Residents

The potential risks from landfill gas trace components and from methane (as a potentially explosive gas) are both assessed as moderate/low. Potential risks to adjacent residents from arsenic in soils are assessed as low.

Potential dust nuisance to adjacent residents is assessed as medium and odour nuisance as high. Potential risks associated with scavenging animals and birds, pests (e.g. flies) mosquitoes and contaminated waters used for recreational purposes are assessed as medium. There is a potential high risk associated with nuisance from landfill fires.

Adjacent Commercial/Industrial Users

The potential risks from landfill gas trace components and from methane (as a potentially explosive gas) from landfill gas are assessed as moderate/low, although the potential risks from landfill gas trace components from contaminated sediments are assessed as moderate. Potential risks to adjacent commercial/industrial users from arsenic in soils are assessed as low.

Groundwater

The risks to groundwater from hydrocarbons (spills and overtopping of bunds) are assessed as moderate. Potential risks to groundwater from arsenic are assessed as negligible and low with regard to ammonia.

Surface Water Canals

Potential risks to surface water canals from both hydrocarbons (spills and overtopping of bunds) are assessed as high. Risks from ammonia and orthophosphate (from groundwater base flow) are assessed as moderate, and from iron are assessed as moderate/low.

The potential risk to canal ecology from potentially contaminated sediments in the canal is assessed as medium.

North Sound

The potential risk to North Sound (adjacent to the canal discharge) from ammonia in canal water is assessed as high. The potential risks from ammonia from contaminated groundwater is assessed as moderate/low and from metals in canal water is assessed as moderate.

The potential risk to North Sound ecology from potentially contaminated sediments in the canal is assessed as medium.

4. Environmental Condition Cayman Brac Landfill

4.1 Location and Setting

Cayman Brac landfill is located on the southern side of the island off South Side West Road as shown on Figure 18. The entrance is located to the north of the road and approximately 280 ft (85m) from the beach.

The landfill site is owned by CIG and operated by the DEH. The total site area (excluding that south of the road) is approximately 20 acres (8 hectares) of which very approximately 9 acres (3.7 hectares) appears to have received waste materials. The northern part of the site has been used for municipal waste disposal by landraising against a natural cliff or bluff of limestone which runs along the northern margin of the site. The lower south western part of the site is used for storage of scrap metal (to the west of the site road) and disposal of green (i.e. yard) waste to the east. The south east quadrant of the site has not been filled and includes a pond, known as the Red Shrimp Lagoon (shrimp lagoon).

The landfill is predominantly a landraise formed by tipping over an area of former scrub. The site has no formal engineered containment (i.e. a basal lining system). Part of the municipal waste area is capped with a thin layer of soil materials but there has been no re-vegetation.

Topography

The site is located at the base of a bluff of limestone which is sub-vertical and some 15-20 ft (5-7m) high where exposed above the waste. It is estimated that up to 24 ft (8m) thickness of waste has been placed against the bluff. Ground below the base of the bluff slopes gently south towards the coastline but now comprises a wedge of infill. Ground level on the southern side of the site is around 5 ft (1.5m) above MSL and the shrimp lagoon is brackish.

There is no known topographical survey available for the site and levels have been inferred from LIDAR data included within a GIS (Geographical Information System) package for the site and shown on the aerial photographs included with the Task 1 environmental review.

Surrounding Land Use

The land usage surrounding the landfill is summarised below, with reference to the Task 1 environmental review:

- To the north is a steep rock face covered with scrub and cactus beyond which is a vegetated limestone plateau;
- To the east and west is undeveloped scrub land with occasional small pools; and
- To the south of South Side West Road is a strip of land some 230 to 300 ft (70 to 100m) wide beyond which is a beach. There are two residential properties to the south of the site entrance which overlook the beach. Beyond the south west corner of the site is a public parking area with beach huts and access to the beach.

4.2 Site Infrastructure

For the purpose of description the site is split into a number of zones identified in Figure 18. The description of each area including photographs is provided in the Task 1 environmental review.

During the April 2015 sampling, the following changes were observed relative to the report based on the November 2014 visit:

- The tyre pile had reduced considerably in size with tyres being progressively transferred into containers and shipped to Grand Cayman;

- Waste oil containers had been moved to an area north of the small site building with the intent to pump these out into a steel shipping tank for transfer off-island. However, transfer into the shipping container had not taken place; and
- The clinical waste incinerator is still not operating and clinical waste is disposed into a pit (referred to as the difficult waste pit in the Task 1 environmental review) and left uncovered; and
- The scrap metal bailer is out of operation pending repair. Several years' accumulation of scrap metal and end of life vehicles at the site.

4.3 Data Sources

There are no known specific environmental reports or studies relating to the landfill. An environmental impact assessment (EIA) was prepared for an alternative landfill site on the island in 2008 by APEC/Tobin[21] but this alternative site, in the centre of the island, did not progress. The EIA contains a brief description of the existing landfill area and some background environmental information for Cayman Brac.

There are no known environmental monitoring data for the landfill other than two surface water samples (locations unknown) taken by DEH in 2001.

4.4 Site History

The site has been in operation since at least 1978 and a brief summary is given in the Task 1 environmental review.

4.5 Waste Inputs

There is no weighbridge at the site. Data provided by DEH indicates the site received approximately 2,240t of waste in 2013. Some 3.9t of waste was processed in the on-site clinical waste incinerator. There is no specific breakdown of waste types but these are considered to be similar to those received at George Town landfill.

4.6 Geology

The central part of Cayman Brac is formed by a plateau known as the Bluff. This is a dolostone and limestone outcrop rising steadily along the length of the island to a maximum 140 ft (42 m) above MSL at the eastern end of the island. The Bluff dolostone and dolomitic limestone grouping includes the Cayman Member and Pedro Castle Member. These are underlain by the Brac Formation.

The Bluff formation forms the outcrop to the north of the landfill. It is characterised by solution weathering with enlarged fissures, and sinkholes. There are a number of caves within the formation.

The south eastern part of the site contains the Red Shrimp Lagoon with an associated small area of mangrove and there are likely to be thin deposits of organic sediments.

Four groundwater monitoring wells (CB1-CB4) were completed at the site in April 2015 using rotary open hole methods (i.e. no cores were recovered). As assessment of the strata was made by Amec Foster Wheeler based on the drilling rate and flush returns. The borehole locations are shown on Figure 19.

These wells proved the following:

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[21] Environmental Impact Assessment for the Proposed Cayman Brac Waste Management Facility. APEC/Tobin, July 2008.

- Made Ground (landfilled wastes of compacted soil with varying amounts of wood, plastic and metal) to depths of between 3 and 13.8 ft (0.9-4.2 m bgl) (CB1-CB3 only);
- Brown fine to coarse sand to 9.8 ft (3 m bgl) (CB4 only); overlying
- A limestone bedrock, anticipated to form part of the Bluff formation, which was typically recovered as white fine grained limestone fragments with some shell and coral fragments. The full depth of the limestone was not determined, with all boreholes drilled to approximately 30 ft (9.1m) bgl.

