ASSESSMENT OF GRAND CAYMAN'S GEORGE TOWN LANDFILL AND APPLICATION OF INTEGRATED COASTAL MANAGEMENT FOR IMPROVED ENVIRONMENTAL SUSTAINABILITY

By

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&
S.C.P

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LIST OF ABBREVIATIONS

CIG:	Cayman Islands Government
DEH:	Department of Environmental Health
DOE:	Department of Environment
DOT:	Department of Tourism
EA:	Environmental Assessment
EIA:	Environmental Impact Assessment
GTLF:	George Town Landfill
ICM:	Integrated Coastal Management
MHSYC:	Ministry of Health, Sports, Youth and Culture
PI:	Petroleum Inspectorate
WDOR:	Waste Disposal Options Review Committee
WAC:	Water Authority Cayman
WWF:	Waste Water Facility

ABSTRACT

Sybersma, S., 2014. Assessment of Grand Cayman's George Town Landfill and Application of Integrated Coastal Management for Improved Environmental Sustainability [graduate project]. Halifax, NS: Dalhousie University.

Abstract: Grand Cayman's George Town Landfill [GTLF] is located approximately 1km from the coast, is surrounded by tidal canals, and is unlined, uncovered, and unenginered. The close proximity of GTLF to the coast and tidal canals, Grand Cayman's geographic structure and the GTLF's operational practices create concern that leachate is migrating into marine and coastal ecosystems, contaminating them. A desktop study was performed to determine if the GTLF is contaminating Grand Cayman's ecosystems. First the geographic and operational vulnerabilities of the GTLF, which could lead to contamination, were studied and explained. Then, groundwater, surface water, marine water, tissue sample and sediment analyses were done to determine if contamination was actually occurring. Results indicate that there was some contamination of marine and coastal ecosystems surrounding the GTLF, however contamination was not at ecosystem threatening levels. It was recommended that Integrated Coastal Management be implemented to create an integrated management plan that will address the geographic and operational vulnerabilities that are aiding contamination. The management plan should be created with the goal of improving and protecting Grand Cayman's ecosystem health, and improving waste management practices to make them more sustainable.

Keywords: Landfill contamination, leachate migration, geographic vulnerabilities, landfill operation vulnerabilities, Integrated Coastal Management, sustainability, decision making, groundwater, surface water, tissue samples, sediment, Caribbean, tropical landfill.

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This one is for Team Sybersma!

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OVERVIEW OF MANAGEMENT PROBLEM

Grand Cayman, the largest of the Cayman Islands, has an unlined, uncovered, unengineered, landfill [GTLF] located near the coast (CardnoENTIRX, 2013; Post, Buckley, Schuh & Jernigan 1992 [Post, et al, 1992b]). The poor design of the landfill paired with certain geological features of the island, and visual discoloration of the water near the GTLF, figure 1.1, cause concern that the GTLF may be contaminating the North Sound (Post, et al, 1992b).

The North Sound is a large body of marine water, home to many organisms and sensitive ecosystems. It is also used for recreational and tourism activates such as swimming, boating, and fishing. The North Sound has been described as “one of the most unique marine ecosystems in the Caribbean” by Post, et al, and is a conservation priority for the Cayman Islands Government [CIG] (Baseado, 1999; Post, Buckley, Schuh & Jernigan, 1992, pp 3-7, [Post, et al, 1992a]). Contamination from the GTLF is worrying because of unknown potential ecological and human impacts (Post, et al, 1992b; Williams, 2005).

Figure 1.1. Areal view of North Sound water discoloration near GTLF. Areal view shows discoloration of North Sound near the GTLF. GTLF is located in the direction of the yellow arrow outside the scope of this picture. The North Sound is the featured body of water on the right, and Seven Mile beach can be seen at top left. (Source: CardnoENTRIX, 2013).

Ocean and coastal environments are sensitive, requiring stable, constant and often specific water chemistry. Contamination, especially from a landfill can have negative effects on these environments. Contamination can change water chemistry, which can create environments that favor invasive species, or are toxic to local flora and fauna (Townsend, 2012). Contamination from GTLF could negatively affect the various ecosystems in and around the North Sound, including mangrove forests, coral reefs and sea-grass beds (CardnoENTRIX, 2013; Post, et al, 1992b; Townsend, 2012).

Additionally the North Sound is used for recreational activities. Contaminates could harm people who enter the water and are exposed to elevated levels (CardnoENTRIX, 2013; Williams, 2005). Landfill leachate contains both biological [bacterial] and chemical [metals, organics] that can pose a health risk. Contaminants also attract and infect vermin such as flies and rats, further spreading disease and toxins (Williams, 2005).

Evaluating the potential for, and actual contamination from the GTLF into the marine environment of Grand Cayman is important as it has many potentially negative effects to humans, ecosystems, and species—impacting multiple stakeholders. The main stakeholders affected by this problem are the Cayman Islands Government [CIG] notably; the Department of Environment [DOE]; Department of Environmental Health [DEH];

Department of Tourism [DOT]; neighboring developers and communities including Dart Enterprises and Camana Bay, tourists in the area, and local home owners.

No one has investigated the GTLF's effects on the marine environment since 1992 warranting this study necessary. This project aims to increase our understanding of the GTLF, and provide management recommendations to preserve and protect the marine resources and coastal zone of the Cayman Islands.

RESEARCH QUESTION and OBJECTIVES

To address this management problem this report will aim to answer the following research question: **Is the GTLF contaminating the marine environment, namely the North Sound, of Grand Cayman?**

To answer this question, the following objectives will be met:

1. Outline the climatic and geologic vulnerabilities of Grand Cayman, and the design and operational vulnerabilities of the GTLF which could lead to marine contamination.
2. Evaluate groundwater, surface water, marine water, tissue and sediment samples at and around the GTLF for evidence of contaminants.

3. Provide recommendations and a management framework to manage the vulnerabilities of the GTLF. Recommendations will aim to reduce actual found contamination [objective 2] and/or potential contamination from vulnerabilities [objective 1].

STRUCTURE of REPORT

The remainder of this report is divided into the following three chapters.

- **Chapter 1: Vulnerabilities.** Chapter 1 addresses objective 1, by conducting a desktop review of the geology and climate of Grand Cayman to explain the natural vulnerabilities of Grand Cayman and the GTLF site. Then the GTLF's design and operational practices are outlined, identifying operational vulnerabilities for contamination.
- **Chapter 2: Data Analysis.** Chapter 2 addresses objective 2. Groundwater, surface water, marine water, tissue data, and sediment data, are analyzed to determine if the GTLF is actually contaminating the marine environment and coastal zone.
- **Chapter 3: Recommendations.** Chapter 3 addresses objective 3, by applying the Integrated Coastal Management [ICM] framework and current waste management best practices to the vulnerabilities discussed in Chapter 1, and actual

contamination found in Chapter 2. This will be done with the intention to improve the protection and health of Grand Cayman’s marine and coastal resources.

CHAPTER 1: VULNERABILITIES

1.1 PHYSICAL DESCRIPTION of GRAND CAYMAN

The Cayman Islands are located in the western Caribbean, south of Cuba, northwest of Jamaica, and east of Mexico. The Cayman Islands are comprised of three separate islands; Grand Cayman, Cayman Brac and Little Cayman. Grand Cayman is the largest of the three islands, at approximately 196km^2 (76 miles^2) and home to the largest population. Cayman Brac is 39km^2 (15 miles^2), and Little Cayman is the smallest at 29km^2 (11 miles^2) with the lowest population (CIG, 2011b). Each island has its own landfill for its waste management. Grand Cayman's George Town Landfill (GTLF), located in George Town, Grand Cayman, is the focus of this report, figure 1.2.

Figure 1.2 GTLF's location on Grand Cayman. Image shows GTLF outlined in red on Grand Cayman, with a closer look at the GTLF's location to the upper right. (Source: Terry-Swaby, 2014)

1.1.1 Geology.

The Cayman Islands are the peaks of an underwater mountain range extending from Sierra Maestra, Cuba to the Gulf of Honduras, on the south end of the North American Plate (Jones, 2000). The underwater mountain range includes the Cayman Trench which is still separating at an estimated rate of ~1cm a year (0.4-0.5 inches) making the islands seismically active (CardnoENTRIX, 2013). The islands are made entirely of calcareous marine deposits, which have been separated into four different formations, Figure 1.3 (Hills, 1998).

The GTLF is situated on the main formation seen on Grand Cayman—Ironshore Formation, from the Pleistocene era. Ironshore is comprised of limestone ($CaCO_3$) and is porous. Additionally there are two other formations that make up the Cayman Islands: Pedro Castle Formation from the Pliocene era, made partially of dolostone ($CaMg(CO_3)_2$ and limestone; and the Cayman Formation, the oldest of the three, from the Middle Miocene made entirely of dolostone (Hills, 1998).[1]

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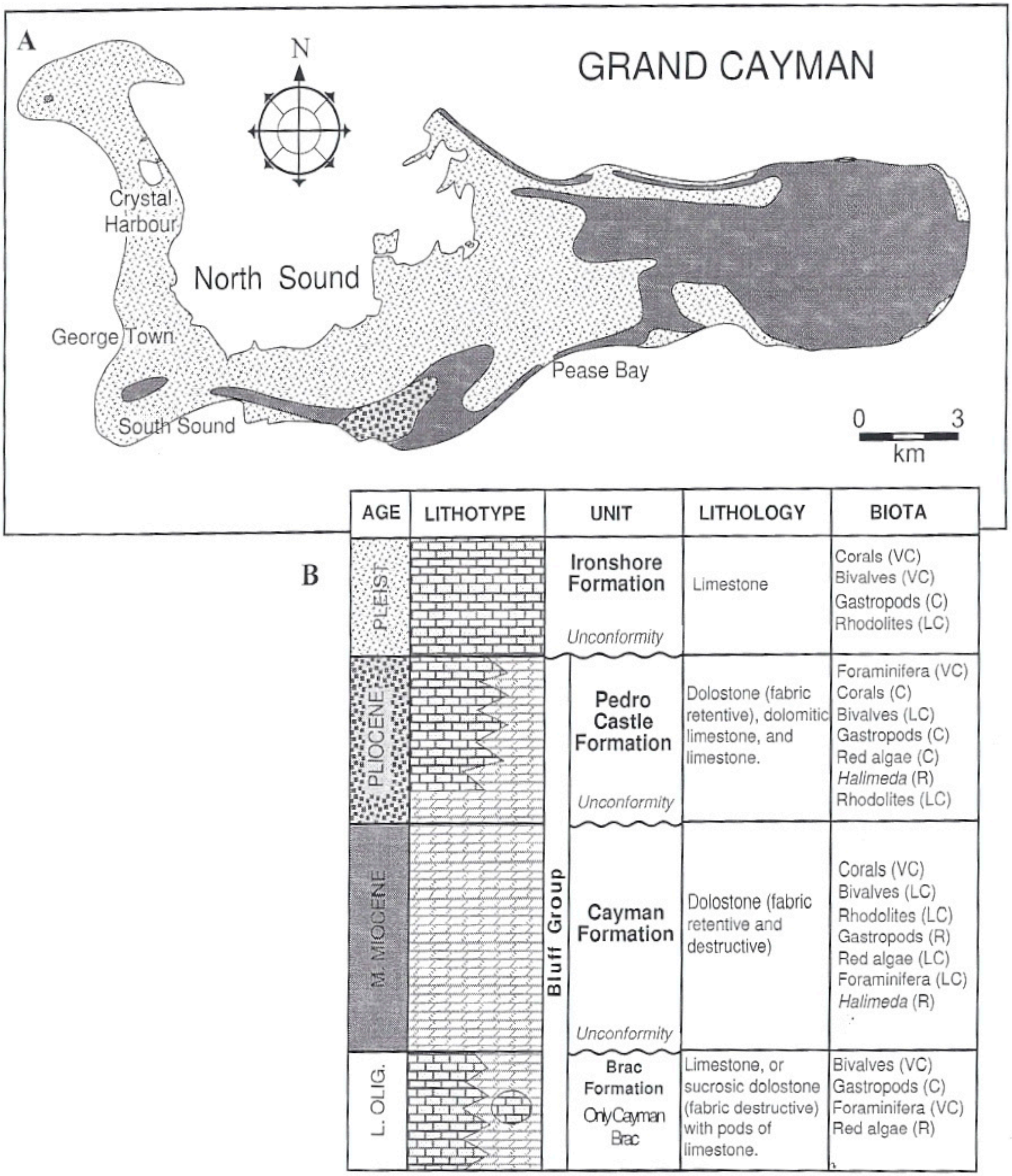
[1] Dolostone develops as dolomite replaces limestone over time. The intermediary stage—as dolomite is replacing limestone can be seen in the Pedro Castle Formation (Brunt and Davies 1994; Jones, n.d.).



AGE	LITHOTYPE		UNIT	LITHOLOGY	BIOTA
PLEIST.			**Ironshore Formation** *Unconformity*	Limestone	Corals (VC) Bivalves (VC) Gastropods (C) Rhodolites (LC)
PLIOCENE		**Bluff Group**	**Pedro Castle Formation** *Unconformity*	Dolostone (fabric retentive), dolomitic limestone, and limestone.	Foraminifera (VC) Corals (C) Bivalves (LC) Gastropods (C) Red algae (C) *Halimeda* (R) Rhodolites (LC)
M. MIOCENE			**Cayman Formation** *Unconformity*	Dolostone (fabric retentive and destructive)	Corals (VC) Bivalves (LC) Rhodolites (LC) Gastropods (R) Red algae (LC) Foraminifera (LC) *Halimeda* (R)
L. OLIG.			**Brac Formation** Only Cayman Brac	Limestone, or sucrosic dolostone (fabric destructive) with pods of limestone.	Bivalves (VC) Gastropods (C) Foraminifera (VC) Red algae (R)

Figure 1.3. Sedimentary make up of Grand Cayman. ‘A’ shows map of Grand Cayman and location of main sedimentary formations. ‘B’ shows age, lithotype, unit, lithology and biota of sedimentary formations. (Source: Hills, 1998; who modified from Jones, et al, 1994).

Cayman is seismically active, with most recorded earthquakes scoring less than 5 on the Richter scale. The highest magnitude earthquake on record was recorded December 2004, scoring 6.8 (CardnoENTRIX, 2013). Seismic activity causes concern for contamination as the activity can disrupt air-pockets or void spaces in the sediment causing sinkholes (United States Geological Survey, 2014). Sinkholes after a seismic event are common for limestone formations. Sinkholes, depending on depth and size can bring leachate or surface water into groundwater aiding contaminant migration into the water table. (CardnoENTRIX, 2013).

1.1.2 Groundwater.

The largest reserves of fresh groundwater are found in the Cayman and Pedro Formations. Smaller quantities of fresh groundwater are found in the Ironshore Formation (Brunt and Davies, 1994). The high porosity of Cayman's surficial soils contributes to the fact that there are no streams on the Islands. Surface water rapidly percolates down as opposed to accumulating on the lands surface and running off (Brunt and Davies, 1994).

The water table is hydraulically connected to the marine environment as groundwater levels fluctuate with tides. This can provide a pathway for contaminates to migrate into the marine environment if groundwater becomes contaminated. The marine connection is also responsible for the general composition of the water lens, as the tidal influence causes mixing. This results in a denser saline layer on bottom, a brackish transition zone, and a fresh water lens on top, figure 1.4 (Brunt and Davies, 1994).

The degree of sediment porosity is reflected in the delay between oceanic tidal change and groundwater tidal change. The different water systems respond to tides at different speeds (Brunt and Davies, 1994). It is thought that deeper wells are more strongly connected to the marine environment as they have shorter time lags between oceanic and water table tides, and shallower water tables respond slower, with longer delays (Brunt and Davies, 1994). The strength of connection to the marine environment is of concern as a stronger connection increases the ease of contaminant migration.

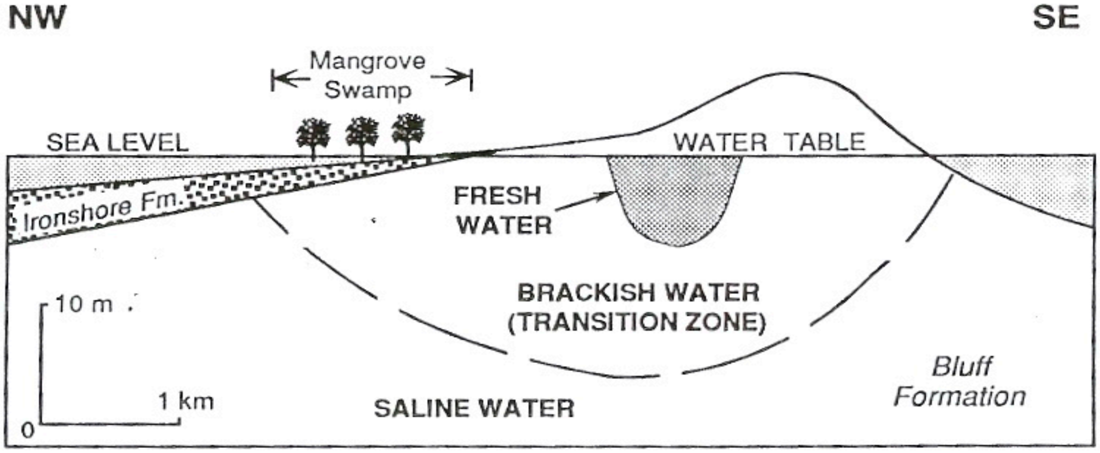


Figure 1.4. Simplified cross-section of water lens. Figure shows a simplified version of a water lens on Grand Cayman. Note the different water layers: saline at bottom, brackish in middle, and fresh on top. (Source: Brunt and Davies, 1994).

The water table is on average 0.5m above sea level, regardless of the islands elevation—Grand Cayman's elevation ranges from sea level (0m) to 18 m (60ft) at the highest point, in East End (Brunt and Davies, 1994) and has an average elevation of 1.7m (5.8ft) (Hurlstone-McKenzie, 2011). The high water table reduces the quality of water as percolating rainwater travels through a thin surficial soil layer with minimal filtration. The average freshwater lens thickness is less than 20m, also minimizing fresh water as a resource (Brunt and Davies, 1994).

1.1.3 Climate.

The Cayman Islands have a warm tropical climate, with temperatures averaging 25.5^{oC} (78^{oF}) in winter and 28.3^{oC} (83^{oF}) in the summer (Cayman Islands Government, 2011a [CIG, 2011a]; National Weather Service, 2014). This is accompanied by an average yearly humidity of 81% (National Weather Service, 2014). The Cayman Islands climate is highly influenced by the ocean, which regulates the temperature and humidity ranges (Brunt and Davies, 1994). Cayman's tides are diurnal, with amplitudes ranging 26cm (10in) on average. Highest-lowest tides range at 1m (3.2ft)—excluding storm surge (Brunt and Davies, 1994).

Hurricane season officially begins June 1st and ends November 30th (Cayman Prepared, 2010). These months have the highest rainfall during the year and highest number of storms, figure 1.5. December- April is dryer with less precipitation, lower humidity and temperatures, and few storms (Cayman Prepared 2010; and CIG, 2011a). Storms, especially hurricanes, pose a threat to the island as rainwater, storm surge and increased winds aid in contaminant transport (CardnoENTRIX, 2013; Williams, 2005).

Table 1.1 provides information about significant storms of category III and higher that have impacted the island over the past 30 years. Some sources suggest that Cayman experiences more hurricanes than any other Caribbean country, with direct hits (eye passing over the island) every nine years and brushes every 2-3 years (Brunt and Davies, 1994; CardnoENTRIX, 2013).

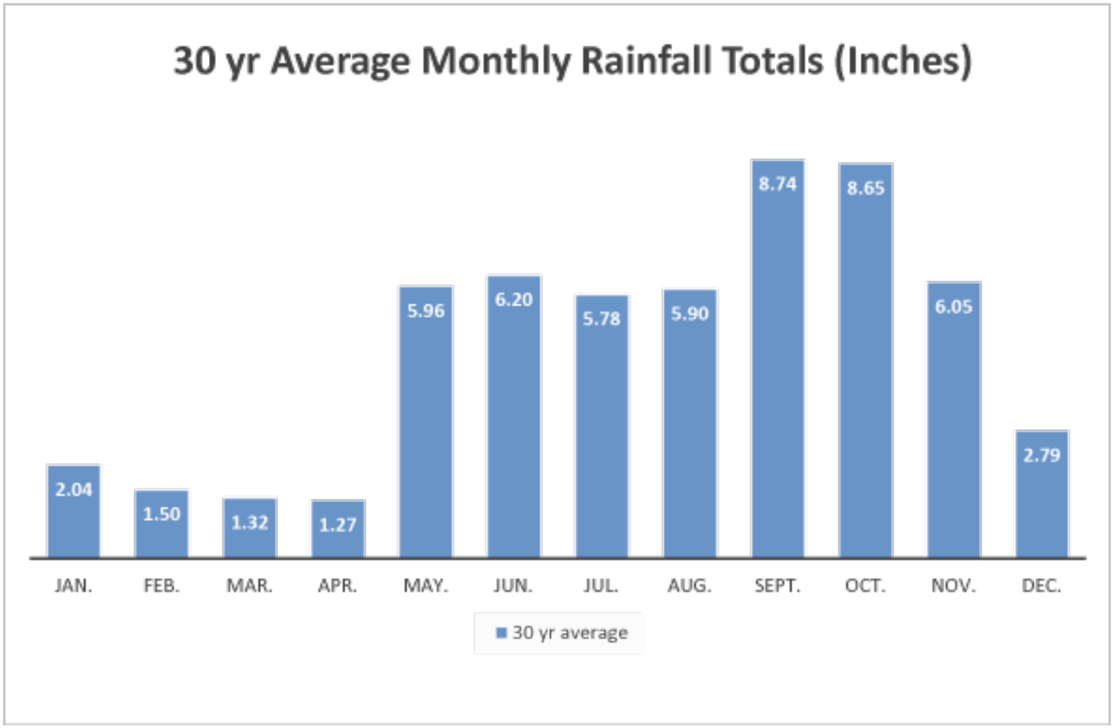


Figure 1.5. Average monthly rainfall (inches). Graph shows the monthly average rainfall as calculated from averages over the past 30 years. Yearly average= 118.9mm (4.68in). December-April average= 45.2mm (1.78in). May- October average= 174.5mm (6.87in). (Source: National Weather Service, 2014).

Table 1.1 Significant hurricanes of category III and higher over past 30 years. Table lists the hurricanes of Category 3 and higher, and the closest point of approach to the Cayman Islands.

(Source: Bubb 2013; as cited in Hurlston-McKenzie 2011).

Year	Hurricane	Category	Closest Point of Approach in km (miles)
1980	Allen	III	90km (56miles)
1988	Gilbert	IV	37km (24milies)
2001	Michelle	IV	209km (130miles)
2004	Ivan	IV	35km (22miles)
2005	Emily	IV	160km (100miles)
2008	Paloma	IV	14km (9miles)

1.2 SOCIOECONOMICS of GRAND CAYMAN

1.2.1 Brief history of Cayman Islands Government.

The Cayman Islands were first discovered in 1503 by Christopher Columbus, and were reportedly uninhabited. In 1670 the Treaty of Madrid gave the British possession of the Cayman Islands. The first settlements were also recorded around this time, between 1661-1671. The first census took place later in 1802 counting 993 persons on Grand Cayman, 545 of whom were slaves. The islands population continued to grow and government developed, with a legislative assembly established in 1831 (Cayman Islands Government, 2005 [CIG 2005]).

In 1863 the British Parliament made Cayman a dependency of Jamaica. This continued until Jamaica became independent in 1962. Cayman, wanted to stay under British rule so an administrator—now governor, took over the responsibilities of the Governor of Jamaica. The administrator was appointed by the crown, and continues to be today. The administrator/governor is responsible for the civil service, police, defense, and external affairs (CIG, 2005). Today the islands are a British Overseas Territory governed by a parliamentary democracy. In addition to the governor there is a legislative assembly (15 members) representing the people, and a Cabinet (7 members) led by a minister appointed by the elected premier (CardnoENTRIX, 2013).

Waste Management and the GTLF is run the by the DEH, which is under the authority of the Ministry of Health, Sports, Youth and Culture [MHSYC]. This ministry is overseen by the Cabinet (Ministry of Health, Sports, Youth and Culture 2014 [MHSYC 2014]).

1.2.3 Population.

The Cayman Islands population has grown constantly since the first census in 1820; from 993 persons—to 55,036 in 2010, figure 1.6. George Town is the most populated district and home to the GTLF (Economics and Statistics Office, 2011 [ESO, 2011]). In 2013, CardnoENTRIX estimated that 14,088 people live within 2 miles of the GTLF, 1583 of which were tourists in hotel rooms, (2014).