4.7 Hydrogeology

Regional Setting

The Bluff formation is very permeable and groundwater levels are estimated at only 1-3 ft (0.3-0. 9m) above sea level (from APEC/Tobin report).

Potable water on the island is provided by Water Authority Cayman from their seawater desalination plant at West End. The sea water is treated by reverse osmosis. There are no known groundwater abstractions in proximity to the site.

Groundwater Levels

Groundwater levels were measured in all of the new groundwater monitoring wells in April 2015 and the results are presented in the Task 2 investigation factual report. Groundwater levels varied between 0.65 ft (0.2m) bgl in CB1 to 13.81 ft (4.21 m) in CB3. In borehole CB4, which is the closest to the shoreline (i.e. sea level), the measured groundwater level was 7.81 ft (2.38 m). This is much deeper than the estimate from the APEC/Tobin report, although the measured depth to groundwater in CB1, the next closest borehole to sea level, is much closer to this estimate. Note that boreholes CB2 and CB3 are located much higher above sea level, as reflected in the greater measured depth to groundwater in these boreholes (7.38 and 13.81 ft, or 2.25 and 4.21 m bgl, respectively).

As part of the Task 2 investigation data loggers were installed in monitoring wells CB1 and CB3 to record fluctuations in groundwater levels. In general, the data show groundwater variation of 0.92-1.25 ft (0.28- 0.38m) over a 24 hr period and are therefore indicative of a tidal influence.

Groundwater Quality

Due to the fact that the limestones are hydraulically linked to the surrounding ocean there is considerable mixing of fresh and salt water due to tidal oscillations. This mixing causes a transition zone of brackish water to develop between the fresh and salt waters with enhanced mixing in the cavernous sections of the aquifer. Such brackish water is present beneath the landfill site.

Amec Foster Wheeler Sampling 2015

Amec Foster Wheeler undertook sampling from new groundwater wells CB1-CB4 installed as part of the Task 2 investigation work on 15 April 2015.

Assessment Criteria

The 2015 sample data has been screened against Florida clean-up standard for poor yield/low quality groundwater. These assessment criteria have been selected due to the brackish nature of the underlying aquifer. The results and assessment criteria are summarised in Appendix F. The nature of the groundwater is summarised below.

General Chemistry

The field measurements of pH were in the range 7.1 to 7.6 which is neutral to slightly alkaline. Electrical conductivity (i.e. conductance) ranged from 31.5 mS/cm in CB2 to 71.7 mS/cm in CB1. Groundwater ammonia varied from 0.4 to 18 mg/l with results from individual wells detailed in Table 4.1.

Table 4.1 Ammonia in Groundwater 2015

	Monitoring Well			
	CB1	CB2	CB3	CB4
Ammonia (mg/l)	1.2	18	0.44	0.4

Grey highlighting denotes exceedance of Florida clean-up standard

The Florida clean-up standard of 28 mg/l was not exceeded. Orthophosphate concentrations range from below LoD up to 0.1 mg/l (CB2). Nitrate (NO3-) plus nitrite (NO2-) concentrations were below LoD in CB1 and CB2 and were 4.4 and 0.14 mg/l in CB3 and CB4 respectively. These concentrations are well below the Florida clean-up standard.

COD in groundwater in April 2015 monitoring was between 62 and 120 mg/l. BOD concentrations ranged between below LoD (CB3 and CB4) to 15 mg/l (CB2). There are no Florida clean-up standards for COD or BOD.

Total dissolved solids (TDS) ranged between 5,300 mg/l (CB2) and 20,000 mg/l (CB4). All results exceed the Florida clean-up standard of 5,000 mg/l. The TDS results are indicative of brackish water.

Cyanide analysis was undertaken on all four samples. All results were below the relevant LoD.

Metals

Metals analysis was undertaken on samples from CB1 and CB2. The majority of metals present at below LoD or at very low concentrations well below the relevant assessment criteria.

Volatile Organic Compounds (VOC)

All VOC results (2 samples, CB1 and CB2) were less than the LoD with the exception of 1,4-Dichlorobenzene in the sample from CB2 (1.3 µg/l). This concentration is well below the Florida clean-up standard of 750 µg/l.

PCBs

All PCB analysis results (2 samples, CB1 and CB2) were less than the LoD.

Pesticides/Herbicides

Analysis on 2 samples (CB1 and CB2) were all less than the relevant LoD.

Hydrocarbons

DRO analysis was undertaken on all 4 samples (CB1 to CB4) of groundwater. Results were in the range 0.12-3.1 mg/l, with the highest result from CB2. GRO analysis was also undertaken on these samples, which recorded concentrations below the relevant LoD with the exception of CB4 (0.059 mg/l). There is no Florida state assessment standard for DRO or GRO.

For the purpose of data contextualisation, WHO guidance states that the application of the lowest WHO guideline value for (aliphatic) hydrocarbons (0.3 mg/l for carbon bands C12-C16, i.e. 'diesel range') to a total hydrocarbon measurement in water will provide a conservative level of protection. This guideline value has been exceeded in the DRO samples from CB1, CB2 and CB3.

4.8 Hydrology and Surface Water Quality

The high permeability of the fractured dolomitic rocks results in the absence of surface streams and a low water table gradient. A brackish pond, known as the Red Shrimp Lagoon or shrimp pond, is located in the south eastern part of the landfill area. This is part of an area known as The Marshes.

2001 DEH Sampling

DEH took two surface water samples from areas adjacent to the landfill in 2001 recorded as 'shrimp pond' and 'surface water'. The data for the shrimp pond analysis is summarised in Table 4.2.

Table 4.2 Shrimp Pond Summary of Water Analysis 2001

Determinand	Result
pH	8.4
Biochemical oxygen demand (BOD)	2.9 mg/l
Chemical oxygen demand (COD)	760 mg/l
Total dissolved solids (TDS)	1,400 mg/l
Total organic carbon	8.2 mg/l
Ammonia as N	0.095 mg/l
Nitrate plus nitrite	0.11 mg/l

Iron and mercury were recorded below LoD. Selected volatile organic compounds were also recorded below laboratory limits of detection.

Amec Foster Wheeler Sampling 2015

In April 2015, Amec Foster Wheeler took two surface water samples from the shrimp pond (BSW1, north side and BSW3, south side) and one from a pond to the west of the landfill (BSW2), which are identified on Figure 20.

Assessment Criteria

The data has been screened against the Florida marine surface water clean-up targets as per the surface water samples from the George Town landfill. The data and screening criteria are summarised in Appendix G.

The following summary can be drawn from inspection of the surface water quality results.