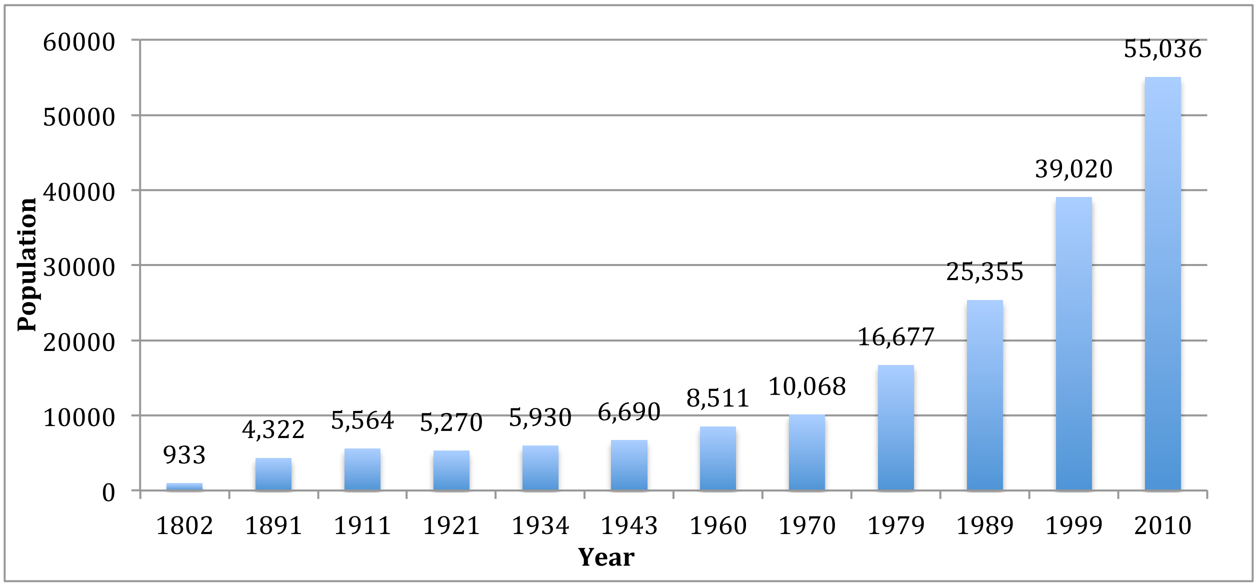


Figure 1.6. Non-institutional Population of the Cayman Islands 1820-2010. Non-institutional population does not include persons in institutions, i.e student dorms, prison, retirement homes[2]. In 2010 there was 420 institutional people, bringing the total population of the Cayman Islands to 55,456. (Modified from ESO, 2011).

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[2] As defined by The Economics and Statistics Office, Cayman Islands Government in the 2010 Census of Population and Housing Report, November 2011.

1.2.2 Legislation for waste management.

Below is a summary of the main legislation related to waste management in the Cayman Islands and specifically the GTLF;

1. The DEH is the regulating and operating authority for the GTLF and all other waste management on the islands. The DEH is responsible for collecting garbage put out by individuals and businesses, disposing of abandoned vehicles, incinerating medical waste, keeping the incinerator up to standards set out in the Public Health Law and operating the GTLF (Litter Law 1998, Public Health Law; Infectious Waste Act 2002, Public Health Law, Garbage and Refuse 2011).
2. The National Conservation Law, passed in February 2014 protects Cayman's species and ecosystems from harm. It creates a legislative framework for EIA's, licenses, development, and protected areas. Notably, it protects the marine environment from adverse effects, some of which are outlined below:

> (c). Alterations of salinity levels, nutrient balance, oxygen concentration, or temperature that may be harmful to wildlife or the ecological or aesthetic value of an area.
>
> (d). Alterations of hydrology, waterflow, circulation patterns, water levels, or surface drainage that may be harmful to wildlife of the ecological or aesthetic value of the area of that may exacerbate erosion,

> (f). The discharge of pathogens, dissolved or suspended minerals or solids, waste materials, or other substances at levels that may be harmful to wildlife or the ecological or aesthetic value of the area
>
> (National Conservation Law, 2014, Part 1, S 2(c, d, f))

3. Cayman is a member of the RAMSAR convention, which requires countries to use wetlands wisely (CardnoENTRIX, 2013; National Conservation Law, 2014). Additionally Cayman is a member of the Convention on the Conservation of Migratory Species of Wild Animals, and the Protocol Concerning Specially Protected Areas and Wildlife of the Regional Concentration [SPAW] Kingston, Jamaica (National Conservation Law, 2014).
4. The Water Authority is responsible for treating sewage, and preventing contamination from fecal matter. The Water Authority must properly process all sewage, keep pipes and facilities working well, and verify that the sewage effluent is up to the standard outlined in the law (Waste Water Collection Law, 2011).
5. Petroleum Inspectorate [PI] is responsible for petroleum and fuel related safety and compressed gas operations. The PI and petroleum operations are regulated under the Dangerous Substances Handling and Storage Law 2003 (CardnoENTRIX, 2013).

1.2.4 George Town Landfill (GTLF).

1.2.4.1 History of waste management and the GTLF.

Prior to 1959 there is no record of waste management on the Cayman Islands, probably because there was not enough waste generated to need a waste management plan. Items were reportedly used and reused. The small population –less than 8,500 people and small economy could not support importing excess goods. Meaning the things people aquired were valued (Winker, 2013). In 1960 the first record of waste management began when the CIG built an incinerator at the hospital to dispose of medical waste. At the same time they initiated a waste management plan for George Town (Winker, 2013).

Waste storage began at the current GTLF site a few years later in the mid 1960's when George Seymour purchased 8.15 hectares of land within the current GTLF's site. Mr. Seymour began to dump his garbage and any extra boxes or crates he could find into the low-lying swampy areas of the property. This was common practice at the time, and was done to add elevation to the property to reduce the swampy areas (Seymour, 1972; Winker, 2013).

The general population found out about this and also began to dump their garbage on Mr. Seymour's property. Mr. Seymour tried to stop this but was unsuccessful. In 1972 the CIG approached Mr. Seymour about using his land for a landfill for five years. Mr. Seymour agreed, and thus use of the area as a municipal landfill was established (Seymour, 1972; Winker, 2013). The GTLF was never lined when the government began using the site, and remains unlined today. An unlined landfill is against waste management best practices as leachate can migrate into ground and surface water contaminating the environment (Tammemagi, 1999; Williams, 2005).

Since 1972 the GTLF has expanded from 8 to 20 hectares as neighboring plots have been purchased. From 1972 to 1985 garbage piles were burned regularly to control size. However health and air quality concerns from the smoke caused the practice to end in 1985 (Post, et al, 1992b). In 1986 the GTLF as we know it today was established when the Government began using a sanitary fill for its waste management. Garbage was placed, compacted, and covered in soil, peat or sediment obtained from the site itself or a contractor (Post, et al, 1992b).

Waste collected from houses, businesses, and restaurants, consisting of food scraps, paper, metals, glass, and other everyday goods was piled together and covered daily. Larger waste items such as yard and construction/demolition waste were covered weekly (Post, et al, 1992b). This was practiced until sometime after 2001 (M. Edelenbos, personal communication, May 27th 2014). Following 2001, after Martin Edelenbos left his position as Assistant Director of the GTLF, the DEH stopped covering the waste piles with no clear date, reason, or mandate explaining the decision. Today the landfill remains uncovered, figure 1.7, which does not reflect best practices. Uncovered landfills allow rain to increase leachate production, allow trash to blow off into nearby ecosystems, have increased odor, attract insects and vermin, and are unattractive to look at (CardnoENTRIX, 2013; Tammemagi, 1999; Williams, 2013).

Figure 1.7. Top of ‘Mount Trashmore’. Image was taken at the top of the GTLF (80m above sea level). Image shows uncovered compacted trash, surrounded by mangrove forest and the North Sound in the foreground. (Personal Collection).

1.2.4.2 GTLF physical description.

1.2.4.2 1 Location.

The GTLF is located in George Town, Grand Cayman, approximately 1 km west of the North Sound, figure 1.8. The North Sound is enclosed by a barrier reef to the north, and by Grand Cayman to the south, east, and west. The North Sound houses sea grass beds, sand, sand with coral heads, and patch reef ecosystems. Additionally there are tourist destinations including Stingray City and the Sandbar (Post, et al,1992a).

Figure 1.8. One mile radius surrounding GTLF. Orange outer circle indicates the 1 mile radius surrounding GTLF. Yellow inner circle indicates 1 km radius. GTLF is outlined in red. The North Sound (right) and Seven Mile Beach (left) are approximately 1 km from the GTLF. Note the mangrove forest surrounding the GTLF. (Source: Terry- Swaby, 2014).

1.2.4.2.2 Geology.

The landfill is situated on the Ironshore Formation (limestone) described earlier. Core samples taken in 1991 by Post, et al, for their EIA showed the general composition of the GTLF site described in Table 1.2 (1992a). In short the sediment can be divided into an upper layer with a porosity of 20% and permeability of 75gpd/ft^2, a middle layer with a porosity of 30%, and permeability of 240gpd/ft^2, and a lower layer with a porosity of 25% and permeability of 110gpd/ft^2.

As mentioned before the Cayman Islands are considered seismically active. However seismic activity is a minimal concern in terms of potential for contamination. There are no tall buildings at the GTLF, so there is little risk of collapse (CardnoENTRIX, 2013). The GTLF does not use pipes to transport waste materials, and is not responsible for sewage or waste-water treatment. If a sewage pipe burst, it would not be the GTLF's responsibility as it is outside of their legal jurisdiction. Wastewater and sewage are the responsibility of the Water Authority (Waste Water Protection Law, 2011; Public Health Law—Garbage and Refuse, 2011). Finally, slope failures, another possible pathway for contamination, are very unlikely because the elevation around the GTLF only changes a few feet. This leaves sinkholes as the main potential source of contamination from seismic activity at the GTLF.

Table 1.2. Sedimentary composition of GTLF. Table outlines the sedimentary composition of the GTLF, as described by Post, et al (1992a). Table shows depth, sediment type, porosity and permeability of the sediment.

Depth meters (ft)	Sediment	Porosity %	Permeability gpd/ft^2	Notes
1.2m (4ft)→ 0.5m (1.5ft) above sea level	Imported soil and road fill	20%	75 (calculated)*	Soil thought to be added to firm ground, and make roads for equipment.
0.6m (2ft)	Water table	*As there is 2.5 ft. of imported soil and road fill and the water level is at 2 ft., the GTLF site would naturally be in 0.5 ft. of water. This coincides with historical accounts of the area being a wetland/swamp.*		
0.5m(1.5ft) → 0m (0ft)	Natural soils: Black with high organic content	20%	75 (calculated)	Lots of leaves, twigs and other local organic matter in soil.
0m **(Sea Level)** → - 0.9m (-3ft)	Natural soils: Calcareous Marl	20%	75 (calculated)	Grey in color, medium stiffness, unconsolidated.
-0.9m (-3ft)→ -2.3m (-7.5ft)	Limestone nuggets	30%	240 (calculated)	Limestone nuggets found in calcareous marl above. Its thought that the calcareous marl consolidated into limestone.
-2.3m(-7.5ft) → -3.4m (-11ft)	Limestone	30%	240 (calculated)	Limestone becomes more firm and consistent forming proper limestone sediment.
-3.4m (-11ft)→ -3.7m (-12ft)	Silt/clay marl			One foot of very soft and small particle silt/clay marl.
-3.8m (-12.5ft)	Hard sedimentary rock	25%	110 (calculated)	To hard to bore, depth unknown, though to be Cayman Formation (Dolomite).
Combined sample		**15%**	**20 (measured)****	

*Calculated rates: values were calculated from particle size analysis, standard permeability curves.

** Measured rates are accurate to 25% (Post, et al, 1992a).

These flow rates are quite fast, when compared to average rates for limestone and dolomite, but within the normal range. Limestone and dolomite has a permeability range of 0.0002-10 gpd/ft and 2-40,000gpd/ft for karst and reef limestone (Harter and Rollins, 2008) . For further comparison clay has a permeability of 0.00002-0.01gpd/ft, fine sand has a permeability of 0.4-200gpd/ft, weathered granite has a permeability of 10-100gpd/ft and fractured rock has a permeability of 0.02-600gpd/ft.

1.2.4.2.3 Groundwater.

The water table under the GTLF is tidal, showing that it is connected to the marine environment (Post, et al,1992b). Studies have found that the water table at the GTLF is approximately 0.15m (0.5ft) above sea level and 0.6m (2ft) below the sediment. The water table has a 45-minute tidal lag between high tide in the North Sound and high tide in the water table. There is a decrease in tidal amplitude from the North Sound by 1.2x (Post, et al, 1992a). The groundwater under the GTLF is thought to move into the North Sound at a rate of 3.7m (12.3ft) per day, when using an average permeability of 20gpd/ft^2 and 15% porosity, allowing contaminants in the groundwater to migrate as well (Post, et al, 1992a).

The ground water found under the GTLF is brackish, so it cannot be used for human consumption. This means that the water quality standards used to monitor the groundwater do not need to meet drinking water standards (CardnoENTRIX, 2013). Furthermore, the brackish nature of the water points again to the marine connection between groundwater and the North Sound. Making a strong argument of the potential pathway for contaminant transport from the water table under the GTLF into the North Sound.

1.2.4.2.4 Surface Water and Storms.

As mentioned previously Grand Cayman is located in the Caribbean, and prone to hurricanes and storms, which bring rain. Rainwater is a concern for contamination because it can flush contaminants out of the landfill mound into surface water, which recharges groundwater systems. Additionally the surface water can flow into the surrounding canals, providing another pathway for contamination.

As the GTLF is surrounded by mangrove wetlands, and canals. Surface run off is a major concern for contamination as there are several pathways for contaminant migration into the North Sound. Figure 1.9 shows the direction of surface water runoff, and the canals that are connected to the North Sound (CardnoENTRIX, 2013). I personally observed the GTLF after a heavy rain and saw an increase in surface water runoff. The surface water was flowing into the nearby canals and dikes, which were openly connected into the North Sound, figure 1.10

Figure 1.9. Areal view of GTLF showing direction of surface run off and canals. Figure shows the direction of surface water run off into the canals and dikes surrounding the GTLF. Blue arrows indicate direction of surface water flow. Light blue outlines water ways, and red is the boundary of the GTLF. Note the canal on the northern boundary that provides a direct link to the North Sound. Stars shows where figure 1.11 next page, was taken. (Source CardnoENTRIX, 2013).

Figure 1.10. Surface water after rain event. Images show surface water on a road near GTLF after a rain event. Image on top shows surface water flowing into a tidal canal connected to North Sound. Image on bottom shows standing water. Images were taken where stars are on Figure 1.10 previous page; top image is the left star, bottom image is right star. (Personal Collection)

Another concern for surface water is storm surge. Storm surge can flood low-lying areas bringing leachate and contaminants directly into the ocean. The base of the GTLF is only 0.15-1.5m (0.5-5ft) above sea level (depending on exact location). A severe storm surge could easily flood the GTLF, as seen during Hurricane Ivan in 2004 (CardnoENTRIX, 2013; Post, et al, 1992b).

1.2.4.2.5 Mangroves and Canals.

The GTLF is surrounded by mangrove wetland forest and a canal system, figure 1.12. The canals were originally designed to manage the mosquito population using the tide to flush mosquito eggs out of the wetland area. The canals are tidal, and deep enough to penetrate the groundwater system. Meaning the canals interfere with groundwater flow rates (Post, et al, 1992a; Post, et al, 1992b).

While the canals are successful at managing the mosquito population, they increase the risk of the GTLF contaminating the marine environment. The tidal flushing creates a direct connection for leachate and GTLF surface waters to enter the North Sound as seen in figures 1.12 and 1.13 (Post, et al, 1992a). The canals also facilitate groundwater flow shortening the tidal delay between the North Sound and the water table (Post, et al, 1992a; Post, et al, 1992b).

1.2.4.3 GTLF operational description.

1.2.4.3.1 Operational Design.

The DEH is responsible for both the GTLF's operation and regulation. This causes a major conflict of interest and is against most accepted best practices. The DEH runs both the GTLF and establishes waste management standards for the Cayman Islands, and could theoretically reduce standards artificially to keep the GTLF operating legally.

Landfilling originally started in the South Mound area, on the lower right [south-east] of figure 1.14. However, the South Mound is not used today. Landfilling currently occurs at the North Mound, in the center of figure 1.11. The area to the west of the North Mound is used for sorting and storing scrap metal, used oil, tires, appliances etc. The biomedical incinerator is located in the northeast corner of the site, and is used for the disposal of biohazard waste. The public drop off is located on the southeast of the site, south of the South Mound, and is where the general public can bring garbage for disposal (CardnoENTRIX, 2013; personal observation, A. Johnson, personal communication, May 21st 2014).

As mentioned earlier the GTLF is unlined, allowing leachate to flush out, seep into ground water, and run into nearby canals and dikes, especially when it rains. Additionally the GTLF is not covered, allowing rain to increase leachate production, wind to blow garbage into nearby ecosystems, create odor problems, and decrease the visual look of the site. The GTLF is in violation of US and UK landfill regulations, and would be closed if in those countries. Basic landfill operations in UK and US require a liner, leachate collection, storm water management system, and an impermeable cover to capture landfill gas, none of which the GTLF have (CardnoENTRIX, 2013; Tammemagi, 1999; Williams, 2005).

Figure 1.11. Operational schematic of GTLF. Image shows the operational design of the GTLF, and lists the current North Mound, old South Mound, and other organizational features such as waste oil containers (Source: CardnoENTRIX, 2013).

The GTLF also has limited capacity. Since 1992, reports have stated that the landfill was 3-7 years away from becoming full. This was stated in reports by Post, et al, in 1992, Pan American Health Organization in 2003, Waste Disposal Options Review Committee in 2003, Ministry of District Administration, Works, Land and Agriculture in 2010, and MHSYC in 2014. Yet, the landfill is still in operation, and not full.

After personal communications with Martin Edelenbos, some clarity was gained about the “full status”. Mr. Edelenbos explained that the GTLF being “full” is a matter of opinion. “Full” can mean that waste cannot be stored on the current landfill footprint. Or “full” can mean the entire GTLF site cannot store any more waste. The GTLF does not have a site plan or closure plan. This means that they can extend the footprint of the landfill as much as desired or necessary, once again in disagreement with best practice methods (M. Edelenbos, personal communication, May 29 2014).

1.2.4.3.2 Types of Waste.

The GTLF has been used for municipal waste management since 1972, and has been used for waste disposal since the mid 1960’s. The MHSYC estimated that the GTLF receives 20 tonnes of waste per day, and 74502.5 tonnes in 2013 (Ministry of Health, Sports, Youth and Culture, 2014). Martin Edelenbos estimated that the GTLF houses a total of 1,18 million tonnes of waste in total, as of early 2014. Edelenbos used census, tourism and waste generation estimates to calculate the total estimate (M. Edelebos, personal communication, May 27 2014). The majority of the waste, 38%, at the GTLF is commercial waste. This is followed by metal waste at 16%. Please see table 1.3 for a complete breakdown of waste at the GTLF.

Table 1.3. Breakdown of types of waste at the GTLF, in tonnes and percentages. (Source: CardnoENTRIX, 2013).

Description	**2011-2012 weight tonnes**	**Average %**
Commercial waste	24,053.98	37.99
Metal waste	10,093.42	15.94
Residential waste	9,506.93	15.02
Yard waste	8,835.93	13.96
Construction waste	6,520.15	10.30
Cardboard	1,456.82	2.30
Pallets	1390.74	2.20
Tires	358.29	0.57
Batteries	282.19	0.45
Derelict vehicles	253.21	0.40
Incinerator (medical waste)	162.12	0.26
Bulk Waste	144.49	0.23
Food Waste	109.406	0.17
Recycling of Oil	34.60	0.05
Special Waste (waste water sludge)	33.77	0.05
Sand	30.28	0.05
Christmas Tree	18.75	0.03
Aluminum Cans	9.49	0,02
Deceased Animals	7.66	0.01
Expired Liquor	6.87	0.01
Foam	1.51	0.00
Total annual tons	**63,309**	**100**

1.3 PREVIOUS STUDY and FINDINGS

This section discusses the previous EA Conducted by Post, et al in 1992. Their study investigated the GTLF's impact on the North Sound, and other surrounding ecosystems. This is discussed here, in Chapter 1, because it is background information—providing an overview of the conditions Post, et al, found in 1992. This information is not part of the data analysis in Chapter 2, as it is too outdated.

1.3.1 1992 Environmental Assessment by Post, et al.

In 1992, Post, et al, conducted an EA on the GTLF and neighboring ecosystems. The study concluded that there was some contamination of water resources from the GTLF but no contaminants were at toxic levels. In short, groundwater data showed that the GTLF leachate was being deposited directly under the landfill with very little migration to other wells. Wells directly under the landfill had elevated readings, but not at toxic levels. Surface water analysis provided similar results. Post, el al, found that there was an algal bloom in many of the surface water testing sites, and elevated nutrient levels. Benzene and toluene was also found in surface water as well indicating a connection to the GTLF (Post, et al, 1992a).

Sediment results correlated with ground and surface water findings. Post, et al, found chromium, iron, and PCB's in the sediment of canals near the landfills, and on a gradient extending out from the GTLF across the North Sound. Levels were once again not considered toxic. Biological tissue was also sampled in the study; sea grass samples had iron concentrations 4x higher than background levels and chromium was found in mangrove and macro-algal tissue. Mercury was also found in multiple plant samples.

Finally, Post, et al, tested fish, and found the highest mercury concentrations within the study. This indicates that contaminants not found in water samples are still present and being accumulated through the food chain and other biological pathways, as mercury was not seen in ground or surface water analysis. Post, et al encouraged further biological investigation to fully understand these impacts, and find other possible contaminants not picked up in water samples (Post, et al, 1992a).

Post, et al's, assessment provides evidence that the GTLF was contaminating the marine environment, but contamination was not at toxic levels. However Post, et al, did not explain what qualifiers they used for toxicity, or if it was acute or chronic. Post, et al's report explains that Florida Standard's are used, but did not specify which standard or any other specifics. Therefore toxicity is not clearly defined.

Post, et al, recommended that further monitoring and investigation be conducted, which has not happened. Therefore in the next section of this report I will look at current groundwater, surface water, marine water, tissue and sediment data to look for trends and evidence that indicate further contamination of the marine environment.

1.3.2 Additional influences on water quality.

There are a few other points of interest that must be mentioned as they could also change or affect water quality within the North Sound.

1. Dredging in the North Sound as maintenance, or to open new waterways, alters water chemistry within the North Sound.
2. Residential, commercial, road, and other developments over the years has altered storm water run off. This can also potentially alter water chemistry as contaminants from roads, yards, golf courses etc., could enter the Sound.
3. Several of the properties near the GTLF use septic tanks. Contamination could also be occurring from individual sources (CardnoENTRIX, 2013).
4. Finally, there is a waste water facility [WWF] run by the Water Authority Cayman [WAC], neighboring the GTLF. This WWF treats sewage and discharges an effluent out of a deep well, in the North Sound

CHAPTER 2: DATA ANALYSIS

2.1 GROUND and SURFACE WATER ANALYSIS

2.1.1 Methods.

Unpublished ground and surface water quality data for the GTLF was collected from the DEH for years 2010, 2011 and 2013 to evaluate water quality at the GTLF site (Department of Environmental Health, 2014 [DEH 2014]). Due to financial reasons testing was not performed in 2012, so data was unavailable. Groundwater was collected from groundwater monitoring wells on the GTLF property. Surface water was collected from ponds, canals, ditches and dikes on the GTLF site. All monitoring sites are shown in figure 2.1.

Samples were then processed by Test America, in Savannah Georgia[3] for Appendix 1 contaminants, per the United States' Protection of the Environment (1993) Federal Regulation. Appendix 1 contaminants are inorganic and organic matter associated with landfill leachate, and are used to monitor water quality near landfills (A., Johnson, personal communication, May 2014).

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[3] Test America Savannah: 5102 LaRoche Avenue, Savannah GA, 31404. Tel: 912-354-7858. TestAmerica Job ID: 680-73249-1

#	Site	Location
1	MW1	On East Side Seymour road near to Flowers
2	MW5	Centre of Landfill Site by Recycling Junction
3	MW8	At the Back Gate
4	MW9	Under the fence at junction of Esterly Tibbetts and Dyke Rd
5	MW10	On the East side of the Mound
6	MW11	Near WAC settlement ponds
7	MW12	By fence by Welding Shop (old)
8	MW13	Left Side of road near WAC Entrance
9	MW14	North-east side of ash cell
10	MW15	South-west side of ash cell
11	MW16	Near New HAZMAT and Recycling area
12	MW17	MW17 - North border miday between MW9 and MW8
13	MW18	Near old Recycling
14	SW1	Mouth of Canal at North Sound
15	SW2	Same canal opposite Back gate
16	SW3	Same canal 200 ft from Esterly Tibbetts
17	SW7	Canal adjacent to landfill mound
18	SW12	Pond adjacent to New Recycling
19	Drain 1	West side of the Mound
20	Drain 2	North Side of the Mound

Figure 2.1. Map of DEH's GTLF monitoring sites. Figure shows map of monitoring sites used by DEH for water quality testing at GTLF. Surface water is analyzed at SW sites [surface water]. Groundwater is analyzed at MW sites [monitoring well]. Note that *MW16, should say MW14. (Source: Johnson, 2014).

Test America Labs use the methods outlined in Table 2.1 for contaminant analysis. Results were then analyzed on Total Access, Test America's reporting software (Version 4.0). Total Access compares results to water quality standards and indicates when results are over thresholds. The DEH and this project used Florida's water quality standards because of climatic and environmental similarities. Specifically, Miami- Dade Country Environmental Protection Standards were used (Miami- Dade County Environmental Protection Ordinance, 2004). Groundwater samples were compared to Groundwater Criteria and surface water samples were compared to Marine Surface Water Criteria, as the surface water can easily mix with the North Sound. Unfortunately baseline water levels for the GTLF site were not available.

Table 2.1. Test America's methods summary. Table lists the methods used by Test America for water quality analysis of the GTLF. All lab tests were done at Test America Labs in Savannah GA. (Source: Test America, 2011).

Test Description	**Method**	**Protocol ***
Volatile Organic Compounds (GC/MS)	8260B	SW846
Organochlorine Pesticides & PCB's (GC)	8081A_8082	SW846
Metals (ICP)	6010B	SW846
Mercury (CVAA)	7470A	SW846
Mercury (CVAA)	7471A	SW846
Conductivity, specific conductance	120.1	MCAWW
pH (Electrometric)	150.1	MCAWW
Solids, Total Dissolved (TDS)	160.1	MCAWW
Turbidity, Nephelometric	180.1	MCAWW
Cyanide, Total	335.4	MCAWW
Nitrogen, Ammonia	350.1	MCAWW
Nitrogen, Nitrate-Nitrite	353.2	EPA
Phosphorus, Ortho	365.1	MCAWW
Sulfate	375.4	MCAWW
Biologic Oxygen Demand, (BOD) 5 day	405.1	MCAWW
Chemical Oxygen Demand (COD)	410.4	SW846
Cyanide, total and or amenable	9012A	SW846
Sulfate, Turbidimetric	9038	EPA

Protocol abbreviations: **SW846**= Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Third Edition, November 1986 and its updates. **MCAWW**= Methods for Chemical analysis of water and wastes, EPA-600/4-79-020, March 1983 and subsequent revisions, and **EPA**= Environmental Protection Agency, USA (Test America, 2011).

2.1.2 Results.

Some of the data from DEH was of minimal use because the minimum test detection limit was higher than Miami-Dade Country's Environmental Protection Criteria. This meant that the test could only detect quantities higher than the criteria and created a grey area between the criteria's threshold and minimum test detection limit. The analyte could be present at a level above the criteria but below the minimum test detection limit. These contaminants are listed in table 2.2.

Most of the analytes listed in table 2.2, were not detected in water samples, but could still be present in the grey area below minimum test limits and above the criteria's threshold. The analytes that were detected, and therefore above reporting limits were;

- Arsenic—found in ground water samples
- Copper, cyanide, lead and nickel found in surface water samples
- Phosphate found in both ground and surface water samples

Further testing is required to see if the other contaminants listed in table 2.2 are present in the grey area between testing limits and threshold. A more sensitive test will be needed to do this. Evaluating the presence of these analytes in more detail is important as it will help managers understand the actual contamination that is occurring into ground and surface water.

Table 2.2. Analytes with minimum test detection limits higher than the Miami-Dade County's Criteria. Table shows analyte, measurement, and test detection limit, compared to marine and ground water criteria. When the threshold value is highlighted in yellow the minimum test detection limit is higher than Miami-Dade County's Environmental Ordinance's Criteria (2004). Meaning the contaminant could be present above criteria's levels but was not detected because of the higher minimum test detection limit. Most analytes were not found in water samples, those that were found are identified with *. Table continues onto next page.

Analyte	Measurement	Miami-Dade Criteria		Minimum test detection limit
		Groundwater ⊙	Marine Water ⊙	
1,1,2,2-Tetrachloroethane	ug/L	0.2[a]	10.8	<1.0
1,2,3-Trichloropropane	ug/L	0.02[a]	0.2[a]	<1.0
1,2-Dibromo-3-Chloropropane	ug/L	0.2[a]	NA [d]	<1.0
1,2-Dibromoethane	ug/L	0.02[a]	13	<1.0
4,4'-DDD	ug/L	0.1	0.0003[a]	<0.48
4,4'-DDE	ug/L	0.1	0.0002[a]	<0.48
4,4'-DDT	ug/L	0.1	0.00059[a]	<0.48
Acrylonitrile	ug/L	0.06[a]	0.2[a]	<20
Aldrin	ug/L	0.002[a]	0.00014[a]	<0.048
alpha-BHC	ug/L	0.006[a]	0.005[a]	<0.048
Antimony	mg/L	0.006[a]	4.3	<0.020
*Arsenic	mg/L	0.01[a]	0.05	<0.020
Beryllium	mg/L	0.004	0.00013[a]	<0.040
beta-BHC	ug/L	0.02[a]	0.046[a]	<0.048
Bromodichloromethane	ug/L	0.6[a]	22	<1.0
Chlordane (technical)	ug/L	2	0.00059[a]	<0.48
**Copper	mg/L	1	0.0029[a]	<0.020
**Cyanide, Total	mg/L	0.14	0.0035[a]	<0.010
Dibromochloromethane	uglL	0.4	34	<1.0

Table 2.2. Continued.

		Miami-Dade Criteria		
Analyte	Measurement	Groundwater ⊙	Marine Water ⊙	Minimum test detection limit
Dieldrin	ug/L	0.002	0.00014	<0.048
Endrin	ug/L	2	0.0023	<0.048
Heptachlor	ug/L	0.4	0.00021[a]	<0.048
Heptachlor epoxide	ug/L	0.2	4E-05[a]	<0.048
**Lead	mg/L	0.015	0.0085[a]	<0.010
Mercury	mg/L	0.002	2.5E-05[a]	<0.00020
Methoxychlor	ug/L	40	0.03	<0.048
**Nickel	mg/L	0.1	0.0083	<0.040
***Phosphorus	mg/L	0.0001	0.0001	<0.10
Silver	mg/L	0.1	0.0004	<0.010
Thallium	mg/L	0.002	0.0063	<0.025
Toxaphene	ug/L	3	0.002	<4.8

⊙ Miami- Dade County Environmental Protection Ordinance (2004).

analyte was found in ground water samples.

** analyte was found in surface water samples.

*** analyte was found in both ground and surface water samples.

Rain water plays an important role in ground and surface water testing. A significant rain event can increase groundwater recharge, bringing extra contaminants down, or diluting those already present. It can also spread and dilute contaminants in surface water as rain mixes with the standing water. Both of these can impact results by increasing or decreasing contaminants.

Rainfall data for Grand Cayman was collected for the week prior to water sample collection to determine if rain events could have impacted results, shown in table 2.3. Results show that there was no significant rain activity during the week prior to testing in 2011 and 2013. However in 2010 there was a significant rainfall event two days before collection on July 4th. A significant rain event is considered 25mm or more in one day. At 25mm a day most soils become saturated, causing groundwater recharge and an increase in surface water (R. Jamieson, Personal Communication, August 26, 2014).

Table 2.3. Rainfall data for the week prior to water sample collection. Table shows the rainfall recorded in mm for the week prior to water sample collection for ground and surface water analysis. The days samples were collected are highlighted and italicized. Tr= trace recording, less than 0.3 mm.

2010	Rainfall Recorded (mm)	2011	Rainfall Recorded (mm)	2013	Rainfall recorded (mm)
June 29	Tr	Oct 4	4.3	April 9	0
June 30	2.5	Oct 5	0.8	April 10	0
July 1	14.0	Oct 6	0	April 11	Tr
July 2	1.8	Oct 7	6.8	April 12	0
July 3	7.8	Oct 8	0	April 13	Tr
July 4	25.6	Oct 9	4.6	April 14	1.0
July 5	0	*Oct 10*	*11.6*	April 15	Tr
July 6	*2.3*	*Oct 11*	*0*	*April 16*	*5.8*
July 7	*Tr*	*Oct 12*	*0*	*April 17*	*4.1*

2.1.2.1 Groundwater results.

Of the 100 plus contaminants tested for, only seven had results above Miami—Dade County Ground Water Criteria; arsenic, boron, iron, lead, phosphorus, sulfate and total dissolved solids. In summary, arsenic was only above threshold limits once in 2011 at MW11, table 2.3b. Boron was above threshold limits in 2011 and 2013 at multiple wells, with the highest level recorded at MW 11 in 2011 of 4.0mg/L, table 2.4b, and the second highest reading at MW5 in 2011, table 2.4a.

Iron was above threshold limits all years, with the highest reading in 2011 at MW5 of 7.3 mg/L table 2.4a, and second highest reading in 2013 also at MW5, table 2.4a. Lead was above threshold limits all years, with the highest reading in 2010 at MW1B, of 0.86mg/L, table 2.3a . Phosphorus was only tested for in 2010, with the highest recording at MW12 of 0.29mg/L, table 2.4b. Sulfate was tested for in 2011 and 2013, with the highest reading at MW13 in 2013 of 1000mg/L table 2.3b. Finally total dissolved solids were analyzed every year with the highest reading at tie between MW8 in 2011, table 2.4a, and MW13 in 2013 of 13000mg/L, table 2.4b.

Table 2.4. Groundwater monitoring analytes with results above Miami—Dade County Ground Water Criteria limits. Tables 4a, 4b and 4c show criteria limits, and the specific results yielded at different wells. Table indicates from left to right: analyte, detection type [type], groundwater criteria, monitoring well number [MW] and year. Analytes above the threshold are highlighted in yellow. Detection Types: D-dissolved, TR- Total recovered, T- total. Tables were split into a b and c to fit the page and are organized numerically by well number then year. All units are in mg/L.

2.4a	Type	Ground Water⊙ (mg/L)	2010	2011	2011	2013	2010	2011	2013
Analyte			MW1B	MW 1	MW 5	MW 5	MW 8	MW 8	MW 8
Arsenic	D	0.01	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Arsenic	TR	0.01	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Boron	TR	1.4	-	**0.61**	**2.7**	**2.5**	**-**	**3.4**	**3.3**
Boron	D	1.4	-	**0.65**	**2.5**	**2.2**	**-**	**3.3**	**3.2**
Iron	D	0.3	<0.050	<0.050	**0.23**	**6.9**	<0.050	<0.050	**0.11**
Iron	TR	0.3	**2.7**	**0.085**	**7.3**	**0.072**	**0.3**	<0.050	<0.050
Lead	D	0.015	<0.010	<0.010	**0.076**	<0.010	<0.010	<0.010	<0.010
Lead	TR	0.015	**0.086**	<0.010	<0.010	**0.051**	<0.010	<0.010	<0.010
Phosphorus	T	0.0001	**0.26**	**-**	**-**	**-**	**0.28**	<0.020	**-**
Sulfate	T	250	-	**54**	**760**	**440**	-	**830**	**310**
Total Dissolved Solids	T	500	**2200**	**1400**	**4800**	**6500**	**9700**	**13000**	**7100**

⊙ Ground water criteria are from Miami- Dade County Environmental Protection Ordinance, 2004. Notes:

Phosphorus was only tested in 2010. Boron and Sulfate were only tested in 2011 and 2013.

2.4b Analyte	Type	Ground Water⦿ (mg/L)	2010 MW 9	2011 MW 9	2013 MW 9	2011 MW10	2011 MW11	2010 MW12	2011 MW13	2013 MW13
Arsenic	D	0.01	<0.020	<0.020	<0.020	<0.020	**0.043**	<0.020	<0.020	<0.020
Arsenic	TR	0.01	<0.020	<0.020	<0.020	<0.020	**0.044**	<0.020	<0.020	<0.020
Boron	TR	1.4	-	**2.5**	**2.1**	**1.4**	**4.0**	**-**	**1.8**	**2.7**
Boron	D	1.4	-	**2.5**	**2.1**	**1.4**	**3.9**	**-**	**1.6**	**2.7**
Iron	D	0.3	<0.050	<0.050	<0.050	**0.08**	**0.2**	**0.074**	<0.050	**0.066**
Iron	TR	0.3	**0.26**	<0.050	<0.050	**3.6**	**0.67**	**2.1**	**2.6**	**0.49**
Lead	D	0.015	<0.010	<0.010	<0.010	**0.025**	<0.010	<0.010	**0.015**	**0.013**
Lead	TR	0.015	<0.010	<0.010	<0.010	<0.010	<0.010	**0.012**	<0.010	<0.010
Phosphorus	T	0.0001[a]	<0.10	<0.020	**-**	**-**	**-**	**0.29**	**-**	**-**
Sulfate	T	250	-	**250**	**420**	**240**	**360**	-	**290**	**1000**
Total Dissolved Solids	T	500	**4100**	**3900**	**7700**	**4100**	**4800**	**3400**	**5800**	**13000**

⦿ Ground water criteria are from Miami- Dade County Environmental Protection Ordinance, 2004. Notes:

Phosphorus was only tested in 2010. Boron and Sulfate were only tested in 2011 and 2013.

2.4c	Type	Ground Water⊙ (mg/L)	2011	2013	2011	2013	2013	2011	2011	2013
Analyte			MW14	MW14	MW15	MW15	MW16	MW 17	MW18	MW18
Arsenic	D	0.01	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Arsenic	TR	0.01	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Boron	TR	1.4	**2.2**	**1.8**	**1.4**	**1.7**	**2.1**	**1.9**	**2.0**	**2.2**
Boron	D	1.4	**2.3**	**1.8**	**1.4**	**1.6**	**2**	**1.9**	**1.9**	**2.4**
Iron	D	0.3	<0.050	**0.17**	<0.050	**0.3**	**1.1**	<0.050	<0.050	<0.050
Iron	TR	0.3	**0.13**	<0.050	**0.089**	<0.050	**0.09**	**0.47**	**2.1**	**0.91**
Lead	D	0.015	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Lead	TR	0.015	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Phosphorus	T	0.0001	-	-	-	-	-	-	-	-
Sulfate	T	250	**490**	**530**	**610**	**640**	**620**	**11**	**380**	**340**
Total Dissolved Solids	T	500	**4300**	**8600**	**3500**	**10000**	**12000**	**5400**	**3500**	**6300**

⊙ Ground water criteria are from Miami- Dade County Environmental Protection Ordinance, 2004.

Notes: Phosphorus was only tested in 2010. Boron and Sulfate were only tested in 2011 and 2013.

Patterns in contaminant distribution were hard to identify. Upon close observation of the results we can see that wells closer to the active landfill area had marginally higher readings than the wells farther from the active landfill area. For example, MW5 and MW11 which are located directly off the active landfill area had higher results than MW 9 and MW 10 on the periphery of the GTLF's property. MW5 had higher iron, lead and sulfate than MW9 and MW10. MW11 had higher boron and sulfate than MW9 and MW10. Furthermore MW 11 is the only well where arsenic was recorded. MW 11 also had the most analytes over quality thresholds, with seven. MW 5 had the second most with six analytes above thresholds. However these results are not conclusive as MW10 had one of the highest iron readings. Furthermore the significant rain in 2010 could be responsible for the lead found in MW1B in 2010.

These results suggest that contaminates are seeping down into ground water, and attenuating as they move away from the active landfill area. This is supported by the lower results at wells farther from the active landfill area, and higher results at the closer wells. However, it is important to mention that this data analysis is not perfect as all wells were not analyzed yearly. Only MW8 and MW9 were analyzed consistently in 2010, 2011, and 2013. Furthermore, not all analytes were analyzed yearly—such as boron and sulfate which were not tested for in 2010 and phosphorus, only tested for in 2010, causing even more discrepancies and inconsistencies with the data. These discrepancies limit the understanding of current groundwater contamination at the GTLF.

What we can conclude from the data currently is: that there is some groundwater contamination at the GTLF, with results over Miami-Dade County's criteria. We have strong evidence that the contamination in the groundwater is from the GTLF as it is higher closer to the active landfill area, and lower on the periphery. This finding provides evidence, which supports the hypothesis that the GTLF is contaminating the North Sound and surrounding ecosystems, as the GTLF's groundwater is connected to the North Sound. This finding causes concern as these contaminants have the potential to mix into the North Sound, with unknown dilution and distribution rates, and unknown effects on biological systems.

All other analytes, not included in table 2.4 were either never detected, or detected under criteria threshold limits. These are listed in table 2.5, with full results available in Appendix A1: Groundwater Results.

Table 2.5. Groundwater analytes not detected or detected under criteria limits. Table lists all analytes that were never detect, or detected under criteria limits repeatedly in 2010, 2011, 2013.

Results always under minimum test detection limit

- 1,1,1,2-Tetrachloroethane
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- 1,1-Dichloroethane
- 1,1-Dichloroethene
- 1,2-Dichlorobenzene
- 1,2-Dichloroethane
- 1,2-Dichloropropane
- 2-Hexanone
- 4,4’-DDD
- 4,4’-DDE
- 4,4’-DDT
- Acetone
- Benzene
- Beryllium
- Bromochloromethane
- Bromoform
- Bromomethane
- Cadmium
- Carbon tetrachloride
- Chlordane (technical)
- Chloroethane
- Chloroform
- Chloromethane
- cis-1,2-Dichloroethene
- cis-1,3-Dichloropropene
- Cobalt
- Cyanide, Total
- Dibromomethane
- Endosulfan I
- Endosulfan II
- Endosulfan sulfate
- Endrin
- Endrin aldehyde
- Endrin ketone
- Ethylbenzene
- gamma-BHC (Lindane)
- Gasoline Range Organics (GRO)-C6-C10
- Heptachlor
- Heptachlor epoxide
- Iodomethane
- Methoxychlor
- Methylene Chloride
- methyl isobutyl ketone
- Methyl Ethyl Ketone
- Nickel
- PCB 1016
- PCB1221
- PCB 1232
- PCB 1242
- PCB 1248
- PCB 1254
- PCB 1260
- Silver
- Styrene
- Tetrachloroethene
- Toluene
- trans-1,2-Dichloroethene
- trans-1,3-Dichloropropene
- trans-1,4-Dichloro-2-butene
- Trichloroethene
- Trichlorofluoromethane
- Vinyl acetate
- Vinyl chloride
- Xylenes, Total

Results below criteria limits

- 1,4-Dichlorobenzene
- Ammonia
- Barium
- Biochemcial Oxygen Demand
- Carbon disulphide
- Chemical Oxygen Demand
- Chromium
- Copper
- Diesel range Organics [C10-C28]
- Magnesium
- Mercury
- Nitrate Nitrite as N
- Orthophosphate
- pH
- Selenium
- Specific Conductance
- Turbidity
- Vanadium
- Zinc

2.1.2.2 Surface water results.

In 2010 and 2011 ten different analytes were detected above Miami- Dade County Marine Surface Water Criteria limits; arsenic, chromium, copper, cyanide, iron, lead, nickel, phosphorus, vinyl chloride, and zinc, all outlined in table 2.6a, and b. No analytes were above Marine Surface Water Criteria limits in 2013.

Arsenic, chromium, copper, iron, lead, and nickel all had their highest result at Drain 1 in 2010, seen in table 2.6b. Phosphorus, only tested for in 2010 and 2011, also had its highest result at Drain 1 in 2010, of 0.55mg/L, table2.6b. Cyanide was only detected once and above threshold limits at Drain 1, in 2011, at 0.017mg/L table 2.6b. Vinyl chloride was only detected once at RCY1 in 2011, at 0.0043mg/L table 2.6b. And finally, zinc had it's highest result at RCY1, in 2011 at 0.0043mg/L, table 2.6b.

Table 2.6. Surface water analytes with results above criteria limits. Tables 6a and 6b show the analytes with results above Miami-Dade County Marine Water Criteria limits. Table indicates from left to right; analyte, detection type [type], Marine Water Criteria limit, Surface water site [SW], and year. Analytes above reporting limits are highlighted in yellow. Detection Type: D- dissolved, TR- Total recovered, T-total. Tables were split into 6a and 6b solely to fit the page, and are organized numerically according to well number, then year. All units are in mg/L.

2.6a		Marine Water ⊙	2010	2011	2011	2013	2010	2011	2013	2010	2011	2013
Analyte	Type		SW1	SW 1	SW 1 Dup	SW1	SW 2	SW 2	SW2	SW 3	SW 3	SW3
Arsenic	D	0.05	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Arsenic	TR	0.05	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Chromium	T	0.05	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chromium	TR	0.05	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Copper	D	0.0029[a]	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Copper	TR	0.0029[a]	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Cyanide	T	0.0035[a]	-	<0.010	<0.010	<0.010	-	<0.010	<0.010	-	<0.010	<0.010
Iron	D	0.3	**0.065**	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Iron	TR	0.3	**0.059**	<0.050	<0.050	<0.050	**0.065**	<0.050	<0.050	**0.087**	**0.056**	<0.050
Lead	D	0.0085[a]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Lead	TR	0.0085[a]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Nickel	TR	0.0083[a]	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
Nickel	D	0.0083[a]	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
Phosphorus	T	0.0001[a]	**0.18**	**0.028**	**0.021**	-	**0.12**	**0.023**	-	**0.1**	<0.020	-
Vinyl chloride	T	0.0024	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	D	0.086	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Zinc	TR	0.086	<0.020	<0.020	<0.020	<0.020	**0.037**	<0.020	<0.020	<0.020	<0.020	<0.020

⊙ Marine water criteria are from Miami- Dade County Environmental Protection Ordinance 2004.

Note: Cyanide was not tested for in 2010 and Phosphorus was not tested for in 2013.

2.6b			2010	2011	2013	2010	2011	2013	2010	2011	2011	2011
Analyte	Type	Marine Water⦿	SW 7	SW 7	SW7	SW 12	SW 12	SW12	Drain 1	Drain 1	Drain 2	RCY 1
Arsenic	D	0.05	<0.020	<0.020	**0.03**	<0.020	<0.020	<0.020	**0.079**	**0.069**	**0.034**	<0.020
Arsenic	TR	0.05	<0.020	<0.020	**0.037**	<0.020	<0.020	<0.020	**0.087**	**0.073**	**0.039**	<0.020
Chromium	T	0.05	**0.017**	<0.010	**0.037**	<0.010	<0.010	<0.010	**0.12**	**0.13**	**0.057**	<0.010
Chromium	TR	0.05	**0.018**	<0.010	**0.036**	<0.010	<0.010	<0.010	**0.098**	**0.11**	**0.059**	<0.010
Copper	D	0.0029[a]	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	**0.12**	**0.028**	<0.020	<0.020
Copper	TR	0.0029[a]	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	**0.3**	**0.12**	**0.038**	<0.020
Cyanide, Total	T	0.0035[a]	-	<0.010	<0.010	-	<0.010	<0.010	-	**0.017**	<0.010	<0.010
Iron	D	0.3	**0.24**	**0.18**	**0.093**	**0.14**	**0.11**	**0.1**	**2.9**	**1.7**	**2.1**	**2.6**
Iron	TR	0.3	**0.3**	**0.26**	**0.054**	**0.2**	**0.17**	**0.16**	**3.6**	**2.3**	**3**	**2.8**
Lead	D	0.0085[a]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	**0.019**	<0.010	<0.010	<0.010
Lead	TR	0.0085[a]	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	**0.025**	<0.010	<0.010	<0.010
Nickel	TR	0.0083[a]	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	**0.081**	**0.073**	<0.040	<0.040
Nickel	D	0.0083[a]	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040	**0.075**	**0.076**	<0.040	<0.040
Phosphorus	T	0.0001[a]	**0.32**	-	-	**0.12**	-	-	**0.55**	-	-	-
Vinyl chloride	T	0.0024	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0043
Zinc	D	0.086	**0.026**	<0.020	<0.020	<0.020	<0.020	<0.020	**0.25**	**0.13**	**0.023**	**0.43**
Zinc	TR	0.086	**0.035**	<0.020	<0.020	<0.020	<0.020	<0.020	**0.3**	**0.21**	**0.12**	**0.1**

⦿ Marine water criteria are from Miami- Dade County Environmental Protection Ordinance 2004.