General Chemistry

The pH range of the 2015 samples was 8.5-9, which is slightly higher than the 2001 result from the shrimp pond and is indicative of alkaline conditions. Electrical conductivity of the 2015 samples ranged between 54.1 to 56.5 mS/cm.

The 2015 sampling identified ammonia concentrations of below LoD (BSW2), 0.15 mg/l (BSW3) and 0.32mg/l (BSW1). These results are around, or above, the 2001 result of 0.095 mg/l. The observed ammonia concentrations in the surface water samples reflect high water quality based on UK guideline values.

The 2015 orthophosphate concentrations range from below LoD (BSW1 and BSW3) to 0.017 mg/l (BSW2). On the basis of the recent round of data, the observed orthophosphate concentrations reflect good water quality based on UK guideline values. Nitrate plus nitrite concentrations were below the LoD in all 3 samples.

The previously recorded (2001) BOD concentration in the shrimp pond was 2.9 mg/l. BOD recorded in surface water samples from April 2015 ranged between 5.2 mg/l (BSW2) and 21 mg/l (BSW3, shrimp pond). A COD concentration of 760 mg/l was recorded in 2001 but did not exceed 540 mg/l in the April 2015 samples. Total suspended solids from the 2015 samples were recorded up to 800 mg/l. There are no marine water assessment criteria for any of these determinands.

Turbidity is recorded for which there is a Florida marine water clean-up standard of 29 NTU. This standard was not exceeded in any of the samples taken in 2015, which recorded results up to 8.9 NTU (BSW3).

Cyanide analysis was undertaken on samples from BSW1 and BSW2, both of which recorded concentrations below the laboratory LoD.

Metals

Metals analysis was undertaken on surface water samples BSW1 and BSW2. The majority of metal analyses returned results below laboratory LoDs. The only exceedences of the clean-up levels were as follows:

- Copper was detected above the clean-up level of 0.0037 mg/l, at 0.0065 and 0.005 mg/l in BSW1 and BSW2, respectively; and
- Lead was detected above the clean-up level of 0.0085 mg/l, at 0.048 and 0.038 mg/l in BSW1 and BSW2, respectively.

Mercury has not been detected above the laboratory LoD of 0.07mg/l in either of the samples.

Volatile Organic Compounds (VOC)

All VOC results (BSW1 sample only) are less than the LoD.

PCBs

PCB analysis has been undertaken on surface water samples BSW1 and BSW2. All results are less than the laboratory LoD.

Pesticides

Analysis for a number of pesticide compounds has been undertaken on surface water samples BSW1 and BSW2. All results are less than the laboratory LoD.

Hydrocarbons

DRO analysis was undertaken on samples from BSW1 and BSW2 in April 2015. Results range from 0.62 mg/l (BSW1) to 2.4 mg/l (BSW2). GRO analysis was also undertaken on both samples, with both results below the relevant laboratory LoD.

For the purpose of data contextualisation, WHO guidance states that the application of the lowest WHO guideline value for (aliphatic) hydrocarbons (0.3 mg/l for carbon bands C12-C16, i.e. ‘diesel range’) to a total hydrocarbon measurement in water will provide a conservative level of protection. This guideline value has been exceeded in the samples from BSW1 and BSW2.

4.9 Ecological Receptors

The Red Shrimp Lagoon can be identified as an ecological receptor. There is a boardwalk leading to the southern side of the lagoon from the road to the south.

National Trust Cayman has acquired some wetland approximately 850 ft (260 m) west of the landfill: (http://www.compasscayman.com/caycompass/2014/09/17/National-Trust-buys-Brac-wetlands/)

Offshore from the public beach to the south east of the site there is a marine designated area of reef and associated dive sites.

4.10 Soil Sampling

In April 2015, Amec Foster Wheeler took five soil samples from the surface of the Hurricane Paloma fill area and a further sample from the former tyre storage area for asbestos analysis. No asbestos was detected in any of the samples.

The sample from below the former tyre storage area was also analysed for PAHs as there was evidence of a previous fire. No PAH compounds were recorded above the laboratory LoD.

4.11 Landfill Gas

The site receives inputs of municipal wastes including organic materials such as food and kitchen wastes, garden wastes, paper, cardboard and timber and therefore likely to produce landfill gas. This is typically a mixture of methane and carbon dioxide together with trace components such as hydrogen, hydrogen sulphide and volatile organic compounds including halogenated organics, aromatic hydrocarbons, alkanes and ketones (Ref. EA LFTGN 03). Trace compounds in landfill gas are responsible for its odour.

Site Inspection 2014

There has been no landfill gas monitoring carried out at the Cayman Brac landfill site. Amec Foster Wheeler undertook some initial measurements during the site inspection by monitoring methane and carbon concentrations at the landfill surface on 18 November 2014.

The data is reported in the Task 1 environmental review, but in summary, methane concentrations of up to 0.2%v/v were recorded in surface cracks and fissures in the waste which confirms the site is actively generating landfill gas.

Gas Probes 2015

Gas monitoring and sampling was undertaken on 14 April 2015 from gas probes (GP21 to GP24) which were installed within the waste mass in April 2015. The gas probe locations are shown on Figure 19. Note that gas probes GP21, GP23 and GP24 only were sampled, as three gas samples are judged to provide sufficient coverage over this relatively small landfill.

Landfill gas monitoring data collected prior to the gas sampling using the portable infra-red gas analyser is presented in the Task 2 investigation factual report. The data shows methane and carbon dioxide concentrations indicative of a relatively poor quality landfill gas (~5.4-31.3% methane and ~16-25.5% carbon dioxide) with no or little (2.1% or less) oxygen in all probes. GP22 showed much lower concentrations of methane (5.4% v/v) and carbon dioxide (16% v/v) compared to the other probes. The highest concentrations of both gases were in GP24.

The gas analysis suite consisted of bulk gas constituents as well as hydrogen sulphide, carbon monoxide and NMVOCs.