Note: Cyanide was not tested for in 2010 and Phosphorus was not tested for in 2013.

Surface water results had a much clearer pattern than groundwater results. Drain 1, Drain 2 and RCY1 had the most analytes above criteria levels, and are coincidentally closest to the active landfill area. In comparison, SW 1, 2, and 3 located on the periphery of the GTLF site only had phosphorous above criteria limits. These results show us that contaminants are highest at the surface water collection sites closest to the active landfill area and lower at collection sites farther away. This suggests that very little surface water contamination is going into the North Sound at this time as contaminants are diluting and/or attenuating as they move away from the source.

Only phosphorus remained above threshold limits at surface water collection sites near and directly connected to the North Sound. This indicates that phosphorus is the main contaminant of concern from surface water contamination. However the other contaminants cannot be ignored as they could still be mixing with the North Sound at levels below detection limits. Furthermore a major storm can increase surface water flow, spreading contaminants farther and faster. In 2010 there was a significant rainfall event two days before collection, which may be why there was Iron in SW7, in 2010 only.

In closing surface water test sites were much more consistent than ground water test sites because the same sites were tested in 2010, 2011 and 2013. Groundwater sites were not as consistent with different sites tested in 2010, 2011, 2013, making analysis more difficult.

All other analytes not listed in tables 2.6a and b were either repeatedly below minimum test detection levels, or detected but below criteria limits and are listed in table 2.7, with full results available in Appendix A2: Surface Water Results.

Table 2.7. Surface water analytes not detected or detected under criteria limits. Table lists all analytes that were never detected, or detected under criteria limits repeatedly in 2010, 2011 or 2013.

<table>
<tr><th colspan="3">Results always under minimum detection limit</th></tr>
<tr><td>1,1,1,2-Tetrachloroethane</td><td>Bromoform</td><td>gamma-BHC (Lindane)</td></tr>
<tr><td>1,1,1-Trichloroethane</td><td>Bromomethane</td><td rowspan="2">Gasoline Range Organics (GRO)-C6-C10</td></tr>
<tr><td>1,1,2,2-Tetrachloroethane</td><td>Carbon disulfide</td></tr>
<tr><td>1,1,2-Trichloroethane</td><td>Carbon tetrachloride</td><td>Iodomethane</td></tr>
<tr><td>1,1-Dichloroethane</td><td>Chlorobenzene</td><td>Methylene Chloride</td></tr>
<tr><td>1,1-Dichloroethene</td><td>Chloroethane</td><td>PCB 1016</td></tr>
<tr><td>1,2-Dibromo-3-Chloropropane</td><td>Chloroform</td><td>PCB1221</td></tr>
<tr><td>1,2-Dibromoethane</td><td>Chloromethane</td><td>PCB 1232</td></tr>
<tr><td>1,2-Dichlorobenzene</td><td>cis-1,3-Dichloropropene</td><td>PCB 1242</td></tr>
<tr><td>1,2-Dichloroethane</td><td>Dibromochloromethane</td><td>PCB 1248</td></tr>
<tr><td>1,2-Dichloropropane</td><td>Dibromomethane</td><td>PCB 1254</td></tr>
<tr><td>1,4-Dichlorobenzene</td><td>Endosulfan I</td><td>PCB 1260</td></tr>
<tr><td>2-Hexanone</td><td>Endosulfan II</td><td>Tetrachloroethene</td></tr>
<tr><td>Antimony</td><td>Endosulfan sulfate</td><td>trans-1,3-Dichloropropene</td></tr>
<tr><td>Antimony</td><td>Endrin aldehyde</td><td>trans-1,4-Dichloro-2-butene</td></tr>
<tr><td>Bromochloromethane</td><td>Endrin ketone</td><td>Trichlorofluoromethane</td></tr>
<tr><td>Bromodichloromethane</td><td></td><td>Vinyl acetate</td></tr>
<tr><th colspan="3">Results above minimum test detection limits but below criteria limits</th></tr>
<tr><td>Acetone</td><td>Diesel Range Organics [C10-C28]</td><td>Specific Conductance</td></tr>
<tr><td>Ammonia</td><td>Ethylbenzene</td><td>Styrene</td></tr>
<tr><td>Barium</td><td>Magnesium</td><td>Sulfate</td></tr>
<tr><td>Benzene</td><td>Methyl Ethyl Ketone</td><td>Toluene</td></tr>
<tr><td>Biochemical Oxygen Demand</td><td>methyl isobutyl ketone</td><td>Total Dissolved Solids</td></tr>
<tr><td>Boron</td><td>Nitrate Nitrite as N</td><td>trans-1,2-Dichloroethene</td></tr>
<tr><td>Cadmium</td><td>Nitrogen, Kjeldahl</td><td>Trichloroethene</td></tr>
<tr><td>Chemical Oxygen Demand</td><td>Orthophosphate</td><td>Turbidity</td></tr>
<tr><td>cis-1,2-Dichloroethene</td><td>pH</td><td>Vanadium</td></tr>
<tr><td>Cobalt</td><td>Selenium</td><td>Xylenes, Total</td></tr>
</table>

2.2 TISSUE SAMPLE ANALYSIS

2.2.1 Methods.

Unpublished tissue sample data was collected from Dart Reality Cayman Ltd. (Dart Reality Cayman Ltd, 2012). Dart Reality Cayman Ltd. partnered with CardnoENTRIX in October 2012 to collect biological tissues samples for; Red Mangrove (*Rhizophora mangle)*, Sea Sponge (*Tedania ignis),* Turtle Grass (*Thalassia testudinum)* and three species of green algea *(Penicillus dumetosus, Microdictyon spp., and Bryopsis spp.*) to analyze for contamination. Samples were collected from the northern coast at Barkers Beach [Grand Cayman] for baseline levels, and near the GTLF, figures 2.2, 2.3 and 2.4. Once collected, tissue samples were airlifted off island and analyzed by Spectrum Analytical Inc.[4] in Tampa Florida, using: SW6010B analysis for inorganic substances including metals, SW7471A for Mercury, and SW8082 for PCB Organics (Dart Reality Cayman Ltd, 2012).

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[4] Spectrum Analytical Inc, 8405-A Benjamin Rd, Tampa, Florida, 33634. Tel 813-888-9507. Lab Reference No./SDG 3507351.

Figure 2.2. Map of tissue sample collection sites. Tissue samples collected at Barkers serve as a baseline. All other tissue samples: NS, GTLF and Camana, were collected from the GTLF to test for contamination, shown in more detail in Figures 2.3. and 2.4 (Google Earth, 2014.)

Figure 2.3. Barkers Beach baseline tissue sample collection sites. Image shows where the Barkers Beach samples were collected. Samples taken from Barkers were used for baseline levels. (Google Earth, 2014).

Figure 2.4. GTLF tissue sample collection sites. Image shows where tissue samples were collected for GTLF contamination analysis. Note that “Camana” sites were tested to the north of the canal, and “GTLF” sites were tested on the south of the canal (Source Google Earth, 2014).

Results as calculated by Spectrum Analytical were compared to baseline levels and in lab generated reporting limits. Reporting limits were calculated at Specrum Analytical, and are based on the test's low calibration standard. The reporting limits indicate the lowest accurate reading of the test, and are used as a quality control measure to confirm test accuracy (M. Gudnason, personal commination August 4th 2014). The reporting limit changes from sample to sample to honor the varying tissue sample sizes so that test results can be properly interpreted regardless of the original tissue sample size (W. Swindell, personal communication, June 12th 2014).

When interpreting figures, baseline values can be used for comparison and the reporting limit can be used as an accuracy check. If the result is higher than the reporting limit the result should be accurate. For more information of the low calibration standards of SW6010b, SW7471A and SW8082 please see SW-846 online at www.epa.gov/epawaste/hazard/testmethods.

2.2.2 Results.

No PCB Organic contaminants were detected in tissue samples. This could be from natural attenuation, or that there are no PCB organic contaminants being transported. Further investigations are required to learn the reason behind the absence of PCB organics in tissues.

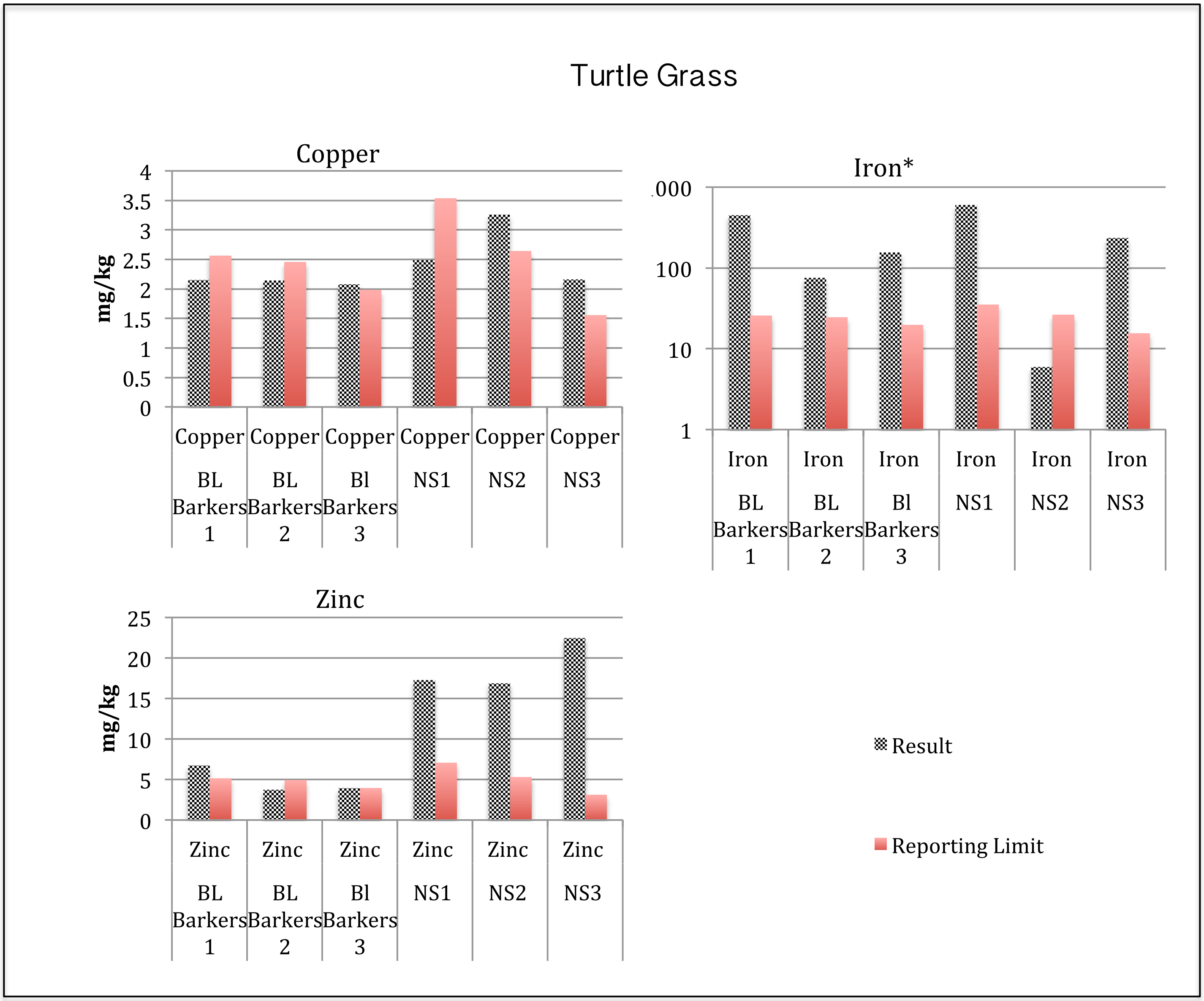
There were numerous instances of metals being detected, with iron, copper, and zinc having the most results higher at GTLF sites than baseline sites. Iron and zinc had higher readings at GTLF sites for all species; figures 2.5, 2.6, 2.7, and 2.8. Copper was higher at GTLF sites for Green Algae- figure 2.5, Turtle Grass-figure 2.6 and Sponge-figure 2.8, but not in Red Mangrove- figure 2.7. Cadmium, chromium, mercury and nickel were only over reporting limits in Sponge, figure 2.8. There were no instances of lead or silver yielding results above reporting limits in any species. A complete list of all results is available in Appendix B.

A summary of metal results are shown in figures 2.5- 2.8. The figures show copper, iron and zinc results for all tissue samples and cadmium, chromium, nickel and mercury results for Sponge, as that was the only specie with those contaminants above reporting limits. When reading the figures note that baseline samples are designated with a “BL” and are located on the left next to the y-axis. Data labels can be seen for the reporting limits that are so low on the y-axis they are hard to read and for result values that go above the y-axis.

*Green Algae: three different species of green algae were tested: Microdictyon spp= Mi spp., Penicillus dumetosus= pe du., and Bryopsis spp.= Br spp.

* *Iron is displayed using a Log scale.

Figure 2.5. Results for Green Algae tissue analysis. Copper, iron and zinc GTLF results are higher than baseline levels.



* Iron: iron is displayed on a log scale.

Figure 2.6. Results for Turtle Grass tissue analysis. Copper, iron and zinc results are higher at GTLF than baselines. Note that Iron has a high baseline value at Barkers 1 compared to Barkers 2 and 3. BL=Baseline.

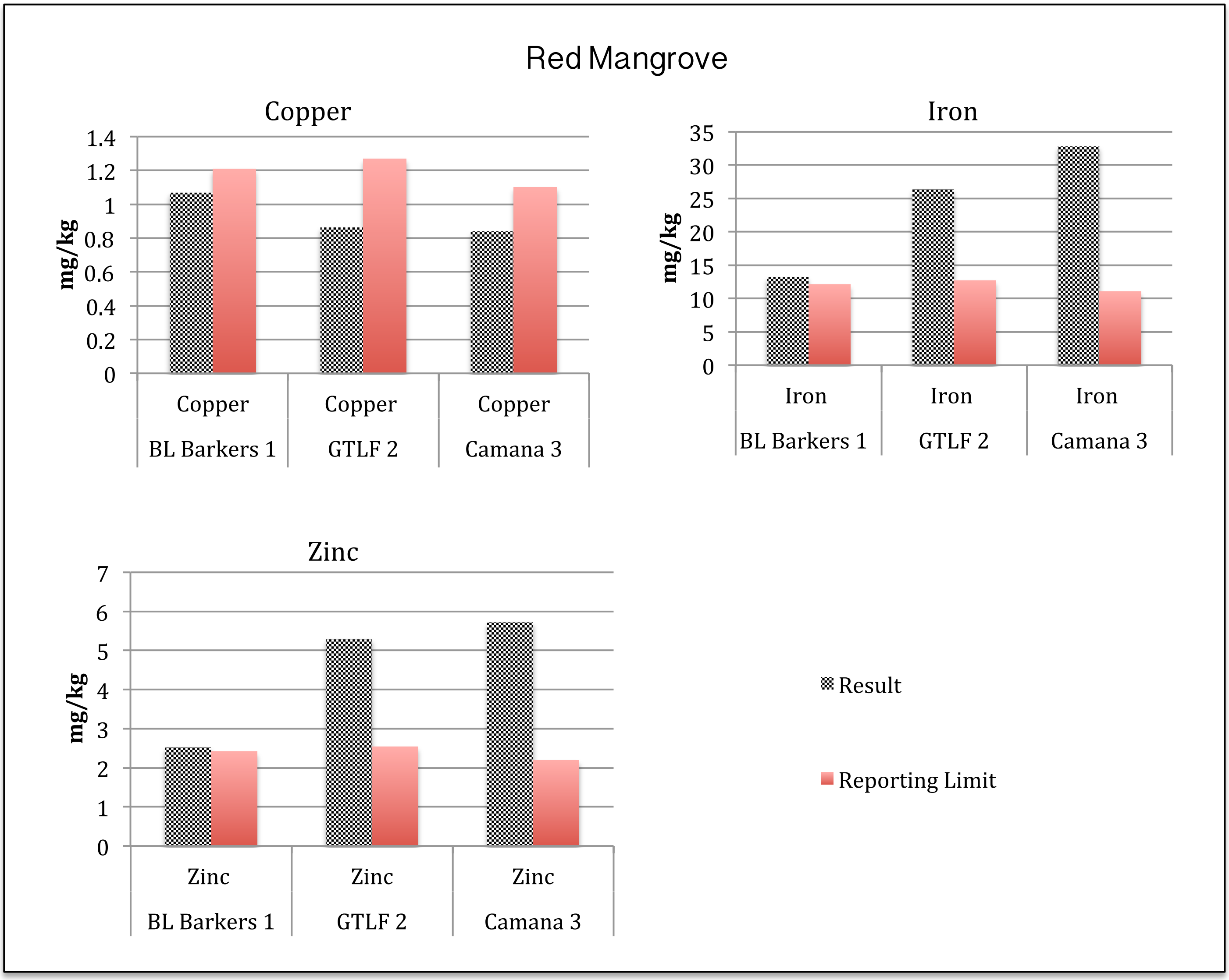
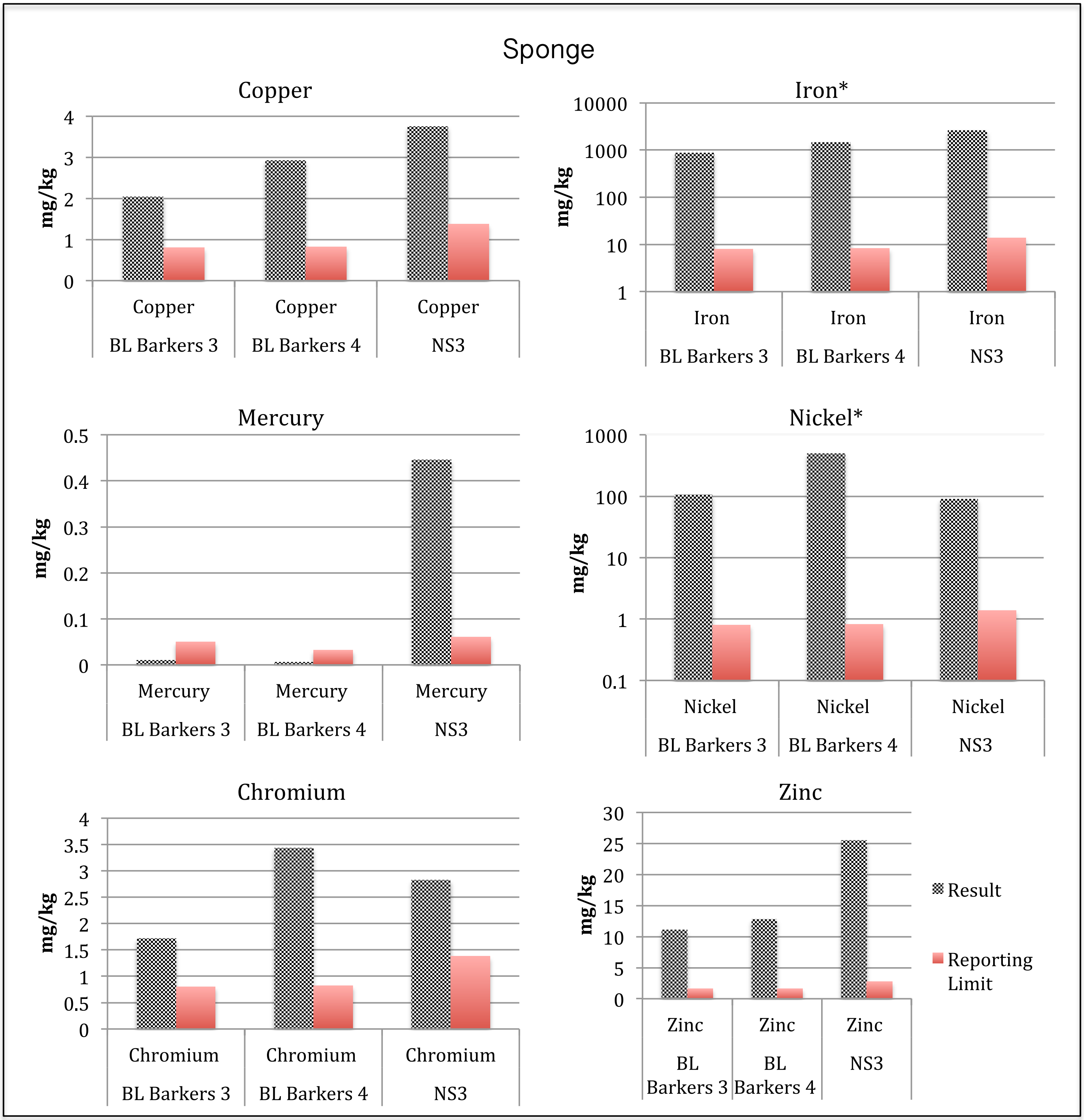


Figure 2.7. Results for Red Mangrove tissue analysis. Iron and zinc were higher at GTLF than baselines. Copper baseline was higher than GTLF results. Note that copper is also below reporting limits indicating results are less than the quality controlled accuracy minimum. BL= Baseline.



* Iron and Nickel are displayed using a Log scale.

Figure 2.8. Results for Sponge tissue analysis. Sponges had the most results above reporting limits. Copper, iron, mercury and zinc had results higher at GTLF than at baselines. Chromium was higher at GTLF compared to one baseline, and lower than the other. Nickel's was lower at GTLF than at both baselines. BL=Baseline.

Overall, tissue sample analysis indicates that there is an increased metal content in the biological tissues near the GTLF. Numerous GTLF test sites had higher results then baseline comparison sites providing evidence that the GTLF is increasing the metal content in the area, and contaminating the North Sound.

However, it cannot be ignored that some baseline sites had results higher than the GTLF sites, as seen in copper with Red Mangrove, and nickel in Sponge. This could mean that there is a source of contamination near the baseline test sites, or that there is more copper and zinc occurring naturally in the soil. Further investigation is needed to learn more about tissue contamination, with baseline sites from other locations around the island, and an increase in the number of phyla tested.

2.3 MARINE WATER ANALYSIS

2.3.1 Methods.

Unpublished North Sound Water Quality Monitoring Data was collected from the DOE (Department of Environment, 2013a [DOE 2013a]; Department of Environment 2013b [DOE, 2013b]). Water samples were collected in the North Sound at GPS recorded locations identified in figure 2.9. Samples were then analyzed by the Water Authority Cayman[5] [WAC] for bacteriological testing, and DOE labs for pH, temperature, conductivity, oxygen, nitrate-nitrite, phosphate and suspended solids. The WAC used SM9230 or Idexx's Enterolert for Enterococci analysis, and SM9223B or SM9222 for Faceal Coliform analysis.

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[5] Water Authority Cayman, P.O. Box 1104 Grand Cayman KY1-1102, Tel: 345-949-2837

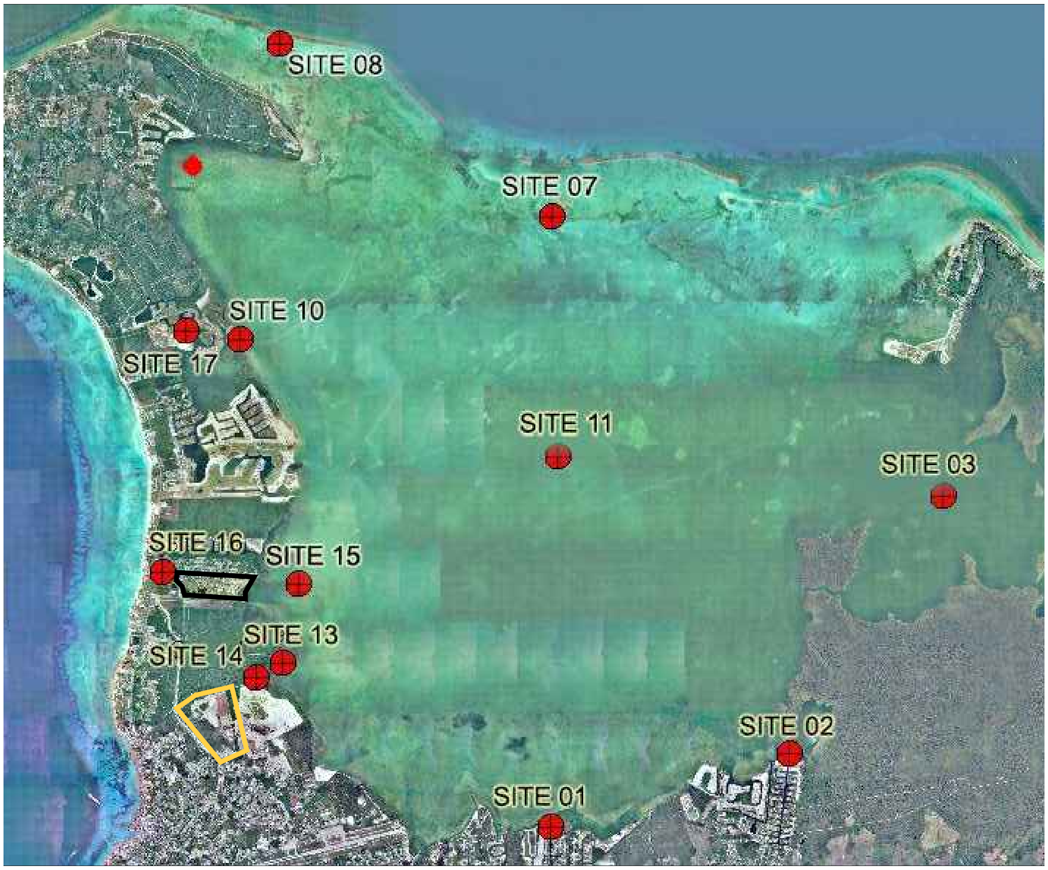

Figure 2.9. North Sound water quality test sites. Map shows DOE North Sound water quality monitoring sites (red circles). GTLF is outlined in yellow, Site 13 and 14 are used to investigate GTLF influenced water quality. Site 11 is used as a baseline as it is centrally located in the Sound. Black outlines a golf course near site 15 and 16. (Source, Source: Terry-Swaby, 2014; modified from DOE, 2013a).

DOE used a modified Strickland and Parsons 1972 method for nutrient testing, and a YSI multiprobe for conductivity, temperature, and oxygen analysis. The Strickland and Parsons method was modified when the first sample was collected and analyzed, and has remained consistent. Therefore all data in the set is comparable, but may not be comparable to other Strickland and Parsons data outside of this sample (J. Bothwell, personal communication June 5th and 10th 2014). For more information on specific methods used by DOE, please contact doe@gov.ky.

The data analyzed in this section of the report is an averaged value from the five most complete data sets (DOE 2013a) and the maximum-recorded value from within the data set (DOE 2013b). Sample sites near the GTLF were compared to sample sites around the North Sound with sites 13 and 14 representing the GTLF and sites 1-11 acting as baselines. Site 11 is the main baseline because of its central location in North Sound.

2.3.2 Results.

Water quality testing in the North Sound indicates that there is some contamination in the marine environment. Sites 13 and 14 closest to the GTLF had higher bacteria readings than sites 1-11, figure 2.10. Additionally, sites 13 and 14 had reduced salinity, figure 2.11. Increased dissolved oxygen, figure 2.12. The highest suspended solids in the North Sound, figure 2.13, and elevated nitrates/nitrites and phosphate, figure 2.14. Furthermore these results are higher at site 14, which is closer to the GLTF than 13, [figure 2.10, 2.12, 2.13, 2.14] indicating that contaminants are coming from land. Contaminants dilute when they move away from a source (Mihelcic and Zimmerman, 2010).

These results are also in agreement with CardnoENTRIX's report from 2013. CardnoENTRIX wrote that the water in the North Sound near GTLF had elevated chlorophyll a, total suspended solids, nitrates/nitrites, and decreased salinity levels. CardnoENTRIX hypothesized that the decreased salinity level was associated with an increase in surface water run off, an idea supported by this data (2013). CardnoENTRIX also reported an ongoing phytoplankton bloom in the North Sound, near the GTLF (2013) which positively correlates with the elevated nutrient levels seen in figure 2.14, and high suspended solids, figure 2.13

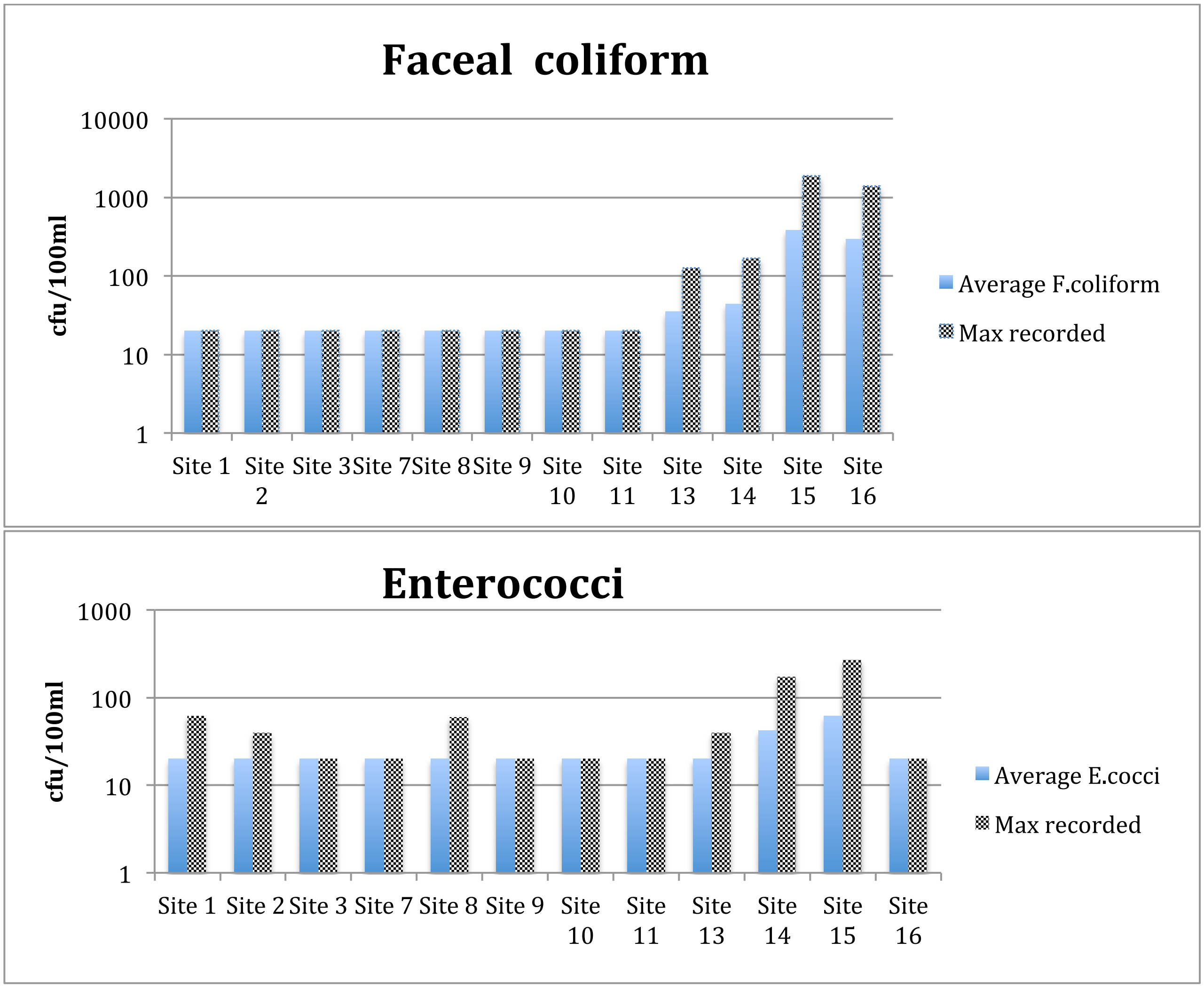

Figure 2.10. North Sound water quality bacteriological results. Figure shows bacteriological analysis for Faceal Coliform on top, and Enterococci on bottom. Sites 13 and 14 represent the GTLF. The average was calculated from five most recent data sets, and the max recorded taken from the averaged data sets. Solid blue is average, grey pattern is highest recorded. Data is displayed using a log scale.

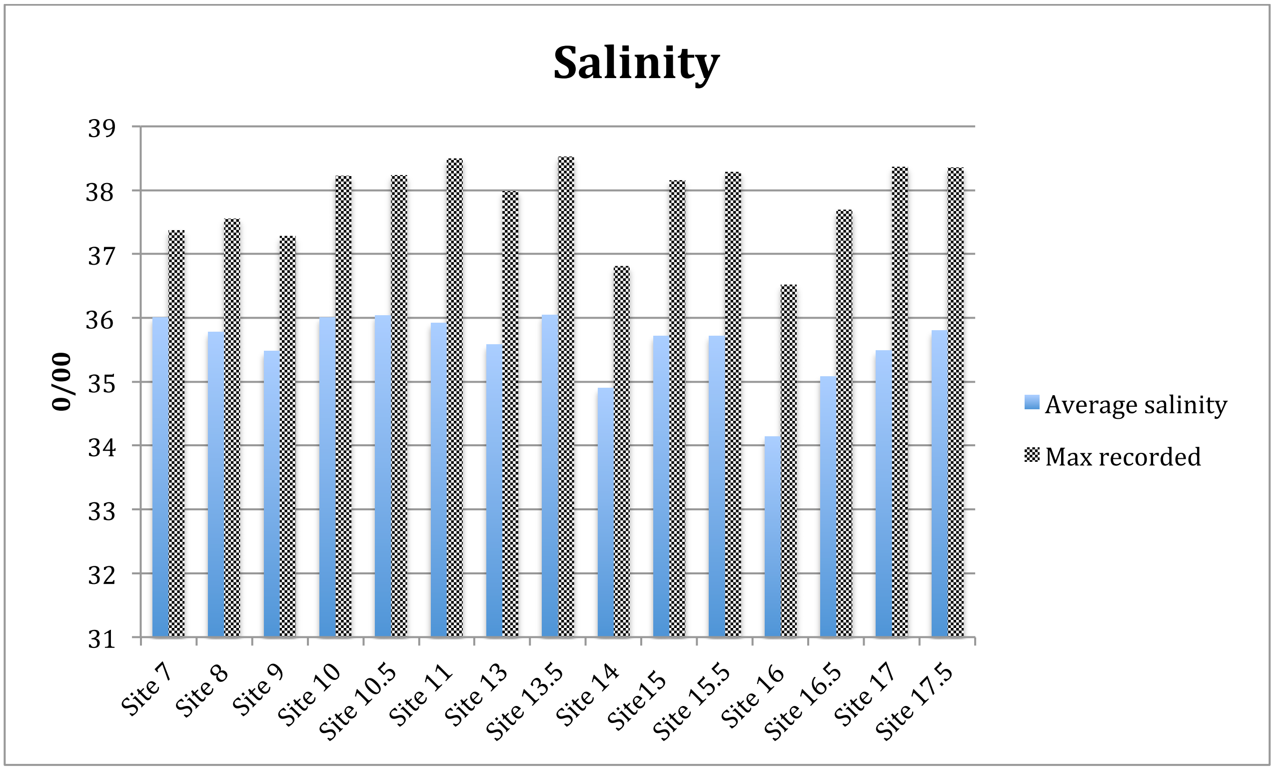

Figure 2.11 North Sound water quality salinity results in 0/00. Figure shows average and maximum salinity. Average is a calculation from five most recent data sets. Maximum is highest recorded within that data set. Sites 13 and 14 respond to GTLF. Site 16 and 14 had the lowest salinity levels indicating high volumes of fresh water inputs. Sites 13 and 15 have normalized readings indicating that the source of fresh water/reduced salinity is coming from land. Site 16 is near a golf course, so high fresh water run off could occur from sprinklers. Site 14 could be receiving fresh water run off from GTLF.

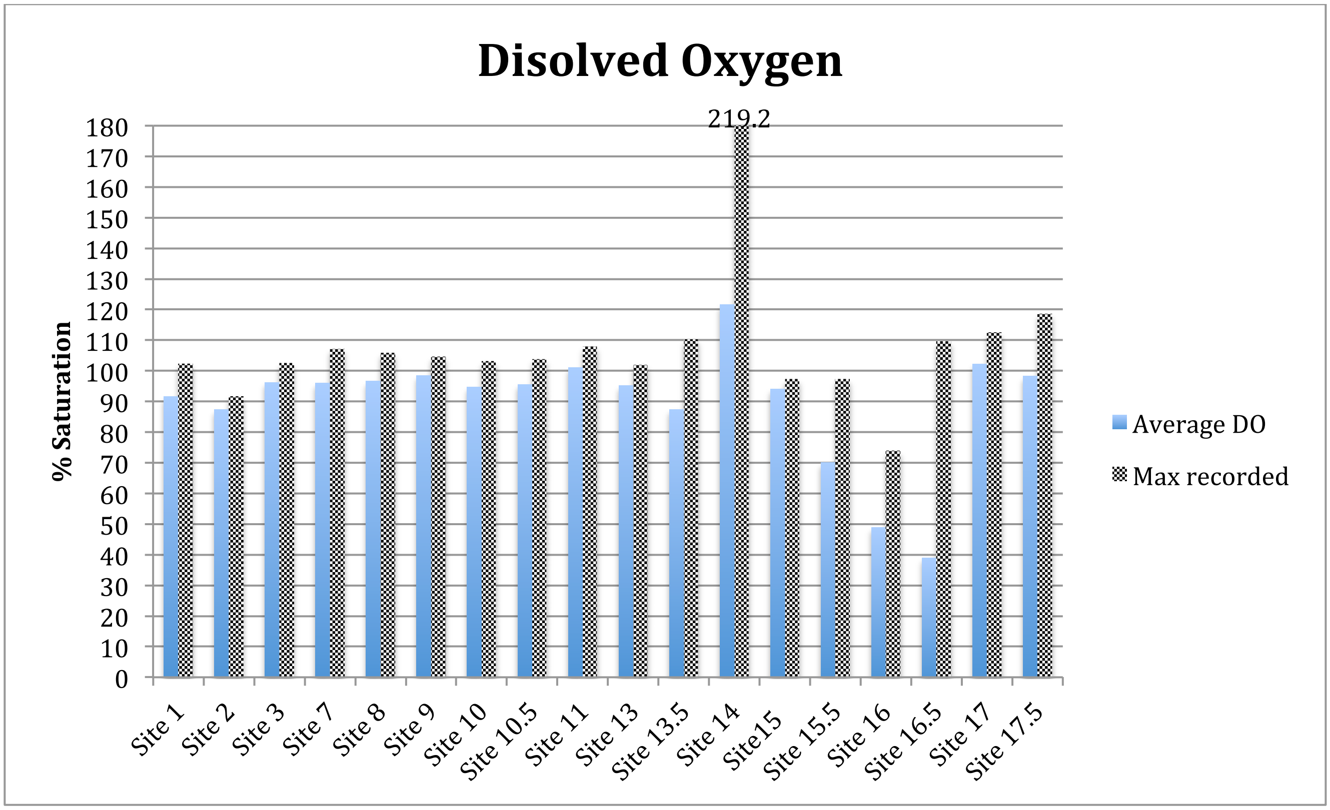

Figure 2.12. North Sound water quality dissolved oxygen results, % saturation. Graph shows average recorded dissolved oxygen and highest recorded dissolved oxygen for North Sound. The average was calculated from five most recent and complete data sets. Dissolved Oxygen % saturation is in the solid, and maximum recorded is in black and white pattern. Site 14 has the highest, oversaturated, dissolved oxygen at 122% on average and a maximum recording of 219.2%. Site 16 has the lowest at 39% on average. *Note that dissolved oxygen levels fluctuate with the time of day. Variances in readings could be related to the time samples were taken from different locations.*

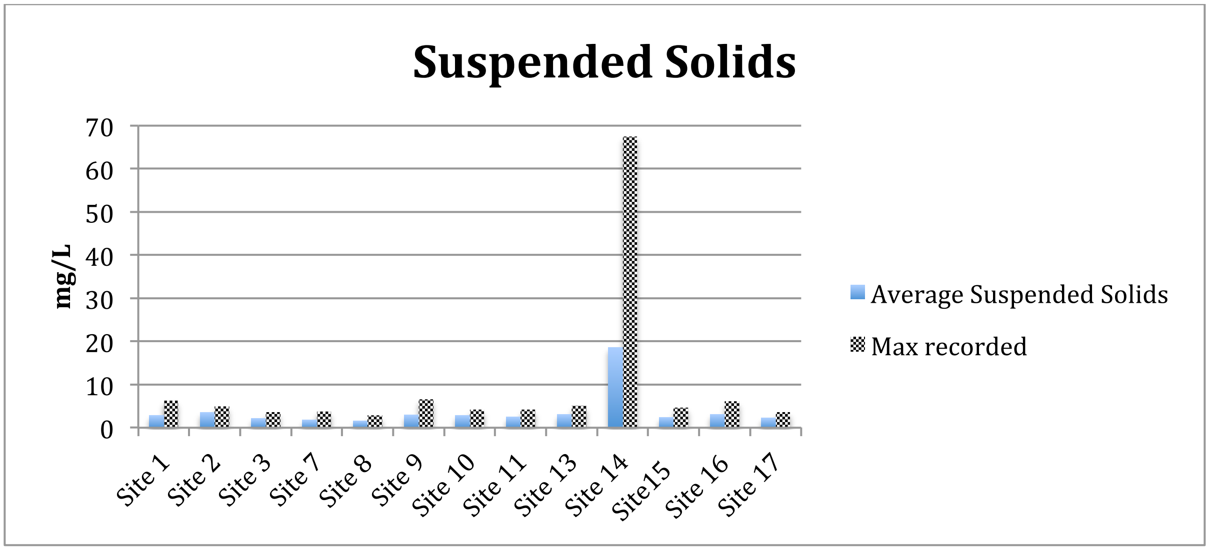

Figure 2.13. North Sound water quality suspended solids results. Figure shows average and maximum recorded suspended solids in the North Sound, in mg/L. Averages were calculated from five most recent data sets. Site 14—closest to GTLF, had the highest reading in the North Sound at 18.57 on average and 67.45 recorded maximum.

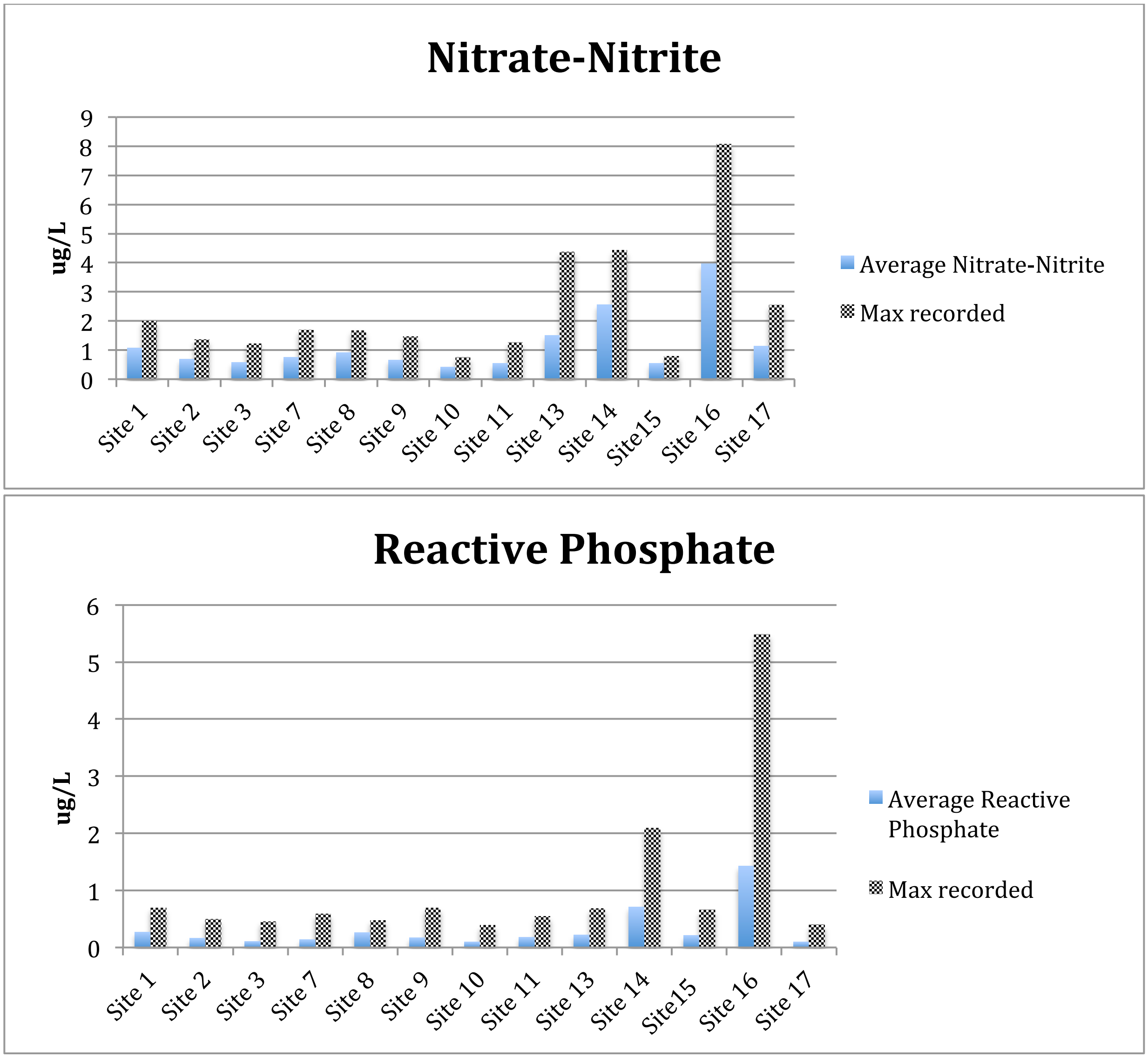

Figure 2.14. North Sound water quality nitrate-nitrite and reactive phosphate results. Figure shows averages and recorded maximums of Nitrate-Nitrite on top, and Reactive Phosphate on bottom. Averages were calculated from five most recent and complete data sets. Averages are solid and maximum recorded is in black and white pattern. Site 13 and 14 have elevated Nitrate- Nitrite levels. Site 14 also has elevated phosphates. Site 16 has exceptionally high Nitrate-Nitrites and high Phosphate results.

Overall site 14 had higher readings than site 13 indicating that contamination is coming from land, and most likely the GTLF area. Contaminants are most concentrated near the source and dilute as they spread away (Mihelcic and Zimmerman, 2010). Furthermore, sites 14 and 13 had higher results than sites 1-11 indicating unusual water composition in the North Sound near the GTLF, further supporting the argument that the GTLF is contaminating the North Sound.

CardnoENTRIX reported in 2013 that there was excessive growth of macro-algae and epiphytes in the Sound near the GTLF. They theorized that this was occurring from lack of grazers, due to poor water quality (CardnoENTRIX, 2013). The data once again supports this statement as salinity levels are low and suspended solids are high: indicating poor water quality for marine species. Furthermore the added nutrients [nitrate-nitrite and phosphate] would stimulate algal growth. This is a negative impact as epiphytes and microalgae compete with sea grass beds. Too many could smother and outcompete sea-grass beds negatively altering the ecosystem (CardnoENTRIX, 2013). Seagrass beds are important because they provide a nursery for many juvenile species (Townsend, 2012).

It is also important to discuss sites 15 and 16 as they yielded unexpected results. Sites 15 and 16 had extremely high Faceal coliform, high Enterococci, low DO saturation, and the highest nitrate/nitrite and phosphate readings of the entire sound, indicating contamination. Readings at site 16 were higher than site 15, showing a land-based source of contamination.

It is unlikely that the contamination seen at sites 15 and 16 is from GTLF as sites 13 and 14 are closer, and have lower results. Additionally the current in the North Sound does not support transportation from sites 13 and 14 to 15 16, as indicated in figure 2.15. The current in the North Sound moves counter clockwise– transport from sites 13 and 14 to 15 and 16 would require a clockwise motion.

However it is possible for the contaminants to move from site 15 and 16 to site 13 and 14, which is important to consider for nitrate-nitrite, phosphorus and bacteria readings, as site 15 and16 had higher results than 13 and 14. But, upon closer analysis of the data site 15 had lower readings than site 14, which does not support transportation of contaminants from 15 and 16 to 13 and 14. For transportation to be occurring results would have to be higher at both 15 and 16, than 13 and 14. This is only the case for bacteriological analysis. However, site 14 is higher than site 13, for bacteria counts, which indicates a land-based source of bacteria, near site 14, and not site 15. I hypothesize that the contamination at sites 15 and16 could be from fertilizer runoff used by the nearby golf, as indicated from the nitrate/nitrites and phosphates course, or damage to a sewage line or septic tank indicated from the bacterial counts. A complete list of all results is available in Appendix C.