Gas analysis results are included in the Task 2 investigation factual report and are summarised as follows:

- Carbon dioxide: 24 v/v (GP1) to 28% v/v (GP23);
- Methane: 14% v/v (GP21) to 33% v/v (GP24);
- Oxygen: 1.3% v/v (GP23) to 2.1% v/v (GP24);
- Nitrogen: 40% v/v (GP24) to 62% v/v (GP21);

- Carbon monoxide, ethane, ethylene, propane and propene: all results below relevant LoD;
- Helium: 0.056% v/v (GP24 only, other results below LoD);
- Hydrogen: 0.082% v/v (GP21) and 0.0081% v/v (GP24), with GP23 below LoD;
- Hydrogen sulphide: 5.1 ppm (GP21), 7.1 ppm (GP23) and 1.7 ppm (GP24);
- NMVOCs: below LoD except:
  - 1,1 Dichloroethene (1.5 ppb, GP24);
  - 1,2,4-Trimethylbenzene (34 ppb, GP24);
  - 1,3,5-Trimethylbenzene (25 ppb, GP24);
  - 1,4-Dichlorobenzene (2.9 ppb, GP24);
  - 2-Butanone (MEK) (47-6,900 ppb, all samples);
  - 2-Hexanone (100 ppb, GP21);
  - 4-Ethyltoluene (10 ppb, GP24);
  - 4-Methyl-2-pentanone (MIBK) 290 ppb, GP21);
  - Acetone (320-19,000 ppb, all samples);
  - Benzene (120-290 ppb, all samples);
  - Carbon disulphide (4.9-340 ppb, all samples except GP23);
  - Ethylbenzene (84-850 ppb, all samples);
  - m,p-Xylene (92-1,000 ppb, all samples);
  - Methylene Chloride (110-200 ppb, all samples except GP24);
  - o-Xylene (37-290 ppb, all samples);
  - Styrene (19-210 ppb, all samples);
  - Tetrachloroethene (5 ppb, GP24);
  - Toluene (520-12,000 ppb, all samples);
  - Trans-1,2-dichloroethene (16 ppb, GP24);
  - Trichloroethene (64 ppb, GP24); and
  - Vinyl chloride (18 ppb, GP24).

Concentrations of bulk LFG are largely consistent with the pre-sampling field data, although the field readings for oxygen differ from the laboratory results by around ±2% v/v. After the pre-sampling field data was taken, each sampled probe was pumped for approximately 5 minutes until readings stabilised to allow sampling. Therefore, the results of the sample analysis are likely to be much more representative than the pre-sampling field data.

The low/below LoD hydrogen concentrations recorded are fairly typical of a landfill in the long methanogenic stage of landfill gas generation.

The hydrogen sulphide concentrations recorded are typical of those usually measured in landfills. The laboratory results are higher than the hydrogen sulphide concentrations measured in the groundwater monitoring boreholes (up to 1.645 ppm, CB4, 17 April 2015) although most of the hydrogen sulphide results from the groundwater boreholes were zero.

With regard to the NMVOCs, those detected above the relevant LoD are generally typical trace components within landfill gas. Some of the trace compounds detected, such as carbon disulphide, toluene and xylene, as well as hydrogen sulphide, are odorous components of landfill gas.

4.12 Fugitive Emissions

Hydrogen Sulphide Monitoring 2015

Fugitive hydrogen sulphide measurements in air were undertaken around the landfill site on 14 April 2015, following the methodology set out in the Task 2 investigation factual report.

A total of 8 locations were monitored, including areas adjacent to the four new gas probes GP21-GP24, locations around new groundwater monitoring wells CB2 and CB3 and a location near the site entrance. Hydrogen sulphide was not detected in any of these locations.

Dust Deposition Monitoring 2015

Dust deposition monitoring was undertaken in accordance with the methodology set out in in the Task 2 investigation factual report. The dust deposition measurement locations described in Table 4.3 and are shown on Figure 20.

Table 4.3 Dust Deposition Monitoring Locations - Cayman Brac Landfill

Monitoring Run	Location	Run time (mins)	Date and comments
Unit R10256 Serial 6709			
Run 9	Placed on top of electric meter near incinerator near site entrance	153	Run on 13 April during drilling of CB1-CB4. Location downwind of landfill.
Run 10	Placed on top of electric meter near incinerator near site entrance	344	Run on 14 April during site operational hours. Location downwind of landfill.
Run 11	Adjacent to CB2	461	Run on 15 April during site operational hours. Location downwind of landfill.

Dust deposition measurement data are included in the Task 2 investigation factual report. In summary, the overall average concentration of dust measured on each run ranged between 0 and 0.003 mg/m^3 with the highest concentration recorded at the incinerator near the site entrance on 14 April 2015. Note that this location is across wind of the main landfill area of the site.

By way of comparison, the EC/UK Air Quality Standard for PM_{10} is 50 µg/m^3 (0.05 mg/m^3) based on a 24 hour mean, which was not breached in any of the locations monitored.

Other Vapour Sources

The waste oils storage area is a potential source of vapours. No vapour monitoring is undertaken at the landfill site.

Fires

A number of fires have been reported at the landfill. These have caused particular problems when they have spread to tyre stockpile. Smoke and combustion products from landfill fires are a potential contaminant/ hazard source.

4.13 Other Issues

The landfill is visible from the two properties located to the south of the site between the road and the beach. It is also visible from the road access area to the public beach, but not from the beach itself. The landfill is also visible from the board walk the shrimp pond.

4.14 Risk Assessment

Approach

The risk assessment approach is described in Chapter 2.

Conceptual Model

A conceptual model have been prepared for the site which identifies potential contaminants and amenity related hazards, potential pathways and receptors. The conceptual model considers both onsite and offsite sources. The conceptual model is summarised in Figure 21.

Summary of Potential Contamination and Hazards

On-Site Sources

From the assessment of historical and current activities and environmental monitoring data (which has been screened against generic assessment criteria) the potential onsite sources are identified in Table 4.4.

Table 4.4 Summary of Onsite Potential Contamination and Hazards

Location	Source	Contaminant (C) Hazard (H)	Type	Quantitative Data Y= yes N= no	Comment
Waste Oils storage area	Hydrocarbons	C	Hydrocarbons	Y	Some surface spills noted. DRO detected in surface water samples from BSW1 and BSW2 and groundwater samples CB1-CB4 in April 2015. GRO detected in groundwater sample CB4.
Groundwater	Leaching from wastes	C	Ammonia	Y	Detected up to 18mg/l in CB2 but not above Florida clean-up standard
Surface water	Leaching from wastes	C	Metals	Y	Elevated concentrations of copper and lead in surface water samples.
Incinerator	Stack emission	C/H	Combustion products	N	No emission test data and incinerator currently out of use.
Landfill area	Landfill Gas	C/H	Landfill gas trace components/bioaerosols	Y	Odours
Landfill area	Landfill Gas	C	Methane and carbon dioxide	Y	Methane is potentially explosive and carbon dioxide an asphyxiant
Landfill area	Municipal waste	H	Smoke from fires	N	Combustion products
Landfill area	Municipal waste	H	Flies and insects	N	Site has a pest control regime
Landfill area	Municipal waste	H	Scavenging animals	N	Evidence of scavenging animals on site
Landfill area	Clinical Waste	H	Biohazards	N	Disposal in uncovered pit within the landfill (clinical waste incinerator not in operation)

Off-Site Sources

No off-site contamination sources or hazards have been identified.

Receptors and Pathways

Receptor groups have been identified in Table 4.5 together with some notes on their status.