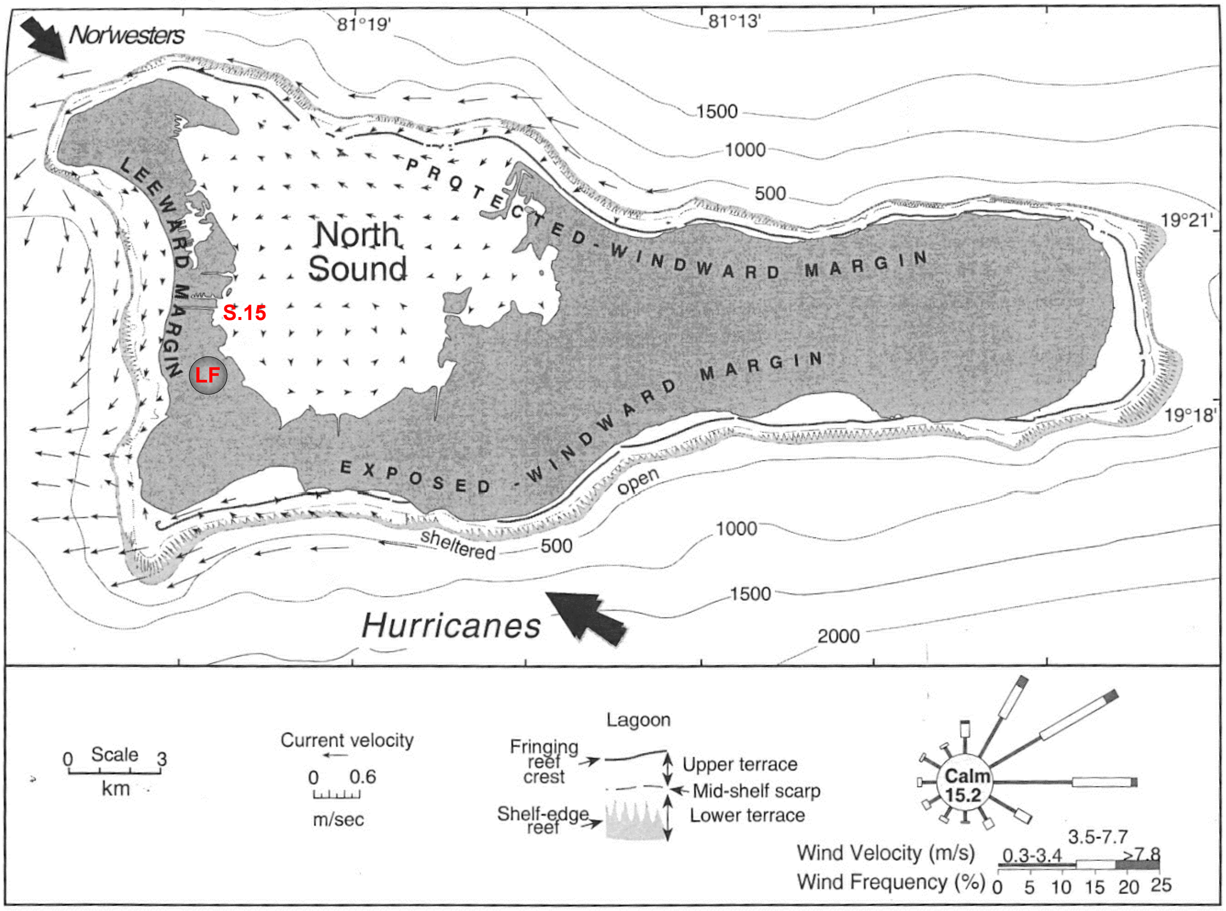

Figure 2.15 Currents and wind directions in Grand Cayman. Image shows the usual wind direction and ocean currents around Grand Cayman. S.15 indicates were marine water monitoring site 15 is, and the circle with LF, indicates the approximate location of GTLF. (Source, Terry-Swabby, 2014; modified from Jones, 2000).

2.4 SEDIMENT ANALYSIS

2.4.1 Methods.

Unpublished North Sound sediment data was collected from the DOE, courtesy of Ray Hayes (Hayes, 2012). DOE partnered with Hayes in May 2012 to conduct a preliminary sediment analysis of the North Sound using an X-Ray-Florescent Spectrometer (XRF). Moist sediment samples were analyzed at 53 locations. The XFR analyzes samples for metals at semi-quantitative values, creating a preliminary understanding of the metals present in the North Sound sediment. More accurate techniques will be needed to learn exact metal content (T. Austin, personal communication June 3rd 2014).

Sediment was tested with a special focus on the area near the GTLF. Sites 33, 34, and 35, serve as natural baselines and sites 38,39, 40, 41, 42, and 43, serve as a developed area comparisons, figure 2.16. Sites 27,28,29, 30, 31, 32, 36, 37, 50, 51, 52, 53, have been removed from the data sample to create a smaller sample set. These sites are from a canal near a housing development and have similar readings to sites 38-42. Sites 44, 45, 46, 47, 48, and 48 correspond to the canal north of the GTLF, and sites 1-26 correspond to the North Sound, near the GTLF, figure 2.17.

Figure 2.16. Map of North Sound sediment analysis sample locations. Sites are indicated by yellow dot, with site number in red.

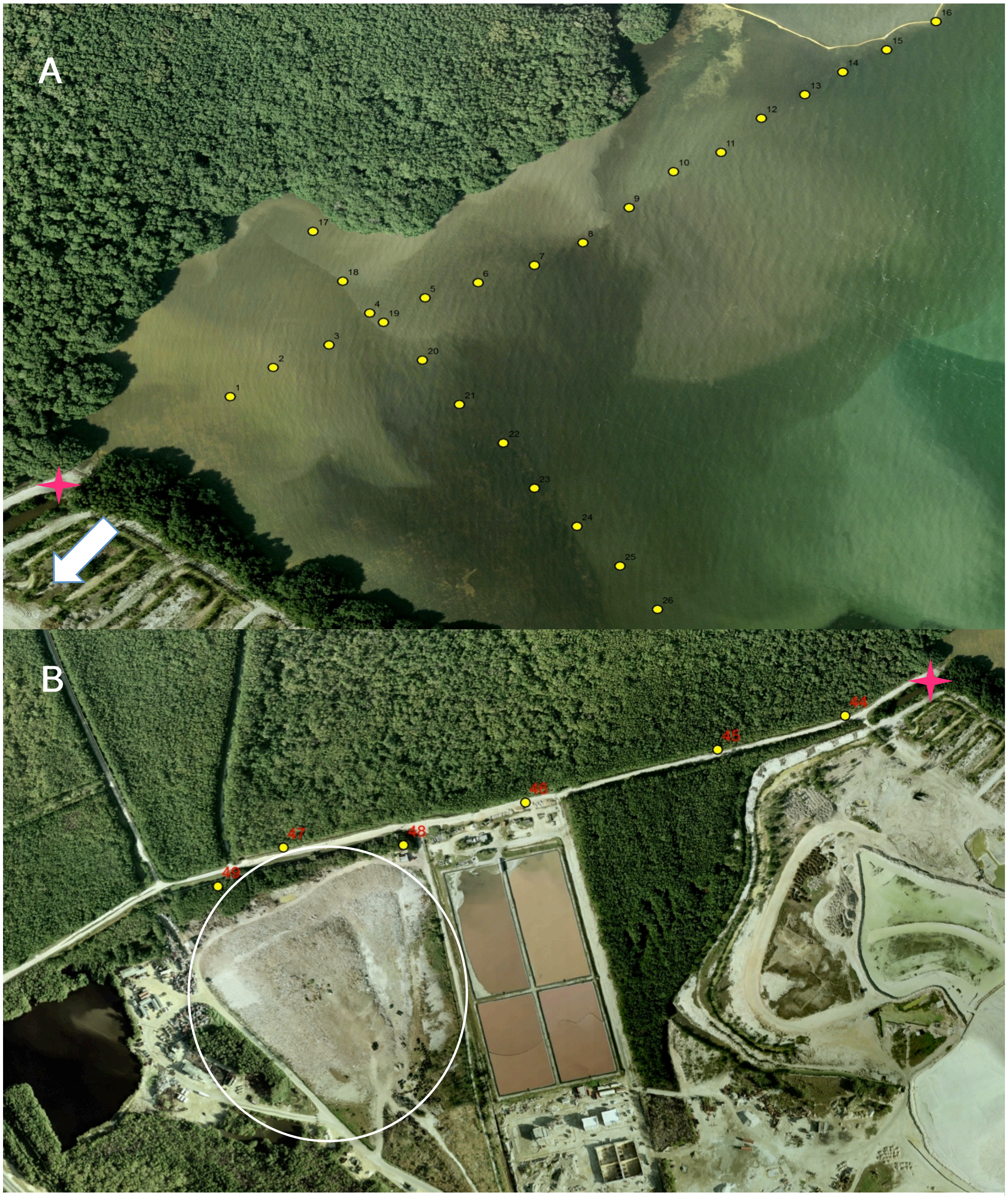

Figure 2.17. Sediment analysis sample sites near GTLF. Image A, top, shows sample sites 1-26 in the North Sound near GTLF, GTLF is in direction of arrow. Image B, bottom, shows sediment sample sites 44-49, in canal north of GTLF which is circled in white. Star serves as point of reference, and marks the same location in each image.

2.4.2 Results.

XRF analysis found varying amounts of the following metals at multiple test locations in the North Sound; chromium, manganese, iron, sulfur, chlorine, potassium, calcium, rubidium, strontium, thorium, titanium, nickel, zirconium, tin, antimony, arsenic, vanadium, copper, zinc, phosphorus, lead, molybdenum, silicon, uranium, cadmium, cobalt, mercury, and selenium. However sediment results were hard to interpret, as no clear pattern was found.

The results for chromium, iron and thorium are focused on in this discussion, as they are usually associated with landfill contamination. Additionally thorium and chromium are not normally found in natural soils at elevated levels indicating a human source for their presence in marine sediment (R. Jamieson, Personal Communication, August 25th 2014). A list of complete results for all metals is available in Appendix D.

Iron, chromium and thorium had a similar but not identical distribution pattern. They had a high reading in the canal near the GTLF (sites #44-48), and random lower readings in the North Sound (sites#1-26) figure 2.18. This indicates a higher concentration of metals in the canal near the GTLF, and a lower concentration in North Sound.

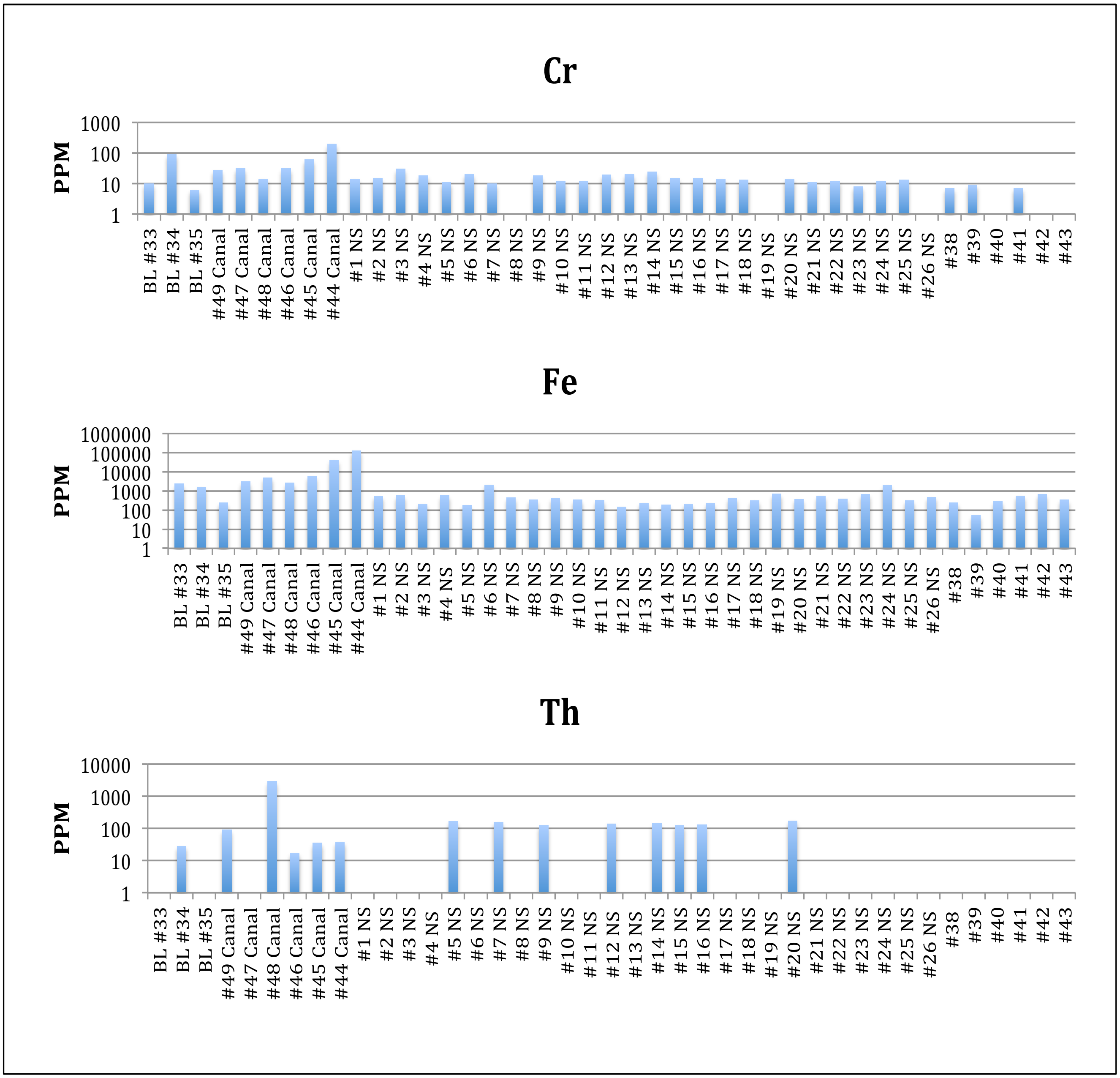

Figure 2.18. North Sound sediment analysis results. Figure shows results for Chromium [Cr], Iron [Fe] and Thorium [Th] after XRF analysis in the North Sound. BL= Baseline, Canal= Canal North of GTLF, and NS= North Sound. Results show a high reading in the canal North of GTLF, and some lower readings in the North Sound indicating a higher metal concentration in the canal near the GTLF than the North Sound. Data is displayed on a log scale.

As XRF provides only a semi-quntitave analysis; further sediment analysis is needed to assess the exact concentration of these metals in the sediment, and to understand distribution and dilution patterns. All we can say from these preliminary results is that there are metals in the North Sound sediment and iron, chromium and thorium have higher concentrations near the GTLF than the rest of the North Sound, providing evidence of GTLF contamination.

2.5 SUMMARY OF RESULTS

In conclusion there is evidence that the GTLF is contaminating the North Sound. The evidence can be seen in the groundwater, surface water, tissue sample, North Sound water quality and sediment analysis results. In short ground and surface water samples had results over Miami-Dade County regulatory limits. Arsenic, boron, iron, lead, phosphorus, sulfate and total dissolved solids had results higher than the Groundwater Quality Criteria. This is worrying because ground water is directly connected to the North Sound and mixing with the North Sound at unknown rates. However, groundwater appears to be diluting and undergoing natural attenuation with higher results at wells closer to the active landfill area.

Arsenic, chromium, copper, cyanide, iron, lead, nickel, phosphorus, vinyl chloride and zinc were over Marine Water Criteria limits. This causes concern because surface water is rapidly transported into the North Sound, and some surface water sites are directly connected to the North Sound. Similarly to groundwater, contaminants in surface water are highest near the active landfill area with dilution and/or attenuation of contaminants as they move away from the active landfill. Phosporus was of particular concern for marine contamination as it had high results in all sample sites including those connected to the North Sound.

Tissue Sample analysis showed that plant tissue near the GTLF had higher metal content than plant tissue from Barkers Beach. Iron, copper and zinc were found in red mangrove, turtle grass, sponge and green algea tissue, with results higher in GTLF samples than baseline samples. Furthermore sponge samples had chromium and mercury readings higher than baseline comparisons.

The North Sound water quality analysis showed differences in the water near the GLTF when compared to the rest of the Sound. These are seen especially in suspended solids, which were elevated when compared to the rest of the Sound. Additionally nutrient levels, dissolved oxygen, and bacteria levels were elevated, and salinity levels were depleted. This indicates an unusual water chemistry near the GTLF, compared to the rest of the Sound. Finally the preliminary North Sound sedimentary analysis showed that there are elevated metals in the sediment near the GTLF. Specifically iron, chromium and thorium had higher readings near the GTLF, than the rest of the North Sound.

In conclusion this data provides evidence that there is some contamination of the natural environment near the GTLF. However, contamination does not appear to be at toxic or ecosystem threatening levels. Further investigation is recommended to better understand these findings as this data does not provide a complete understanding of the GTLF's effects. More specific testing is needed in the future to evaluate effects on marine species, especially benthic organisms, and marine sediment. Additionally, more baseline samples should be collected so that there is a more complete data set to compare the GTLF's results too.

This data analysis was performed using the data currently available to create a preliminary report of what is currently known about the GTLF and surrounding ecosystems. Please read chapter 3 for recommendations and next steps specific to the problems outlined.

CHAPTER 3: RECOMMENDATIONS

3.1 REVIEW of POTENTIAL and ACTUAL PROBLEMS FOUND at GTLF

Chapter 1 discussed the operational and design problems with the GTLF. In summary; the GTLF's location on a tropical island, with a high water table, permeable sediment, and annual hurricane season creates potential for leachate to migrate and contaminate nearby ecosystems. Furthermore the landfill is unlined allowing leachate to seep into groundwater and flow into surface water. The landfill is uncovered, which allows garbage to blow off the landfill mound into nearby ecosystems, increases odor, attracts insects and vermin, and is visually unappealing. There is also no site or closure plan. Finally, the GTLF is run and regulated by the same authority—the DEH, which causes a conflict of interest.

Furthermore, Chapter 2 found evidence of contamination, with contaminants present in ground and surface water samples, abnormal marine water quality results near the GTLF, increased metals in tissues near the GTLF, and metals in marine sediment near the GTLF. However, as stated previously in Chapter 2 these tests were not perfect. Ground and Surface water data was inconsistent between years. Not enough phyla were analyzed in the tissue analysis as no crustaceans, fish, reptiles or mammals were tested. And, the XRF used for the sediment analysis is not specific enough to provided quantitative results.

After this desktop review it is easy to see that there is a lot of potential for the GTLF to contaminate the ecosystems of Grand Cayman [Chapter1], and evidence suggesting it is already happening [Chapter 2]. Management procedures at the GTLF must to be modified to reduce the potential for, and actual contamination occurring. There are many different management frameworks that can be implemented to address this issue. I recommend the Integrated Coastal Management [ICM] framework be used with current waste management best practices.

3.2 MITIGATION: INTEGRATED COASTAL MANAGEMENT

3.2.1 Why Integrated Coastal Management should be used.

ICM is a management framework that provides a thorough, forward thinking, multilevel approach to managing the coastal area (Meltzer, 1998). The coastal area is normally defined as the area where ocean and land interact. This can be as narrow as high-tide to low-tide, or as wide as a few kilometers (Kay and Alder, 2005; Meltzer, 1998). ICM can be used for the GTLF as tidal canals connected to the North Sound surround the GLTF. Additionally the GTLF is approximately 1km from the main body of the North Sound. The GTLF can easily affect the North Sound, as suggested in evidence collected in Chapter 2, and the North Sound can affect the GTLF with storm surge. In short the GTLF is a land-based problem that affects the ocean: and therefore falls under the realm of coastal management.

3.2.2 Integrated Coastal Management framework.

ICM is a management framework which focuses on coordination and integration to overcome a coastal issue (Cicin-Sain and Knecht, 1998; Meltzer, 1998). The framework is continuous, engages stakeholders, has a seaward and landward limit, and tends to focus on the precautionary approach (Kay and Alder, 2005; Meltzer, 1998). Most importantly ICM is interdisciplinary, using natural sciences, social sciences, law, engineering and economics, etc. to overcome problems and create a strategic plan (Meltzer, 1998).

The ICM framework is divided into four main phases[6], Initiation, Planning, Implementation, and Monitoring and Evaluation (Sterr and Maack, 2010). During initiation the need of an ICM plan is identified (Cicin-Sain and Knecht, 1998). The issue is defined, background information is collected using DPSIR analysis, and stakeholders are analyzed and consulted with (Kay and Alder, 2005, Sterr and Maack 2010). DPSIR represents Drivers, Pressures, State, Impact and Responses, and is best described by Sterr and Maack, in the following quote:

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[6] Some descriptions of ICM frameworks have six stages, issue identification, program planning and preparation, formal adaption and funding, implementation, operation, evaluation (Cicin-Sain and Knecht, 1998). The content of these six stages is present in the four outlined above. However, some are grouped together to make four instead of six.

> “The DPSIR concept shows **drivers**, e.g. increase in seaside building and economic activities, produce serious **pressures** such as pollution and overfishing. In consequence these pressures change the **state** of the environment, typically in a negative direction, and **impact** both ecosystems and socioeconomic conditions. These impacts call for short term and long term **responses**, e.g. enhanced natural conservation measures, improved environmental legislation, monitoring, regulation and control mechanisms e.g. formulated as regional management plans. Ideally, the responses will then feed back to the starting point and change the driving factors,…” (pp. 276, 2014)

In summary, during Initiation information is collected about the coastal issue and potential solutions are established, termed “responses”. Responses should aim to be sustainable, integrated, forward thinking, and should target the initial drivers and pressures, which led to the coastal problem (Sterr and Maack, 2010). Most coastal issues are related to some sort of stakeholder conflict. The coastal zone has multiple users with varying and often conflicting needs, for example recreation vs. business. (Kay and Alder, 2005; Meltzer, 1998)

Planning, the second phase, is completed when all the background information has been collected, and stakeholders have been established. During the planning phase experts consult with stakeholders to create a management plan that addresses the initial drivers of the issue, and associated impacts using both short and long-term plans (Cicin-Sain, and Knecht, 1998; Kay and Alder, 2005). Plans should be spatially, horizontally and vertically integrated, described later (Sterr and Maach, 2010). The plan should also include “plans” for implementation, and monitoring and evaluation, the next two steps in ICM (Cicin-Sain and Knecht, 1998).

Once planning is complete implementation begins. During implementation the plan is put into place or activated. This can take days, weeks, or years depending on the plan. Legislation may have to be drafted to address a loophole in existing policy, or facilities built, such as a lab to analyze samples (Cicin-Sain and Knecht, 1998; Kay and Alder, 2005). Initiation is arguably the most important step of ICM. If the plan is never implemented, then the issue may not be resolved. Or, if the plan is implemented poorly then additional damage could happen (Kay and Alder, 2005).

Monitoring and evaluation, the final step, usually begins at the same time as implementation. Monitoring mechanisms are established during the planning stage and begin as soon as parts of the plan are implemented (Cicin-Sain and Knecht 1998). Monitoring and evaluation is done to insure that the plan is doing what it was intended to do. By monitoring the plans success, and evaluating it against the goals of the plan progress can be checked, and the plan modified to align closer with the strategic goals. ICM is designed to by cyclic with constant room for improvement, outlined in figure 3.1. Monitoring and evaluating the plan to improve its function is a core component to the ICM framework (Kay and Alder, 2005; Sterr and Maach, 2010).

During all stages of ICM it is vital to keep the community and stakeholders involved (Cicin-Sain and Knecht, 1998; Kay and Alder, 2005; Meltzer, 1998). If stakeholders are left out the process, the final product may not address their needs (Meltzer, 1998). Furthermore if the community is not involved they may become resistant to the plan, and negatively affect its success (Kay and Alder, 2005).