Table 4.5 Receptors

Receptor Groups	Comments
Site workers and visitors	Site has open access and members of the public can access out of hours
Adjacent residents	Three properties located immediately south of the site.
Adjacent public recreation areas	Public beach located 230 ft (70m) south of the site
Groundwater	Groundwater is brackish. There are no known abstractions in the vicinity of the site.
Surface water in shrimp pond	Brackish water with possible groundwater base flow.
Marine water	Potential groundwater mixing along the coastline
Ecological receptors	Some birds were noted in the shrimp pond onsite. This forms part of The Marshes wetland area. National Trust for the Cayman own wetland 850 ft (260 m) west of the site. A marine park is located offshore.

Potential pathways are considered in Table 4.6.

Table 4.6 Potential Receptors and Pathways

Receptor	Pathway
Site workers and visitors	Dermal contact, direct contact, ingestion, inhalation
Adjacent residents	Ingestion of dusts, inhalation
Adjacent public recreation area	Ingestion of dusts, inhalation
Groundwater	Leaching and migration
Surface Water (shrimp pond)	Run-off, migration and groundwater base flow
Marine Water	Groundwater base flow/mixing

Risk Assessment Methodology

The development of the conceptual models have identified a number of potential contaminant and hazard linkages (contaminant/hazard-pathway-receptor linkages) between receptors and the landfill site. These are tabulated in Appendix H. Each contaminant linkage has been qualitatively assessed using the following criteria:

i) Potential consequence of contaminant/hazard linkage;

ii) Likelihood of contaminant/hazard linkage; and

iii) Risk classification.

The risk assessment criteria assessment methodology is provided in Chapter 2.

The updated environmental risk assessment for the site is included in Appendix H. This comprises an analysis of potential contaminant/hazard linkages (contaminant/hazard-pathway-receptor) between potential receptors and the landfill site.

4.15 Risk Assessment Outcomes

The outcomes from the risk tables in Appendix H are summarised below. The first paragraph summary for each receptor considers contaminants and the second amenity hazards.

Site Workers and Visitors

The potential risks from landfill gas trace components are assessed as moderate to low and from methane (as a potentially explosive gas) as moderate. The risks to site workers/visitors from hydrocarbons from the waste oil storage spills is assessed as low, assuming appropriate PPE is worn.

The risk to site users and visitors from the clinical waste disposed in the uncovered pit within the landfill is assessed as medium.

Adjacent Residents

The potential risks from landfill gas trace components are assessed as low and from methane (as a potentially explosive gas) as moderate/low.

Potential dust and odour nuisance to adjacent residents is assessed as medium. There is a potential medium risk associated with nuisance from landfill fires. Potential risks associated with pests (i.e. insects) are assessed as medium and are low with respect to scavenging animals and birds.

Groundwater

Potential risks to groundwater from hydrocarbons are assessed as moderate and from ammonia are assessed as moderate to low.

Shrimp Pond

The potential risks to the shrimp pond from metals leached from the landfill are assessed as moderate.

Potentially elevated nutrients and iron from run-off and groundwater base flow have as assessed medium impact on water quality in the shrimp pond.

Ocean

There is an assessed medium risk to water quality from potentially elevated nutrients and iron in groundwater base flow.

5. Environmental Condition Little Cayman Landfill

5.1 Location and Setting

Little Cayman landfill is located in the central part of the island off Olivine Kirk Drive. The entrance is located to the west of the road and beyond an area occupied by the island power generation plant. It is approximately 0.5 miles (0.8km) from the north coast. Figure 22 identifies the site location.

Little Cayman landfill site is owned by the CIG and operated by the DEH. The total site area is approximately 50 acres (21 hectares) of which approximately 2.2 acres (1 hectare) has received waste materials. The site is flat lying and has very little infrastructure. Deposited municipal wastes are regularly set-alight and the landfill comprises a burning ground with piles of unburned refuse.

Topography

There is no known topographical survey data for the Little Cayman landfill site other than from LIDAR data included within a GIS package for the site and shown on the aerial photographs in the Task 1 environmental review. This indicates the landfill area to be at approximately 5 ft (1.5m) above MSL with higher ground to the north and south. Based on observations made during the site visit the site is relatively flat lying and partially surrounded by mangrove scrubland.

Surrounding Land Use

The land usage surrounding the landfill is summarised below, with reference to the Task 1 environmental review:

- The landfill is surrounded by areas of seasonally flooded mangrove scrubland to the west and dry forest and woodland on slightly higher land to the north and south;
- The island power generation plant is located approximately 1,500 ft (450 m) east of the current burning area; and
- The nearest residential property is some 1,800 ft (550 m) to the south.

5.2 Site Infrastructure

For the purpose of description the site is split into a number of zones identified in Figure 22. The description of each area including photographs is provided in the Task 1 environmental review.

During the April 2015 sampling the following changes were observed relative to the report based on the November 2014 visit:

- It appears that the site has been extended to the west by approximately 25-50m (82-164 ft) into the adjacent mangrove scrubland; and
- There is evidence of an illegal waste oil disposal pit at the site, near the plant storage building.

5.3 Data Sources

There are no known specific environmental reports or studies relating to the landfill on Little Cayman and there are no known studies for an alternative waste facility on Little Cayman.

There are no known environmental monitoring data for the landfill other than one surface water sample taken by DEH in 2001. The sample location is unknown.

5.4 Site History

The site appears to have been constructed at some point between 1971 and 1994. A brief site history is provided in the Task 1 environmental review.

5.5 Waste Inputs

There is no weighbridge at the site and no data on input tonnages, although these are small considering the resident population is approximately 170. There is no specific breakdown of waste types but these are considered to be similar to those received at George Town landfill.

5.6 Ecological Receptors

The National Trust for the Cayman Booby Pond nature reserve is located approximately 0.5 miles (0.8 km) south west of the site. This Nature Reserve is designated as a "Wetland of International Significance" under the terms of the Ramsar Convention.

Some 0.5 miles (0.8km) north of the site is the sea which is designated a marine park with a number of diving sites.

5.7 Geology

Little Cayman is a low lying dolostone and limestone outcrop. There is no specific stratigraphic information but the dolostone and dolomitic limestone grouping probably includes the Cayman Member and Pedro Castle Member. These are underlain by the Brac Formation.

The dolostone and limestone is locally characterised by solution weathering with enlarged fissures.

5.8 Hydrogeology

The dolostone and limestone is likely to be of variable permeability. There are some small ponds shown on the land survey map in proximity to the site. These may be freshwater or brackish pools.

There is no specific hydrogeological information for the site or its surrounding environs. There are no known groundwater abstractions in proximity to the site.

5.9 Hydrology

As noted above, some small surface water pools are identified on survey map in proximity to the site. Some small areas of surface water ponding within the site were noted during the site visits. It is noted the amount of standing water had reduced significantly since the site inspection in November 2014; this is consistent with the April 2015 sampling being undertaken at the end of the dry season on the islands. It is unknown whether the offsite ponds are hydraulic continuity with the site (e.g. via groundwater base flow).

2001 DEH Sampling

DEH took one surface water samples from the landfill (location unknown) in 2001 recorded as 'Little Cayman Landfill SI'. The data for this sample is summarised in Table 5.1.

Table 5.1 Little Cayman Summary of Water Analysis 2001

Determinand	Result
pH	7.4
BOD	<2 mg/l
COD	120 mg/l
Total dissolved solids (TDS)	6,000 mg/l
Total organic carbon	18 mg/l
Ammonia as N	0.48 mg/l
Nitrate plus nitrite	<0.05 mg/l

Mercury was recorded below the laboratory LoD. Selected volatile organic compounds were also recorded below laboratory limits of detection.

The TDS result of 6,000 mg/l is indicative of brackish water.

Amec Foster Wheeler Sampling 2015

In April 2015, Amec Foster Wheeler took two surface water samples, LSW2 (a small very shallow pond near the midpoint of the southern site boundary form which it was difficult to recover a sufficient volume of water for all analytical suites) and LSW3 (a water body at the end of a track approximately 1 mile/1.5 km west of landfill) which are identified on Figure 23. LSW3 was selected to give an indication of 'background' surface water quality on the island. Note that there is no LSW1 sample, which was scheduled to be taken from the Booby Pond which is the main potential receptor south west of the landfill but water within the pond could not be safely accessed for sampling.

Assessment Criteria

The data has been screened against the Florida marine surface water clean-up targets as per the surface water samples from the George Town site. The data and screening criteria are summarised in Appendix I.

The following summary can be drawn from inspection of the surface water quality results.

General Chemistry

The BOD recorded in the 2015 samples were 8.8 mg/l (LSW3) and 57 mg/l (LSW2). These results are at least an order of magnitude higher than the 2001 result. The COD results were 730 mg/l (LSW2) and 960mg/l (LSW3) which are nearly an order of magnitude higher than the 2001 result. There are no marine water assessment criteria for either of these determinands.

The 2015 sampling identified ammonia concentrations of below LoD (LSW3) and 0.31 mg/l (LSW2). These results are below the 2001 result of 0.48 mg/l. The observed ammonia concentrations in the 2015 surface water samples reflect high water quality based on UK guideline values.

The 2015 orthophosphate concentrations were 0.028 mg/l (LSW2) and 0.04 mg/l (LSW3). On the basis of the recent round of data, the observed orthophosphate concentrations reflect good water quality based on UK guideline values.

Total suspended solids from the 2015 samples were recorded up to 43,000 mg/l. There are no marine water assessment criteria for this determinand.

Cyanide analysis was undertaken on the sample from LSW2, which recorded a concentration below the laboratory LoD.

Metals

Metals analysis was undertaken on surface water sample LSW3. The majority of metal analyses returned results below the relevant laboratory LoD. The only exceedences of the clean-up levels were as follows:

- Copper was detected above the clean-up level of 0.0037 mg/l, at 0.014 mg/l; and
- Lead was detected above the clean-up level of 0.0085 mg/l, at 0.056 mg/l.

Hydrocarbons

DRO analysis was undertaken on samples from LSW2 and LSW3 in April 2015. Results were 1.9 mg/l (LSW2) and 2.5 mg/l (LSW3). GRO analysis was also undertaken the LSW2 sample, recording a result of 0.059 mg/l.

For the purpose of data contextualisation, WHO guidance states that the application of the lowest WHO guideline value for (aliphatic) hydrocarbons (0.3 mg/l for carbon bands C12-C16, i.e. 'diesel range') to a total hydrocarbon measurement in water will provide a conservative level of protection. This guideline value has been exceeded in the samples from LSW2 and LSW3.

The data indicates some low level contamination both in the site SW2 sample and the offsite SW3 sample.

5.10 Soil Sampling

In April 2015, Amec Foster Wheeler took five soil samples from the surface across the site. The laboratory analysis included asbestos, cyanide, metals, water soluble sulphate and PAHs as well as soil leaching tests for metals and PAHs to establish the leachability of soils in relation to potential groundwater impact.

The results are summarised as follows:

- No asbestos was detected in any of the samples;
- PAHs were not detected in soils above the relevant LoD, with the exception of naphthalene, which was detected at a concentration of 44 µg/kg. This concentration is well below the Florida clean-up standard for commercial/industrial land of 300 mg/kg;
- PAHs were not detected in the soil leaching test results above the relevant laboratory LoD;
- Metals concentrations in the soil samples were below the relevant laboratory LoD for all samples for beryllium and thallium, and for all but one of the results for silver (0.74 mg/kg, LSS4). Where metals were detected, concentrations were below the relevant Florida soil clean-up target level for commercial/ industrial land with the exception of arsenic, which was detected at concentrations of 14-310 mg/kg against a clean-up target of 12 mg/kg. As before, the Florida clean-up standard for arsenic is exceptionally low when compared to UK assessment criteria for the same commercial/industrial use scenario (which is 640 mg/kg);
- Metals concentrations in leaching test results were below the laboratory LoD for all samples for beryllium, cobalt, silver and thallium, with most results for cadmium and nickel also below the LoD. Where metals were detected in leachate, concentrations were below the relevant Florida surface water clean-up target level or marine surface water criteria with the exception of arsenic (LSS4 only, 0.059 mg/l); copper (all samples, up to 0.18 mg/l) and lead (all samples except LSS2 and LSS5, concentrations up to 0.016 mg/l);
- Cyanide was detected in all samples except LSS5 at concentrations of up to 0.61 mg/kg (LSS3), although this concentration is well below the Florida clean-up standard for commercial/industrial land of 11,000 mg/kg; and
- Water soluble sulphate was detected in all samples at concentrations up to 14,000 mg/kg (LSS3). There is no Florida clean-up standard for sulphates.

In summary, there were exceedences of the relevant clean-up standards for arsenic in soils (although the clean-up standard is very low compared to that for the UK) and for arsenic, copper and lead in leaching test soil samples submitted for leaching tests.

5.11 Fugitive Emissions

Dust Deposition Monitoring 2015

The landfill is a potential source of fugitive emissions in terms of dust. Ash and clinker from burning is not covered.

Dust deposition monitoring was undertaken in accordance with the methodology set out in in the Task 2 investigation factual report. The dust deposition measurement location is described in Table 5.2 and is shown on Figure 23.

Table 5.2 Dust Deposition Monitoring Locations – Little Cayman Landfill

Monitoring Run	Location	Run time (mins)	Date and comments
Unit R10256 Serial 6709			
Run 12	Placed on top of metal drum near western boundary	246	Run on 16 April during sampling works during site operational hours. Location downwind of landfill.

Dust deposition measurement data are included in the Task 2 investigation factual report. In summary, the overall average concentration of dust measured on the run was 0 mg/m^3. Note that this location is downwind of the main landfill area of the site.

By way of comparison, the EC/UK Air Quality Standard for PM_{10} is 50 µg/m^3 (0.05 mg/m^3) based on a 24 hour mean, which was not breached in the location monitored.