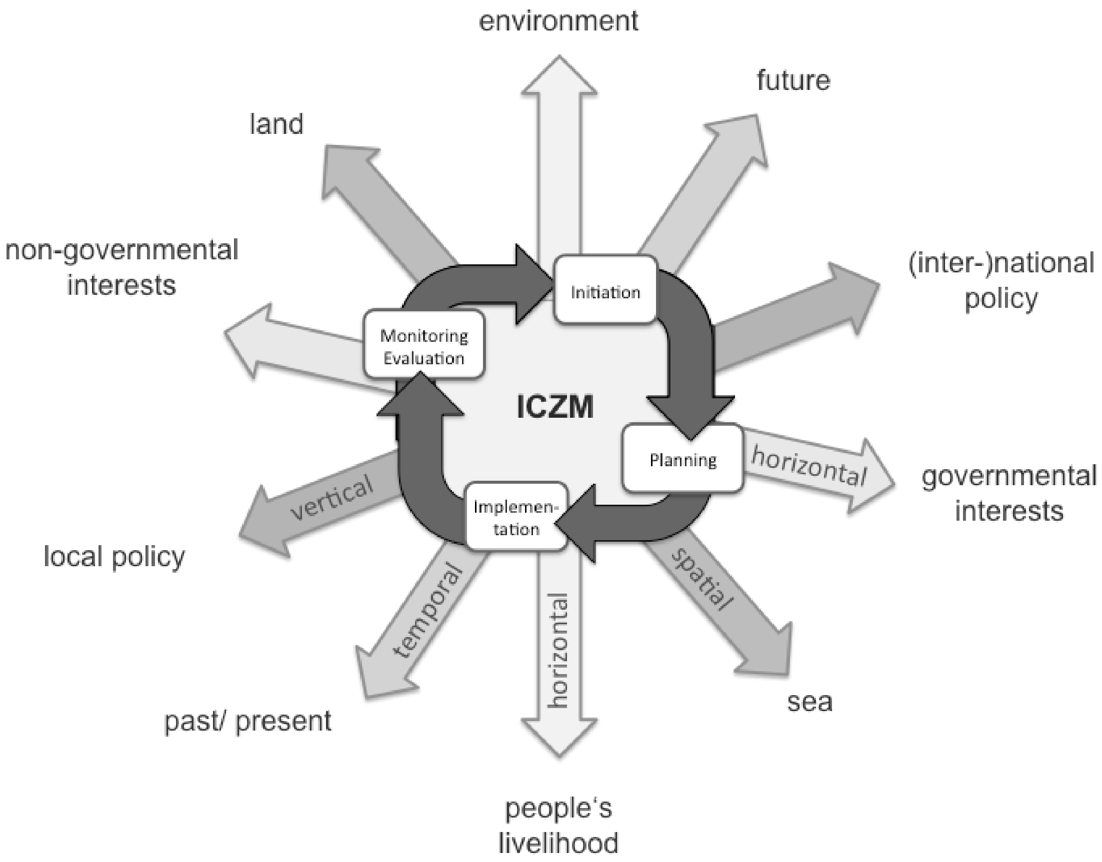

Figure 3.1. Phases of integrated coastal management. Image above outlines the four phases of ICM, and helps to visualize the cyclic nature of the framework. Figure also notes the main integration factors: vertical, temporal horizontal and spatial. (Source: Sterr and Maack, 2010).

3.2.2.1 Integration.

As mentioned above integration is an important aspect of ICM, specifically spatial, horizontal, vertical and temporal integration (Cicin-Sain and Knecht, 1998; Kay and Alder, 2005; Meltzer, 1998; Sterr and Maack, 2010). Temporal integration aims to create a plan that is both immediate, and also forward thinking. To be temporally integrated means that the plan meets immediate needs, as well as those in the distant future, so that all aspects of time are considered. Climate change is an important aspect to consider with temporal integration (Sterr and Maack, 2010).

Spatial integration aims to insure that all aspects of space are considered. Some issues are consolidated into small areas; others have far reaching effects. To be spatially integrated the plan must incorporate all aspects of land, sea and air that are related to the issue, be it in close proximity or as far away as impacts are felt. The spatial scale of the issue is normally defined during initiation (Cicin-Sain and Knecht, 1998; Kay and Alder, 2005; Sterr and Maack, 2010).

Horizontal integration aims to incorporate all stakeholders into the management plan (Sterr and Maack, 2010). This is done to create a feeling of community involvement, to avoid isolating or restricting a sector, and to insure that no needs are ignored. Horizontal integration can also include integration among disciplines; such as social sciences, natural sciences, politics, engineering etc. in the final management plan (Kay and Alder, 2005; Weinstein, et al, 2007).

Vertical integration aims to incorporate all administrative levels into the management plan. Plans should be vertically integrated to as high a level as possible, e.g. the federal government, and a low as possible, e.g. community volunteers (Sterr and Maack, 2010). Recent research suggests that the bigger a role the local community plays in a management plan the higher chance of the plans success (Weinstein, et al, 2007). Vertical integration is also important between nations if an issue is international (Kay and Alder, 2005).

Integration is important throughout the whole ICM process, from initiation to monitoring and evaluation (Kay and Alder, 2005). If a plan is not fully integrated during initiation stakeholders may be left out of discussions, or impacted areas ignored. If a plan is not fully integrated during planning and implementation management problems could arise from the local community or administrative leaders. If integration is not considered during monitoring and evaluation important study areas could be ignored or poorly managed. Integration is vital to the ICM process, and of course the final management plan.

3.3 RECOMMENDATIONS

The remainder of this report will provide management recommendations to reduce the potential for and actual contamination of the North Sound from the GTLF. The recommendations will be made following the steps of ICM, and be based off the information gathered in Chapters 1 and 2. Recommendations will incorporate waste management best practices when applicable.

3.3.1 Step 1- Initiation.

The first step of initiation is to complete the DPSIR analysis. I began the DPSIR analysis, shown in Table 3.1 using information gathered in Chapters 1 and 2. The analysis outlines the Drivers, Pressures, States, Impacts and Responses learned from this desktop review, and outlines where additional information is still needed.

Table 3.1 GTLF DPSIR analysis. The table below shows the results of the DPSIR analysis based on this desktop review.

* Hypothetical: results are based off of information implied from research and theory, but not explicitly stated in this desk-top review.

DPSIR	Data from desktop review	Hypothetical*
Drivers: *What led to the issue*	A fast growing population drove the government to quickly create a landfill to meet its waste management needs.	--
Pressures: *What is causing concern*	Contaminant migration [pollution] into surrounding wetlands and marine ecosystems: specifically mangrove forests, sea grass beds and coral heads.	There could be human health risks from contamination, and decreases in tourism as the GLTF is in a touristy area.
State: *Changes in environment*	There is discoloration of the North Sound near GTLF. Organic and inorganic contaminants have been found in ground and surface water. Plant and sea sponge tissues have elevated metals, there are metals in marine sediments.	There could be health risks, from toxins. The GTLF is unattractive to look at, impacting happiness, and has an odor. GTLF could be impacting economic revenue from tourism.
Impacts *What are the consequences*	*Ecological:* Degradation of natural environment and ecosystems. *Social:* Unattractive to look at.	Unknown environmental impacts. Unknown health risks, potential reduction in tourism.
Responses *What can be done to address drivers and pressures*	*Short Term:* Reduce and prevent leachate migration, and improve management practices.	Plus any immediate social or economic needs.
	Long Term: Improve Cayman's waste management practices, reduce the amount of waste going into the landfill, reduce leachate production, and leachate migration.	Plus any long-term social or economic needs.

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From the results of the DPSIR analysis we can see that more background information is needed. At this point in time there is almost no data outlining the social issues associated with the GTLF. The main social issues of concern at this time are potential health hazards and impacts to the economy from a reduction in tourism. Furthermore all stakeholders need to be identified so that all persons and sectors impacted by the GTLF are known, and can be included in the ICM process. This will also insure complete horizontal and vertical integration of the management plan (Cicin-Sain and Knetch, 1998; Meltzer, 1998; Kay and Alder, 2005).

Additionally more environmental data is needed. The existing data, discussed in Chapter 2 provides a baseline, but is too inconsistent from year to year, and too incomplete to form an actual management plan. With the exception of the ground and surface water data from the DEH the data evaluated in Chapter 2 was not designed to monitor contamination from a landfill. There are multiple frameworks available to collect the remaining DPSIR data, and improve the environmental data. Some examples are; Environmental Impact Assessment, Environmental Effect Monitoring, Life Cycle Assessment, and/or Social Impact Assessment. By collecting more data the full extent of this problem, environmentally and socially, can be learned, allowing a more accurate and integrated plan to be created.

As a conversation point, Kay and Alder developed a list of common drivers for coastal ecosystem threats. According to them the main driver for land-based pollution [toxins] into the costal zone are; lack of awareness; increased pesticide and fertilizer use; and unregulated industry (pp. 22, 2005). It would seem that the first and last items on this list apply to the GTLF.

3.3.2 Step 2- Planning.

As discussed previously the management plan should target the drivers, which led to the coastal issue, and be horizontally, vertically, temporally and spatially integrated. An effective plan will also incorporate current waste management best practices. Some of today's commonly accepted waste management best practices for landfills are:

- Covering landfill daily with inert material
- Construct an impermeable liner under landfill to collect leachate[7]
    - Collect and treat leachate
- Construct an impermeable cover on top of landfill to collect landfill and greenhouse gasses
    - Collect and burn or process gasses

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[7] Constructing a liner under an existing landfill would be near impossible. However a liner could be constructed for newer parts of the mound, or under a new landfill area.

- Monitor landfill and surrounding environment

(Source: Tammemagi, 1999; Williams, 2005)

The plan should also address short term and long term time frames. Short and long term plans need to be compatible, with similar overarching goals (Meltzer, 1998). Short term plans should focus on improving day-to-day management and mitigating immediate needs. Long term plans should focus on strategy (Kay and Alder, 2005; Meltzer, 1998). There should also be some sort of risk management plan for fires and storms.

During the planning stage plans should also be made for implementation and monitoring and evaluation (Cicin-Sain and Knecht, 1998). This should be done during planning so that implementation of the plan and monitoring and evaluation are aligned to the plans overarching strategies and end goals. If these stages are not created with the rest of the plan then they could be out of synch with the final objectives and goals (Cicin-Sain and Knecht, 1998; Kay and Alder, 2005)

3.3.2.1 Short-term goals.

The short-term plan should be focused on the immediate needs of the coastal issue. The short-term plan should set goals which are achievable within the next few years (Kay and Alder, 2005). I recommend that these goals be focused on reducing contaminant migration and improving GTLF operational practices. These should be done with the intention of reducing the GTLF's environmental impact. I also recommend that any social needs, which become apparent as more data is collected are mitigated.

From the data that has been collected at this point in time I would recommend that the short-term plan prioritizes;

- Identifying methods to temporarily reduce leachate migration to reduce environmental impacts
- Identifying methods to temporarily manage storm water
- Improve environmental monitoring
- Re-implement covering the landfill as part of weekly practices.
- Separate regulatory and operating bodies to eliminated the current conflict of interest.
- Conduct a socio-economic study to identify social, health, and economic impacts, then address the finings in both long and short term plans.

The items on this list can feasibly be addressed in a short time period, while the long-term plan works to create a strategized permanent solution.

3.3.2.2 Long-term goals.

The long-term plan should be focused on strategic objectives, to counter the initial drivers. The long-term plan should be holistic and sustainable (Kay and Alder, 2005). Its strategies should focus on protecting the environment, not burden future generations, and conserve resources, Figure 3.2 (Tammemagi, 1999). The long-term management plan should also focus on the waste management hierarchy originally developed in the European Union, Waste Management Directive, 1975 (Williams, 2006). This hierarchy, shown in figure 3.3, shows landfilling as the least desirable waste management practice, and encourages more environmentally friendly alternatives such as recycling, waste reduction, and waste to energy, to divert as much waste from the landfill as possible (Williams, 2006).

At this point in time the main driver identified with this issue was the rapidly growing population on Grand Cayman, which put pressure on the government to establish a waste management solution quickly. In the long term I recommend that waste management on Cayman be revamped, focusing on the higher goals of the waste management hierarchy, and addressing any current or future climate change vulnerabilities. In terms of climate change Cayman is vulnerable to sea level rise and increasing storm frequency and intensity (Hurlstone-Mckenzie, 2011). Long-term recommendations at this point in time are:

- Divert as much waste as possible from GTLF
    - Reduce waste from the manufacturing level up to consumption level; though education, awareness and possibly legislation
    - Improve re-use programs and awareness

  - Improve recycling and composting capabilities on Grand Cayman
- Consider implementing a waste to energy facility
- Improve daily GTLF operations
  - Construct a liner if possible
  - Construct an impermeable cover to trap landfill gas if possible
- Address existing geographic vulnerabilities
- Address climate change vulnerabilities
- Address social, health and economic impacts

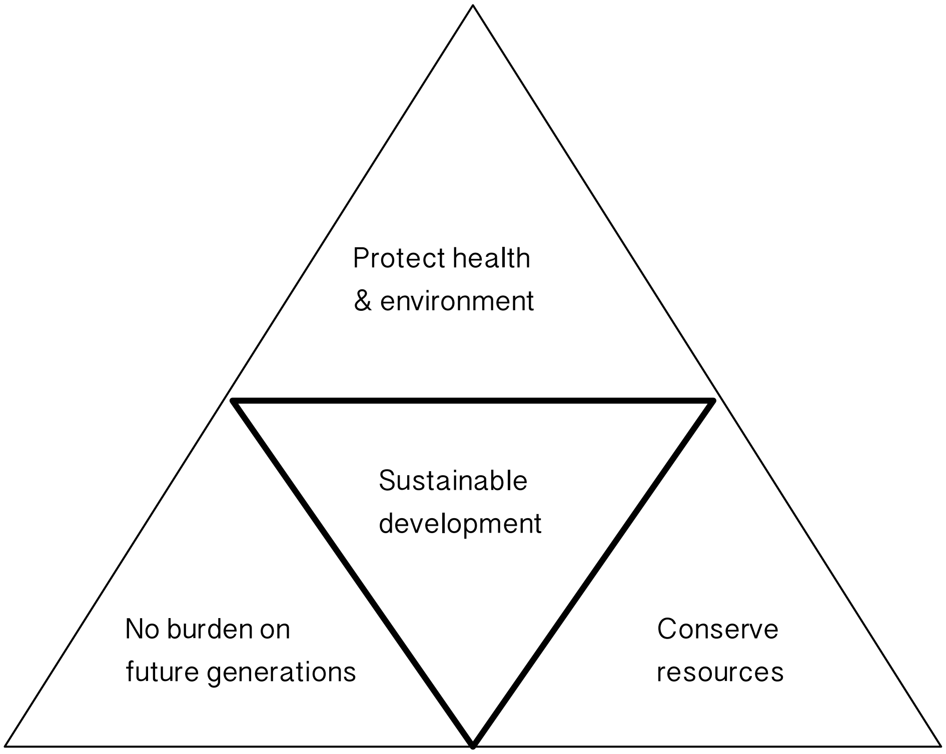
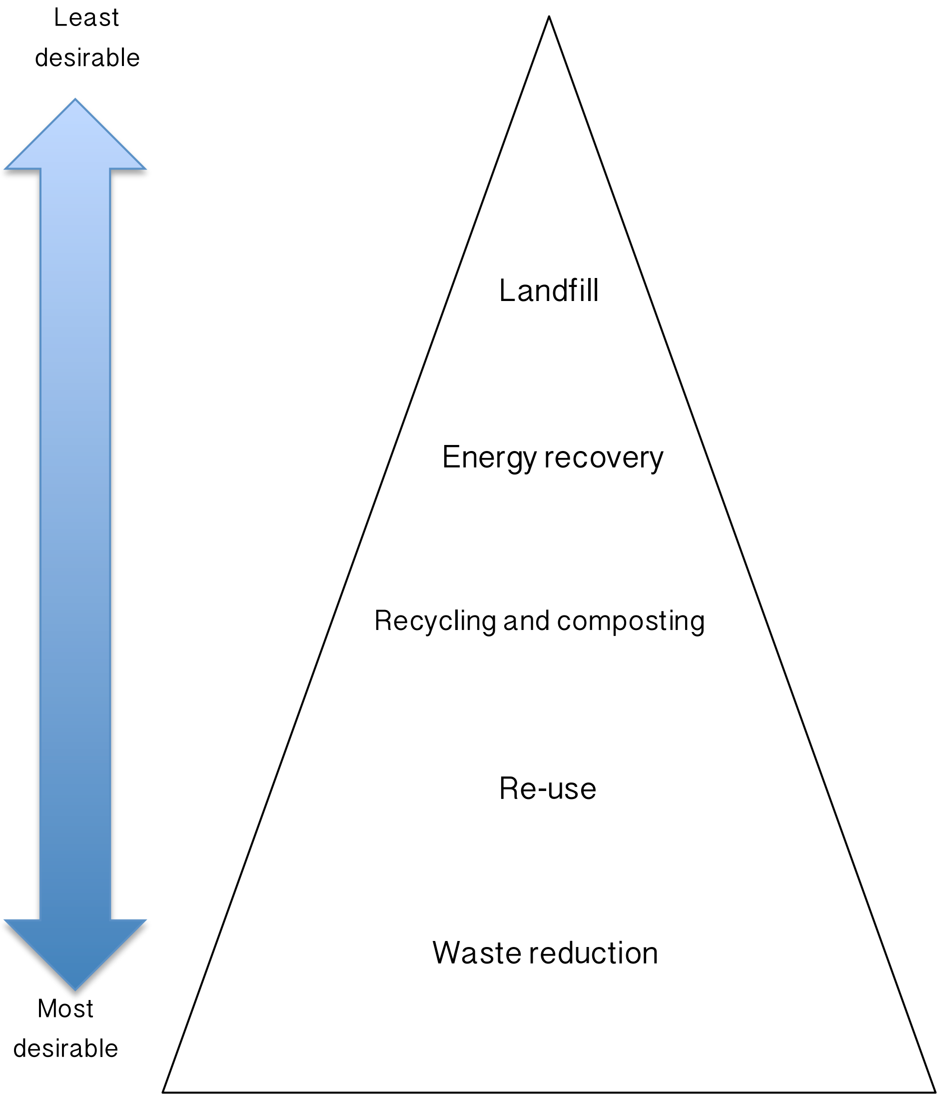


Figure 3.2. Sustainable development for waste management principles. Image shows the major focus' of sustainable development. (Source: Tammemagi, 1999).



Landfilling is least desirable. Organics break down over time, producing CO_2 and Methane green house gases.

Energy recovery is the process were waste is incinerated or landfill gas, which is generated by decomposing organics, is captured and burned. The energy generated can be used on site or exported to larger power grids. Energy recovery is expensive to set up but pays for itself through energy savings.

Recycling is taking a waste product and changing it back to its original form, to be re-purchased. This saves on raw materials, but can require energy and new raw material inputs. Make sure benefits out way costs.

Re-use is using products in their original form repeatedly. Examples: reusing glass bottles as glass bottles, or using old tires as boat fenders. However make sure the re-use benefit is not lost on the cost to re-use, for example cleaning and

Reduce waste at the manufacturing level: reduce packaging, improve technology, create longer lasting products. Reduce raw products and energy used when creating a product. Reduce unnecessary packaging.

Figure 3.3 Waste Management Hierarchy. Figure shows a modified waste management hierarchy, from least desirable on top to most desirable on bottom. A brief expiations of each stage can be found to the right in the boxes. (Adapted from: Williams, 2006).

3.3.2.3 Risk Management.

During the planning phase attention must also be paid to risk preparation and management, which is an essential aspect of waste management best practices. Risk management should consider the types of waste, potential pathways of contamination and any other vulnerabilities to the specific landfill (Tammemagi, 1999). As outlined in Chapter 1, Cayman is vulnerable to tropical storms and hurricanes (Hurlstone-McKenzie, 2011), which can increase contaminant migration. Additionally landfill fires are a big risk with potential environmental and social impacts. A risk assessment and subsequent management plan should be created for disastrous events so that the community is not overwhelmed (McAlister, 2004).

A risk management plan should begin with a risk analysis to understand the scope of potential disasters, then identify specific mitigation measures (Tammemagi, 1999). Completing a risk analysis and management plan before a disaster saves time during recovery, and allows managers to reduce vulnerabilities in preparation for an event (Anderson and Woodrow 1989; McAlister 2004). Today a lot of money goes predicting disasters so that hazardous areas can be better prepared (Alexander, 1993).

There are multiple frameworks that can be used to create a risk management plan. I recommend two, Anderson and Woodrow's framework, and Soby, Simpson and Ivey's framework. Anderson and Woodrow's framework is very user friendly, and can be applied pre-emptively to a hazard. In their framework, the material, environmental, social and economic vulnerabilities and capacities are identified, so that vulnerabilities can be decreased and capacities increased.

A vulnerability is an item which is susceptible to a disaster, or plays a role in weakening the area of interest, for example a low laying coastal area. A capacity is a strength, or a way to decrease the risk to the area of interest, for example a large environmental fund. Anderson and Woodrow's framework shows managers where weaknesses (vulnerabilities) and strengths (capacities) are so that the weaknesses can be strengthened. The framework can also be used to show progress if vulnerabilities are reduced over time by comparing the framework over multiple years (Anderson and Woodrow, 1989). Time and scale are also very important aspects in risk management, and must be considered during the overall analysis (Alexander, 1993).

Additionally Soby, Simpson and Ivey's framework for risk management is also very good (1993). Like ICM it is integrated, cyclic—feeding into itself with constant evaluation, and encourages the use of policy to address issues. The Soby, et al, framework is divided into five stages with a central "communication" step joining all stages together, figure 3. 4. Soby, et al's, framework starts with (1) hazard identification and risk prioritization, then moves to (2) risk assessment including risk characterization, then (3) policy decision, then (4) policy implementation, and finally (5) policy evaluation, which then feeds back into (1) hazard identification and risk prioritization (1993). The Soby, et al, framework is beneficial because it provides a framework to address the entire risk management cycle.

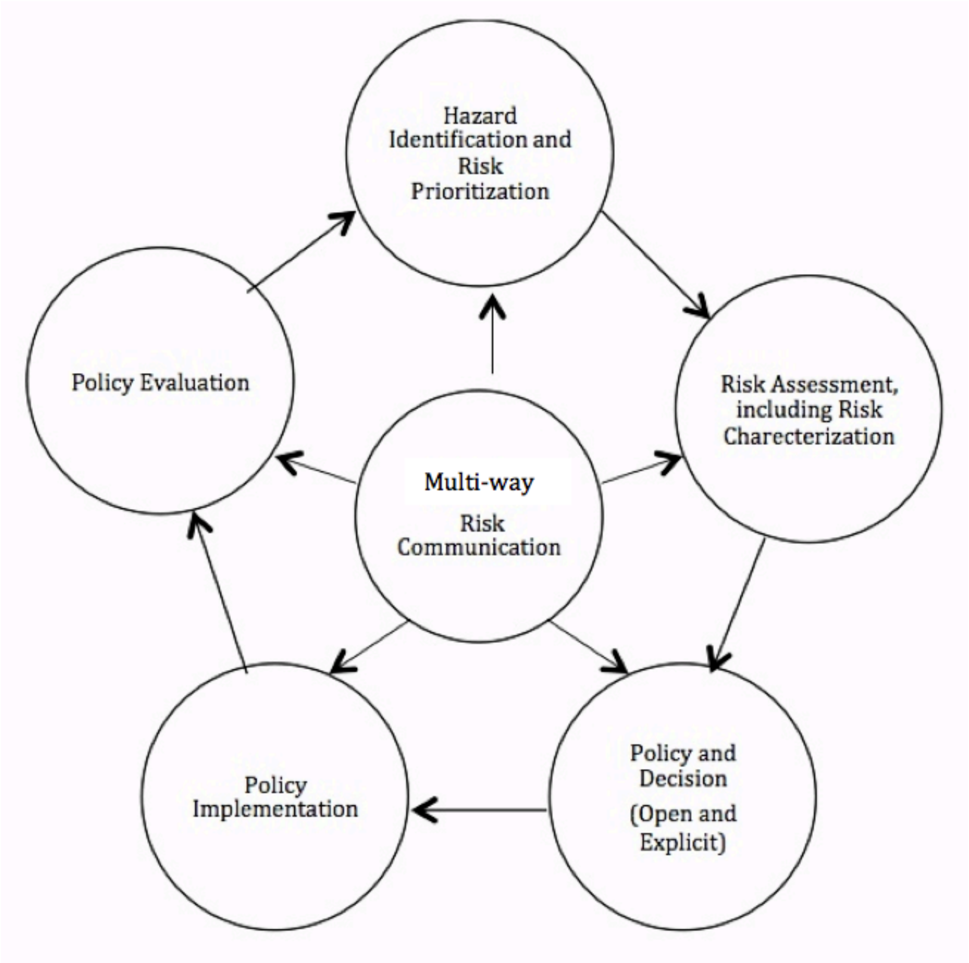


Figure 3. 4. Soby, Simpson and Ivey's Risk Management Framework. Figure shows the cycle proposed in Soby, et al's risk management framework. (Source: Soby, et al, 1993).