Smoke

The site receives municipal wastes including organic materials such as food and kitchen wastes, garden wastes, paper, cardboard and timber. The wastes are routinely burnt and produce smoke. The prevailing wind direction for the Cayman Islands is from the ENE.

As the wastes are burnt at the site is not considered to have any potential for landfill gas generation.

Other Vapour Sources

The waste oils storage area is a potential source of vapours although with the relatively small quantities stored this is not considered a significant source. An illegal oil disposal pit was also identified at the site during the April 2015 visit. No vapour monitoring is undertaken at the site.

5.12 Other Issues

The landfill is in an isolated location and is not visible from any residential properties.

5.13 Risk Assessment

Approach

The risk assessment approach is described in Chapter 2.

Conceptual Model

A conceptual model have been prepared for the site which identifies potential contaminants and amenity related hazards, potential pathways and receptors. The conceptual model considers both onsite and offsite sources. The conceptual model is included as Figure 24.

Summary of Potential Contamination and Hazards

On-Site Sources

From the assessment of historical and current activities and the limited environmental monitoring data (which has been screened against generic assessment criteria) the potential onsite sources are identified in Table 5.3.

Table 5.3 Summary of Onsite Potential Contamination and Hazards

Location	Source	Contaminant (C) Hazard (H)	Type	Quantitative Data Y= yes N= no	Comment
Waste Oils storage area	Hydrocarbons	C	Hydrocarbons	Y	Some surface spills noted. DRO detected in both surface water samples, GRO in surface water sample LSW2.
Illegal waste oil disposal pit	Hydrocarbons	C/H	Hydrocarbons	N	Illegal waste oil disposal pit at the site, near the plant storage building.
Groundwater	Leaching from burning area	H/C	Metals	Y	Arsenic, copper and lead detected above relevant standards in soil samples submitted for leaching tests
Offsite pond	Leaching from waste and groundwater base flow	H/C	Metals	Y	Copper and lead above relevant Florida clean-up levels
Burning Ground	Ash and clinker	C	Metals	Y	Arsenic above relevant Florida clean-up level in soils
Burning Ground	Smoke	C/H	Combustion products	N	

Off-Site Sources

The island power generation facility is located east of the landfill area. This is diesel powered and a potential source of hydrocarbon contamination. No other off-site contamination sources or hazards have been identified.

Receptors and Pathways

Receptor groups have been identified in Table 5.4 together with some notes on their status.

Table 5.4 Receptors

Receptor Groups	Comments
Site workers and visitors	Site has open access and members of the public can access at any time.
Offsite residents	The nearest properties are some 0.35 miles south of the site.
Groundwater	Groundwater depth and quality is unknown. There are no known abstractions in the vicinity of the site.
Surface water in offsite ponds	Most likely brackish water with possible groundwater base flow.
Booby Pond nature reserve	Internationally important site approximately 0.5 miles south-west of the site.

Potential pathways are considered in Table 5.5.

Table 5.5 Potential Receptors and Pathways

Receptor	Pathway
Site workers and visitors	Dermal contact, direct contact, ingestion, inhalation
Adjacent residents	Ingestion of dusts, inhalation of smoke
Groundwater	Leaching and migration
Surface Water (offsite ponds)	Run-off, migration and groundwater base flow
Fauna in Booby Pond nature reserve	Smoke and combustion products from waste burning

Risk Assessment Methodology

The development of the conceptual models have identified a number of potential contaminant and hazard linkages (contaminant/hazard-pathway-receptor linkages) between receptors and the landfill site. These are tabulated in Appendix J. Each contaminant linkage has been qualitatively assessed using the following criteria:

i) Potential consequence of contaminant/hazard linkage;

ii) Likelihood of contaminant/hazard linkage; and

iii) Risk classification.

The risk assessment criteria assessment methodology is provided within the Task 2 investigation factual report.

The updated environmental risk assessment for the site is included in Appendix J. This comprises an analysis of potential contaminant/hazard linkages (contaminant/hazard-pathway-receptor) between potential receptors and the landfill site.

5.14 Risk Assessment Outcomes

The outcomes from the risk tables in Appendix J are summarised below. The first paragraph summary for each receptor considers contaminants and the second amenity hazards.

Site Workers and Visitors

Potential risks to site workers and visitors from combustion products and metals in soils are assessed as moderate/low and from hydrocarbons in soils are assessed as low.

Adjacent Residents

Potential dust and odour nuisance to adjacent residents is assessed as low due to the distance from the landfill. Potential risks associated with scavenging animals/birds and insects are assessed as low and medium, respectively. There is also a potential medium risk associated with nuisance from landfill fires.

Groundwater and Offsite Pools

Potential risks to groundwater from hydrocarbons are assessed as moderate and from metals are assessed as moderate/low. Risks to groundwater from ammonia are assessed as low. Risks to offsite pools from metals are assessed as moderate/low.

There is also a potential medium risk to offsite pools associated with elevated nutrients, iron and solids.

Booby Pond

Potential risks to the Booby Pond from air transport of smoke and combustion products is assessed as medium.

6. Conclusions and Recommendations

6.1 Conclusions

Basis of Study and Data

This Task 2 environmental review of the landfill sites on Grand Cayman, Cayman Brac and Little Cayman is an interpretation of data collected from monitoring and survey in April 2015. The scope of the investigations was determined from an earlier Task 1 study (Amec Foster Wheeler, January 2015).

For George Town landfill on Grand Cayman the interpretation also includes consideration of some pre-existing analytical information available from periodic monitoring of groundwater, surface water and marine water in North Sound. No relevant pre-existing environmental monitoring information was available for the smaller landfills on Cayman Brac and Grand Cayman.

This data has been collated and screened against Florida state clean-up assessment criteria for waters and soils. Landfill gas monitoring and analysis was undertaken on the George Town and Cayman Brac sites and based on the collected data air quality modelling has been undertaken for the George Town site.

Amenity related issues have also been considered for each site; these are hazards such as dust, landfill fires and nutrients in waters for which there are no direct assessment criteria.

George Town Landfill

The George Town site receives around 62,000 t/annum of municipal and commercial waste for disposal within the landfill and further 16,000 t/annum of other materials including scrap metals, tyres and waste oils which are stored pending recycling. There are significant stockpiles of metal and tyres representing a number of years accumulation. The waste disposal area is an un-engineered land raise, rising to approximately 80 ft (24.4m) above sea level. The current active landfill area is not capped and has a thin soil cover on one flank. The old landfill area to the south east of the site has a thin soil cap and has to some extent naturally regenerated. A clinical waste incinerator is present in the north east part of the site.

The following have been identified as significant receptors:

- Site workers and visitors (the general public have access to parts of the site);
- Adjacent residential development to the west (Lakeside and Parkside Close) being only 330 feet (100m) from the landfill boundary and downwind of the site. Other residential development and a school are located north west and north respectively;
- Groundwater below the site is brackish and tidal and the hydraulic gradient is believed to be to the east towards the North Sound;
- Perimeter canals which flank the site to the west and north with an outfall into North Sound; and
- Marine ecology within North Sound.

The contamination and amenity risk assessments have identified the following key[22] risks associated with the landfill:

- **Site users and visitors**: arsenic in soils as well as hydrogen sulphide and methane;
- **Adjacent residents:** nuisance from odour and landfill fires;

[22] Key contamination risks are regarded as those that are assessed as moderate and above. For amenity risks, which are much more subjective in nature, key risks are defined as high risks only.

- **Adjacent commercial/industrial site users:** hydrogen sulphide from sediments contaminated by various sources including the landfill, as well as nuisance from odour and landfill fires;
- **Groundwater:** hydrocarbons from spills and overtopping of bunds;
- **Surface water:** hydrocarbons from spills and overtopping of bunds, ammonia and orthophosphates from groundwater; and
- **North Sound:** ammonia and metals from canal water.

The landfill also has a significant visual impact from various viewpoints.

Cayman Brac Landfill

The landfill receives around 2,200T/annum of waste. The site has nominally separate areas for disposal of municipal, green and construction and demolition waste but there is some cross contamination of waste streams. There is no engineered containment or capping of the disposal areas. Large stockpiles of scrap metal are stored at the site. Waste oils and batteries are stored in uncontained areas pending offsite transfer. There is a very small clinical waste incinerator which has intermittent operation and has been put of action since at least November 2015 resulting in clinical waste disposal in a pit in the landfill.

The following significant receptors have been identified:

- Site workers and visitors (the general public have unfettered access to the site);
- Adjacent residential development, three properties are located south of the site beyond which is a public beach;
- Groundwater below the site is brackish and tidal and the hydraulic gradient is likely to be to the ocean to the south; and
- A surface water body known as the Red Shrimp lagoon which is present on the site, and the adjacent ocean.

The contamination and amenity risk assessments have identified the following key risks associated with the landfill:

- **Site users and visitors**: methane from landfill gas;
- **Groundwater:** hydrocarbons from waste oil storage spills to ground; and
- **Surface water:** metals leaching from landfill.

Little Cayman Landfill

There is no measure of waste inputs into the site but the island resident population is small (around 170). Municipal waste deposited at the site is regularly set alight and the disposal area is effectively a burning ground. Scrap metal, waste oil and batteries are stored in uncontained areas pending off-site disposal.

The following significant receptors have been identified:

- Site workers and visitors (the general public have unfettered access to the site);
- Groundwater, it is unknown if this is freshwater or brackish, the hydraulic gradient is likely to be to the west;
- The Booby Pond RAMSAR site located 0.5 miles south west of the site.

The contamination and amenity risk assessments have identified the following key risks associated with the landfill:

- **Groundwater:** hydrocarbons from illegal waste oil disposal pit.

6.2 Recommendations

Amec Foster Wheeler's recommendations resulting from assessment and interpretation of the data in this report and the resultant risk assessments are summarised in the following tables.

Table 6.1 Recommendations for Environmental Improvements and Monitoring at George Town Landfill

Ref	Source/Risk	Proposed Work	Objective/Rationale
1	Fugitive gas emissions from the landfill surface	Progressive engineered capping of completed areas of the landfill to minimise landfill gas emission and enable gas collection for energy recovery Application of daily cover to landfilled wastes	Reduction in emission of odorous gas constituents and methane which is a significant greenhouse gas Prevent vermin accessing the landfilled wastes
2	Landfill gas	Repeat of flux box tests Bulk gas monitoring in existing gas probes at least every three months Gas pumping trials following first phase of capping	Better definition of landfill gas emission rates Ongoing evaluation of gas quality Recovery of landfill gas and use in electricity generation.
3	Incinerator emissions	Establish emissions monitoring programme	Provide quantitative assessment of emissions from incinerator and their likely impact
4	Landfill fires	Removal of stockpiled tyres which are a particular fire hazard Monitoring for airborne PAH's during waste fires	Burning tyres pose a significant risk in terms of combustion Evaluation of potential health impact to offsite receptors (note capping of the wastes will reduce the potential for fires).
5	Groundwater contamination	Progressive capping of the site Monitoring of existing groundwater wells on at least an annual basis	Reduce leaching potential from the wastes and impact on groundwater Continued evaluation of impacts
6	Surface water contamination	Monitoring in North Canal on at least a six monthly basis	Continued evaluation of impacts
7	Marine water contamination	Reinstate annual DoE sampling in North Sound	Continued evaluation of impacts

Table 6.2 Recommendations for Environmental Improvements and Monitoring at Cayman Brac Landfill

Ref	Source/Risk	Proposed Work	Objective/Rationale
1	Clinical waste disposal in the landfill	Reinstate the incinerator to prevent direct disposal If continued landfill disposal in the short term then cover the disposal area daily	Cease landfill disposal of clinical waste Good practice and reduced risk of vermin nuisance or public health incident
2	Incinerator emissions	Establish emissions monitoring programme when incinerator is operational	Provide quantitative assessment of emissions from incinerator and their likely impact
3	Landfill gas as a greenhouse gas	Bulk gas monitoring in existing gas probes at least every three months Consideration of whether engineered capping and gas recovery for flaring is of cost benefit	Ongoing evaluation of gas quality Potential reduction in uncontrolled gas emission by may not be economically viable due to small size of landfill
4	Groundwater contamination	Monitoring of existing groundwater wells on at least an annual basis	Continued evaluation of impacts
5	Surface water contamination	Monitoring of shrimp pond on at least an annual basis	Continued evaluation of impacts

Table 6.3 Recommendations for Environmental Improvements and Monitoring at Little Cayman Landfill

Ref	Source/Risk	Proposed Works	Objective/Rationale
1	Illegal oil disposal pit	Prevent access Further assessment and remediation	Potential health and safety hazard and prevent further disposal Assessment of remediation requirements
2	Continued uncontrolled landfill expansion	Management and restrictions to prevent further expansion of burning area	Limit on uncontrolled site expansion, especially in direction of Booby Pond.

Figures

Appendix A
Screened Groundwater Data, George Town Landfill

Appendix B
Screened Surface Water Data, George Town Landfill

Appendix C
Time Series Plots, George Town Landfill

Appendix D
Screened Soils Data, George Town Landfill

Appendix E
Risk Assessment Tables, George Town Landfill

Appendix F
Screened Groundwater Data, Cayman Brac Landfill

Appendix G
Screened Surface Water Data, Cayman Brac Landfill

Appendix H
Risk Assessment Tables, Cayman Brac Landfill

Appendix I
Screened Surface Water Data, Little Cayman Landfill

Appendix J
Risk Assessment Tables, Little Cayman Landfill

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