3.3.3 Step 3- Implementation.

Implementation is the process of activating the management plan. Depending on the complexity of the plan this can take days, weeks, months or years. Implementation is crucial for the plans success; if the plan is never initiated then its benefits are never actualized (Kay and Alder, 2005). At this point in time there are limited recommendations that can be provided for implementation, as the plan itself has not been created. However, there are some generic recommendations and guidelines, which can be given to help with overall implementation of a plan.

As mentioned previously it is very important for the management plan to include an implementation plan, including a timeline for implementation milestones (Cicin-Sain, 1998; Kay and Alder, 2005). Implementation usually requires new laws, management boards, jobs, and other items, which take time to establish. These particularly need to be outlined in the management plan's implementation plan.

It is also important for those who made the plan to be involved in its implementation. Those involved in drafting the plan have a better understanding of it's strategies and desired goals; they will understand how implementation is targeting the objectives and be better positioned to make adjustments (Kay and Alder, 2005). It is also important for implementation to be fully supported by the government and key stakeholders (Cicin-Sain and Knecht, 1998; Meltzer, 1998).

It is important to make sure that implementation is integrated. Important questions to be addressed include: does implementation address all temporal and spacial aspects of the plan (Kay and Alder, 2005)? Is it horizontally integrated—are all stakeholders involved and aware? Is it vertically integrated—do governments, organizational leaders, employees and volunteers know what is expected of them (Meltzer, 1998)?

Education, community involvement, training and stakeholders are all vital to implementation success (Kay and Alder, 2005; Meltzer, 1998; Moffat, 1998). Communication strategies should consider the education level and cultural differences between stakeholders and community members (Moffat, 1998). Overall, the more the community is engaged, and feel included in the project, the more success it usually has (Meltzer, 1998).

Finally, it is common for new legislation to be drafted during implementation to address the drivers of the issue from a policy level (Cicin-Sain and Knecht 1998; Kay and Alder, 2005, Meltzer, 1998). If new legislation is drafted it too should also be integrated. However, policy integration is different than ICM integration. Underdal defines policy integration as being comprehensive, aggregated and consistent (1980). Comprehensive refers to the scope; time, space, issue and actors, of the policy. For a policy to be comprehensive it must adequately address all of these factors individually. Aggregated refers to the policies comprehensiveness, do the individual factors—scope: time, space, issue, actors—connect to each other, does the policy effectively address its goals from a big picture point of view? Does the law successfully address the overall issue? Finally consistency "is the law in harmony with itself" is the law synchronous vertically, and horizontally? (Underdal, 1980, p. 161).

3.3.4 Step 4- Monitoring and Evaluation.

As stated previously ICM is cyclic, with constant room for improvement. Monitoring and evaluation mechanisms must be incorporated into the management plan so that the plan can be adjusted to achieve its strategic goals. (Cicin-Sain and Knecht, 1998; Kay and Alder, 2005). Monitoring and evaluation should begin during implementation as parts of the plan are activated (Cicin-Sain and Knecht, 1998), and should continue indefinitely to monitor progress for environmental, economic and/or social conditions (Meltzer, 1998).

Monitoring and evaluation is the longest stage of ICM, as it usually begins when the plan is being created—to gather background data—and continues into the future well past the plans implementation (Kay and Alder, 2005). The evaluation of monitoring data and indicators is important. Without evaluating the plans results "honestly" you cannot know if it is working, (Burroughs, 2011 pp. 26) and doing what it was designed to do (Kay and Alder, 2005). Furthermore, the management plan must also be flexible so that necessary changes can be incorporated (Moffat, et al, 1998).

Monitoring and evaluation of an ICM plan can be done in a different ways. Two potential ways are to monitor objectives or needs. Objective based monitoring compares the plan's results to its strategic objectives to determine if it is meeting the desired goals. Needs based monitoring compares monitoring results to specific needs; such as the needs of a stakeholder or a sensitive ecosystem, to see if the plan is satisfying the desired requirements. (Kay and Alder, 2005).

It is important for the indicators used during monitoring to be connected to the final goals of the plan. If the indicators are not aligned then important signs demonstrating if the plan is working or not could be missed. It is also important for indicators to be easily used and verified. If the monitoring mechanisms are too complex to understand than assumptions about the plans success cannot be made. Finally it is important to make sure that the crew in-charge of monitoring are qualified and capable of collecting and analyzing the desired data (Moffat, et al, 1998). The type of evaluation and subsequent indicators used for the management plan will ultimately depend on the plan itself. (Kay and Alder, 2005).

Monitoring is also an important part of waste management best practices. Landfills around the world follow government established guidelines and standards to evaluate its impacts on the surrounding environment (Tammemagi, 1999; Williams, 2005). The European Union legally requires landfill monitoring to include ground and surface water sampling [which is currently done at the GTLF], landfill gas volume and composition monitoring, leachate volume and composition monitoring, and on occasion atmospheric data: precipitation, wind, and temperature monitoring (Williams, 2006). Settling rates of the landfill are also routinely monitored (Tammemagi, 1999).

At this point in time very few recommendations can be provided since a plan has not been created. However, I can recommend that monitoring considers;

- Environmental, economic and social data related to the management plans objectives be collected regularly, and evaluated against a pre-determine criteria.
    - Environmental monitoring mechanisms for the management plan are integrated with waste management landfill monitoring best practices.
- The evaluation of monitoring data be performed regularly and consistently to ensure the plans is successful.

- Training programs are established to improve and maintain monitoring techniques used, and to train new staff (this should be considered during implementation).

CONCLUDING REMARKS

In conclusion the GTLF is an environmental and social hazard for the Cayman Islands. This desktop study outlined its environmental and operational vulnerabilities, and looked at preliminary data that suggests contamination is occurring. However, the GTLF does not appear to be causing major environmental or social issues yet.

A disaster or significant event from contamination is a serious and very real possibility, which can be avoided if we act preemptively; using the precautionary approach. By addressing these vulnerabilities sooner, rather than later, the Cayman Islands environment can remain pristine, saving money down the road. Many organizations and governments are acting preemptively, predicting and mitigating hazards (Alexander, 1993; Kay and Alder, 2005). The Cayman Islands Government should be no different. Changing human behavior is more sustainable, and cheaper than changing the environment (Alexander, 1993). Let us take this opportunity to prioritize our environment and health now, before it becomes a crisis.

EXECUTIVE SUMMARY

Grand Cayman, the largest of the three Cayman Islands, has an unlined, uncovered, unengineered landfill—George Town Landfill [GTLF]. Visual discoloration of the North Sound near the GTLF, paired with operational and geographic vulnerabilities caused concern that the GTLF is contaminating the North Sound. No one has studied the GTLF's impact on the surrounding ecosystems since 1992, warranting the need for a study. This report aimed to fulfill that need by evaluating the GTLF in three parts. 1. Grand Cayman and the GTLF's geographic and operational vulnerabilities were outlined. 2. Environmental data; groundwater, surface water, marine water, tissue sample and sediment data, were analyzed to determine if contamination was actually occurring. 3. Management recommendations using Integrated Coastal Management were provided.

CHAPTER 1: VULNERABILITIES

Grand Cayman is a flat, low-lying island, with an average elevation of 1.7m (5.8ft) above sea level. Most of the island is formed of limestone sediment ($CaCO_3$), which is porous, allowing surface water to percolate down and groundwater tables to form. Grand Cayman's water table is high, sitting on average at 0.5m (1.5ft) above sea level. Its high placement means there is minimal filtration of water, allowing contamination in surface water to percolate down into groundwater easily. Furthermore the water table is tidal, indicating a marine connection, allowing contaminants to mix with the North Sound, creating a pathway for transportation.

Grand Cayman has a wet season and a dry season. The wet season, from June 1-Nov 30 is frequently visited by tropical storms and hurricanes. Storms aid contaminant migration. Grand Cayman's low elevation makes it vulnerable to storm surge, which can bring contaminates directly into the ocean. Additionally, rain spreads contaminants on the surface, and brings contaminants down into groundwater as water tables recharge after significant rain events.

The GTLF was developed out of need for a government run waste management facility to accommodate the needs of a fast growing population. In 1972 the Cayman Islands government approached George Seymour to temporarily use his land as a government operated landfill. Seymour agreed, and government operations began, and continue on the same site today. The Department of Environmental Health is currently responsible for managing and operating the GTLF. The department is also the regulatory body for waste management, creating a conflict of interest as they both operate and regulate the GTLF.

The GTLF is located approximately 1 km from the coast and is surrounded by tidal canals. Like the rest of Grand Cayman it is situated on the Limestone formation with a groundwater table under it, at a depth of 0.6m. The groundwater under the GTLF is brackish and thought to move to the North Sound at a rate of 3.7 m a day, providing a direct pathway for contaminant migration.

This is supported further by the fact that the landfill is not lined. The landfill was never lined when the government began using the site in 1972, and remains unlined today. This is against best practices as it allows leachate to seep down into groundwater, and flow into surface water creating multiple pathways for contaminant transport. Furthermore the landfill is not covered by soil, does not collect landfill gas, has no site or closure plan, and has no storm-water management plan, all of which aid in contaminant migration and goes against US and UK best practice recommendations. The GTLF would be closed if operated in one of those countries today.

CHAPTER 2: DATA ANALYSIS

Surface water and groundwater data was collected from the Department of Environmental Health. Groundwater analysis revealed that arsenic, boron, iron, lead, phosphorus, sulfate and total dissolved solids were present in groundwater above Miami-Dade County Groundwater Quality Criteria limits. Close analysis of groundwater results revealed that results were marginally higher at wells closer to the landfill area, and lower on the periphery of the GTLF site. This indicates that contaminants are naturally attenuating.

Surface water analysis revealed that arsenic, chromium, copper, cyanide, iron, lead, nickel, phosphorus, vinyl chloride and zinc were present in surface water above Miami-Dade County Marine Water Criteria limits in 2010 and 2011. However, no analytes were detected over threshold limits in 2013. Surface water contaminants are also thought to be naturally attenuating as they move away from the active landfill area; as wells closer to the active landfill site had higher results than wells on the periphery of the GLTF property. Phosphorus is the contaminant of most concern as it was the only analyte present in surface water sample sites directly connected to the North Sound. Note that, ground and surface water testing was inconsistent between years, with different wells and analytes tested in 2010, 2011, and 2013. Further testing is needed to fully understand the extent of ground and surface water contamination.

Tissue Sample analysis found no PCB Organics in any biological tissues, however metals were found in multiple samples. Green Algae tissue samples had iron, copper and zinc present, at levels higher than baseline site comparisons. Turtle Grass samples had zinc higher than baselines, and two of three samples with copper and iron higher than baselines. Red mangrove samples had iron and zinc results higher than baselines. Sea Sponge samples had copper, iron, mercury and zinc results higher than baselines, and chromium higher than one baseline, but lower than the second. In summary, tissue sample analysis revealed that there are increased levels of metals in the biological tissues near the GTLF when compared to baselines. However further testing is needed—with a larger range of analytes, and a broader range of phyla—to fully understand effects.

Marine water quality testing in the North Sound showed that there were abnormalities in the water near the GTLF. Bacteriological analysis showed that Enterococci and Faceal Coliform were higher near the GTLF than compared to baseline sites. There was reduced salinity near the GTLF; and higher dissolved oxygen saturation when compared to baselines. There was a large increase in suspended solids near the GTLF, when compared to baseline. And finally, higher nitrate-nitrite and reactive phosphate levels than baselines. Abnormal marine water quality near the GTLF causes concern for sea grass beds, which are an important ecosystem that can easily be outcompeted by macro-algae and epiphytes.

A semi-quantitative sediment analysis revealed that there are elevated quantities of metals in the North Sound's sediment near the GTLF. Chromium, thorium and iron had higher readings in the canal north of the GTLF than other North Sound baseline comparison sites. However as values are only semi-quantitative further testing, with more sensitive methods, is required to fully understand metal concentrations in the North Sound's sediment.

Overall results provided evidence that the GTLF is contaminating the North Sound, but contamination is not at ecosystem threatening levels. Further analysis is needed to completely understand the extent and effects of contamination so that proper management can be implemented to reduce negative impacts.

CHAPTER 3: RECOMMENDATIONS

Due to the potential for contamination outlined in Chapter 1 and evidence that contamination is occurring, in Chapter 2, it is recommended that Integrated Costal Management [ICM] be implemented to reduce potential and actual sources of contamination. This should be done with the intention of protecting Grand Cayman's coastal and marine resources.

ICM in a cyclic, forward thinking management framework with four main stages.

1. Stage 1- Implementation: the need for a management plan is identified, background information using the DPSIR analysis is collected, the problem is scoped, stakeholders are engaged.
2. Stage 2- Planning: the management plan is created. The plan should address the initial drivers, which led the management issue. Short and long term plans are created to address short term needs and long term strategies. Plans for

implementation, and monitoring and evaluation, the next two stages, are also created at this time.

3. Stage 3- Implementation: the management plan is activated, according to the plan created in Stage 2. This is arguably the most important stage of ICM.
4. Stage 4- Monitoring and evaluation: monitoring mechanisms are established to evaluate the plans success. Monitoring and evaluation is done to insure that the plan is achieving its strategic goals and desired outcomes. If evaluation indicates that the plan is not meeting its goals then the management plan should be adjusted to rectify the gap in outcome.

The key themes of ICM are integration: temporal, spatial, horizontal, and vertical, and stakeholder and community involvement.

My recommendations for applying ICM to the GTLF follow. During implementation I recommend that more information is collected. At this point in time not enough is known about the social, health and economic impact of the landfill, which must be learned to fully understand and manage it. Secondly more environmental data is also needed. The data collected and analyzed in Chapter 2 provides a baseline, but is not comprehensive enough to create a management plan.

For planning I recommend that a short term plan, focusing on reducing contaminant migration and improving the GTLF's management practices; and, a long term plan focusing on improving Cayman's overall waste management practices are made. These plans should incorporate current international waste management best practices. Additionally a risk management plan for fires and storms should be created to improve preparedness for significant events.

For implementation I recommend integration and stakeholder engagement be prioritized. I recommend that proper time and attention is given to implementation. I also recommend that any policy drafted for the management plan follow Underdal's guidelines for policy integration.

For monitoring and evaluation I recommend that social, environmental and economic sectors are monitored. Monitoring devices should incorporate waste management and landfill monitoring best practices. Finally, monitoring data should be evaluated against the plan regularly and consistently to make sure the plan is performing the way it was intended to. The management plan should be adjusted when needed.

In closing Cayman has the opportunity to act preemptively, and protect its coastal and marine resources before contamination reaches toxic or ecosystem threatening levels.

Acting preemptively saves money on mitigation after events, and keeps Cayman's environment pristine.

LITERATURE CITED

CAYMAN ISLANDS LAWS

National Conservation Law EG 9/ 2014 S 1 (2014).

Public Health Law; Garbage and Refuse G. 26/ 2011 S 14 (2011).

Public Health Law; Infections Waste Regulations G.12/2002 S 14 (2002).

Waste Water Collection and Treatment Law G.4/2011 S 3 (2011).

USA REGULATIONS

Miami- Dade County Environmental Protection Ordinance. Ord. No. 04-214, §§ 1, 5, (2004). [Previously called: Environmental Protection, Biscayne Bay and Environs designated Aquatic Park and Conservation Area, the Biscayne Bay Environmental Enhancement Trust Fund, and the Environmentally Endangered lands program, FL Miami-Dade Code, Chapter 24, Article III, Division 3, Section 24-44.2] Retrieved from http://www.miamidade.gov/environment/library/guidelines/ordinance-ch-24.pdf

Protection of the Environment, 40 C.F.R § 258.50-258.59 (1993).

ALL OTHER WORKS CITED

Alexander, D. (1993). *Natural Disaster*. New York: Chapman and Hall.

Anderson, M., and Woodrow, P. (1989). *Rising From Ashes*. Paris: UNESCO and Westview Press.

Baseado, J. (1999). Vision 2008; National Strategic Plan 1999-2008. Cayman Islands Government.

Brunt, M.A., and Davies J.E (Eds.). (1994). *The Cayman Islands: Natural History and Biogeography.* Netherlands: Kluwer Academic Publishers.

Bubb, Hayley. (2013). *Talking Trash* (unpublished B.Sc Honors project). University of Reading, College of Estate Management, UK.

Burroughs, R. (2011). *Coastal Governance*. Washington: Island Press.

CardnoENTRIX (2013) Grand Cayman Waste Management Facility: Draft Environmental Statement. Cardno Entrix and Dart Cayman Islands, April 2013. Retrieved online: http://www.forcayman.com/documents&pid=22

Cayman Islands Government [CIG]. (2005). *History*. Retrieved from http://www.gov.ky/portal/page?_pageid=1142,1481082&_dad=portal&_schema=PORTAL

Cayman Islands Government [CIG]. (2011a). *Climate*. Retrieved from http://www.gov.ky/portal/page?_pageid=1142,1481074&_dad=portal&_schema=PORTAL

Cayman Islands Government [CIG]. (2011b). *Location and Geography*. Retrieved from http://www.gov.ky/portal/page?_pageid=1142,1481077&_dad=portal&_schema=PORTAL

Cayman Prepared, Cayman Islands National Emergency Website. (2010). *Hurricane*. Retrieved from http://www.caymanprepared.gov.ky/portal/page?_pageid=3701,6816026&_dad=portal&_schema=PORTAL

CIA World Fact Book. (2014). *Central America and Caribbean, Cayman Islands*. Retrieved from: https://www.cia.gov/library/publications/the-world-factbook/geos/cj.html

Cicin-Sain, B., and Knecht, R.W. (1998) Integrated Coastal and Ocean Management; Concepts and Practices. Island Press, USA.

Dart Reality Cayman Ltd. (2012). *Grand Cayman Waste Management Facility Tissue Analysis [*raw data]. Unpublished.

Department of Environment [DOE]. (2013a). *North Sound Water Quality Averages 2010-2013* [raw data]. Unpublished.

Department of Environment [DOE]. (2013b). *North Sound Water Quality, Minimums, Maximums and Standard Deviations* [raw data]. Unpublished.

Department of Environment [DOE]. (2014). *National Conservation Law; Questions Answered*. Retrieved from: http://www.doe.ky/laws/national-conservation-law/

Department of Environmental Health [DEH]. (2014). *George Town Landfill Groundwater and Surface Water Quality Monitoring Data 2010, 2011, 2013* [raw data]. Unpublished raw data. Retrieved from Antoinette Johnson, Lab Manager at DEH.

Economics and Statistics Office, Cayman Islands Government [ESO]. (2011*). 2010 Census of Population and Housing Report*. November 2011. Retrieved from http://www.eso.ky/UserFiles/page_docums/files/uploads/docum436.pdf

Google Earth. (2014). Google Earth (version 7.1.2.2041) [computer software].

Harter, T., and Rollins, L. (Eds). (2008). *Watersheds, Groundwater and Drinking Water: A Practical Guide*. California: University of California Agriculture and Natural Resources.

Hayes, R. (2012). *North Sound, Grand Cayman XRF Sediment Analysis* [raw data]. Unpublished.

Hurlston-Mckenzie, Lisa-Anne. (2011). *Climate Change Issues for the Cayman Islands: Towards a Climate Change Policy, 2011* (Technical Report of the National Climate Change Committee). Retrieved from National Trust [Cayman Islands] Archives.

Jones, Brian. (n.d.) *The Geological Development of the Cayman Islands Over the Last 30 million years*. Department of Geology, University of Alberta, Edmonton, Alberta.

Jones, Brian. (2000). *Geology of the Cayman Islands*. Department of Geology, University of Alberta, Edmonton, Alberta.

Kay, R., and Alder, J. (2005). *Coastal Planning and Management*. London and New York: SPON press.

McAlister, I. (2004). From Disaster Relief to Modern Peace Building: Introductory Perspectives, In *Through a Glass Darkly: From Disaster Releif to Modern Peace Building (pp. 5-27)*. Cornwallis Park: Canadian Peacekeeping Press.

Meltzer, E. (ed.). (1998). International Review of Integrated Coastal Zone Management: Potential Application to the East and West Coasts of Canada. Canadian Technical Report of Fisheries and Aquatic Sciences 2209. Retreived from Department of Fisheries and Oceans, Canada. Retrieved from http://www.dfo-mpo.gc.ca/Library/253987.pdf

Mihelcic, J.R., and Zimmerman, J.B. (2010). *Environmental Engineering: fundamentals, sustainability, design.* New Jersey: John Wiley & Sons, Inc.

Ministry of District Administration Works, Lands, and Agriculture, Cayman Islands Government [CIG]. (2010). *Comprehensive Solid Waste Disposal Management and Waste to Energy Facility.*

Ministry of Health Sports, Youth and Culture [MHSYC], Cayman Islands Government. (2014). *Strategic Outline Case: Integrated Solid Waste Management System*. 24th April, 2014. Retrieved from: http://www.ministryofhealth.gov.ky/press-room/press-releases/20140523/waste-management-doc-now-public

Moffat, D., Ngoile, M.N., Linden, O., and Francis, J. (1998). The reality of the stomach: coastal management at the local level in eastern Africa. *Royal Swedish Academy of Sciences; Ambio*: 27 (8) 590-598.

National Weather Service, Cayman Islands Government. (2014). *Climate*. Retrieved from http://www.weather.gov.ky/pls/portal/url/page/nwshome/climate/rainfall

Pan American Health Organization. (2003). Regional Evaluation Municipal Solid Waste Management Services; Country Analytical Report; Cayman Islands Evaluation, 2002. October 2003.

Post, Buckley, Schuh & Jernigan. (1992a). *Environmental Assessment of Grand Caymans Sanitary Landfill, Grand Cayman, B.W.I*. Cayman Islands Government Department of Health and Social Services, Environmental Health Section, May 1992.

Post, Buckley, Schuh & Jernigan. (1992b). *Solid Waste Management Plan, Grand Cayman Island, BWI*. Cayman Islands Government Department of Health and Social Services, Environmental Health Section, September 1992.

Soby, B.A., Simpson, A.C.D., and Ives, D.P. (1993). *Integrating Public and Scientific Judgements into a Tool Kit for Managing Food-Related Risks, Stage 1: Literature Review and Feasibility Study*. Research Report No. 16, Environmental Risk Assessment Unit. Norwich: University of East Anglia.

Seymour, G. (1972). *Letters*. [Private letters between George Seymour and the Cayman Islands Government discussing land use for waste management]. Central Registry (File: Heal/Pub/3). Cayman National Archives, Grand Cayman.

Sterr, H., and Maack, S. (2010). Attempting ICZM in the Baltic Green Belt. In *Proceedings of the 2nd Baltic Green Belt Forum; Towards Sustainable development and the Baltic Sea Coast*, *Palanga, Lithuania*, *13-16 April 2010 (pp. 274-280)*.

Tammemagi, H. (1999). The Waste Crisis: Landfills, Incinerators, and the search for a sustainable future. New York: Oxford University Press.

Terry-Swaby, D. (2014). Various unpublished images. Decco, Dart Enterprises; Grand Cayman. Unpublished.

Test America. (2011). *Methods Summary; for Job ID: 680-73249-1. Project/Site: Georgetown Landfill Monitoring*. Retrieved from the Cayman Islands Department of Environmental Health.

Total Access (version 4.0) [computer software]. Grand Cayman: Department of Environmental Health

Townsend, D. (2012). *Oceanography and Marine Biology; an introduction to Marine Science*. MA, USA: Sinauer Associates Inc. Publishers.

Underdal, A. (1980). Integrated Marine Policy; what why how? *Marine Policy*, 4(3) 159-169

United States Geological Survey [USGS]. (2014). *The USGS Water Science School; Sinkholes*. Retrieved from http://water.usgs.gov/edu/sinkholes.html

Waste Disposal Options Review Committee. (2003). *Interim Report for the Management Collection, Treatment and Disposal of Municipal Solid Waste, in the Cayman Islands* (2nd e.d). Cayman Islands Government.

Weinstein, M.P., Baird, R.C., Conover, D.O., Gross, M., Keulartz, J., Loomis, D.K., Naveh, Z., Peterson, S.B., Reed, D.J., Roe, E., Lawerence Swanson, R., Swart, J.A.A., Teal, J.M., Turner, R.E., and van der Windt, H.J. (2007). Managing coastal resources in the 21st century. *Frontiers in Ecology and the Environment,* 5(1), 43-48.

Williams, P. (2005). *Waste Treatment and Disposal* (2nd ed.). Sussex England: John Wiley & Sons, ltd.

Winker, C. (21 May 2013) How the George Town Dump Came to Be; Rubbish was used to fill swamp. *Cayman Compass*. Retrieved from http://www.compasscayman.com/caycompass/2013/05/21/How-the-George-Town-dump-came-to-be/