Fiji Islands' Naboro Landfill Leachate Quality Analysis and the Applicability of Developed versus Small Island Developing State Discharge Standards

By

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This report "Fiji Islands' Naboro Landfill Leachate Quality Analysis and the Applicability of Developed versus Small Island Developing State Discharge Standards" is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

Civil and Environmental Engineering

Master's International Program

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Preface

The motivation for this research came out of my experience while serving as a Peace Corps Volunteer for 24 months in Fiji from August 2007 to July 2009. I worked as an officer in The Fiji Department of Environment in the capitol city of Suva, Fiji. My role was to assist their Waste and Pollution Control Unit in overseeing the operations of the Naboro Landfill while also building capacity amongst the Unit in the field of solid waste management.

This report is submitted to complete my master's degree in Environmental Engineering from the Master's International Program in Civil and Environmental Engineering at Michigan Technological University. This paper is a product of research done to determine if any information was available on landfill leachate management in tropical climates, typical leachate characterizations, corresponding leachate constituent range of values, and standards for discharge into surface water bodies in various countries around the globe.

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Thank you to my lovely family and friends who helped me to remain positive and upbeat even during the most frustrating of times. Also, I'd like to acknowledge the tireless ladies of the Waste and Pollution Control Unit at the Department of Environment in Fiji who work so hard for the betterment of Fiji's environs. They were great co-workers and friends that will not be soon forgotten.

Thank you to Mark and Reshma Hirst who welcomed me onto their sailboat many weekends in Suva for some much needed time to appreciate my surroundings. I'd like to say vinaka sa vakalevu to the Fiji Islands women's softball team in Suva for allowing me to participate in their wonderful organization and feel a part of the Fijian culture.

Last but not least, to my phenomenal Peace Corps Fiji Volunteers whom I had the pleasure of serving alongside and kept me going on a daily basis. Loloma yani vei iratou na PCVs.

Abstract

The characteristics of leachate can vary widely due to a number of site specific factors. The manner in which the resulting leachate is collected, treated, and released are a function of the initial water quality, the design of the overall landfill area, and the desired or regulated effluent water quality standards. (Johannessen, 1999) The standards to which leachate must adhere for landfills within developed nations have all been established by the extensive research performed on solid waste compositions, landfills in general, and the subsequent leachate studied over the past century in these countries. However, for landfills built within developing nations, such as Fiji, comparatively little research has been performed in order to justify any sort of criteria for leachate effluent and the necessary treatment required to reach those levels. Consequently, the leachate standards that have been set by the few developing nations with the funding to build engineered landfills have been based on developed world standards. Yet, site specific factors that characterize the initial leachate produced are for the most part drastically different in developing nations from that seen amongst the developed nations; in particular, waste composition and climate. Furthermore, the leachate treatment systems available to developing nations are generally more constrained due to financial limitations for installation as well as operation, maintenance, and monitoring of these systems.

A number of leachate quality sampling events have been performed on the leachate treatment train since the start of operations. The objectives of this research report are to compile all leachate quality analyses performed on Naboro Landfill leachate treatment system since the commencement of operations and compare to leachate analyses performed in the developed world; analyze and compare leachate sampling results recorded for Naboro Landfill with

established standards and values set for leachate being discharged into a surface water stream; and determine if the leachate quality achieved at Naboro Landfill, or any other future landfills located in a similar climate and waste composition, should be required to meet the same standards of water quality as landfills in developed countries.

The Naboro Landfill leachate data used for this research was minimal, with only five sampling events, as well as inconsistent in the constituents tested. In comparing the overall strength of the initial leachate produced at Naboro Landill, pH, TDS, Ammonia, BOD and COD were compared to a range of values observed in developing countries' leachate. The leachate being generated at Naboro Landfill is considered to be weak relative to other countries which is likely a result of the dilution factor provided by the high annual rainfall. When applying the United States Environmental Protection Agency's effluent limitations guidelines for the landfills point source category and Fiji Regulations for National Liquid Waste Standards to Naboro's effluent leachate, it was found that both standards were unattainable for the current effluent concentrations being reported at Naboro.

Chapter 1 Title Introduction and Background

1.1 Introduction

"One of the most important issues related to siting, planning, design, operation, and long-term management of a municipal solid waste (MSW) landfill is the management of leachate."

Lars Mikkel Johannessen

Leachate is a type of wastewater produced from liquid percolating through a body of solid waste. It is a product of two sources of moisture; the first being from moisture intrinsic to the discarded solid wastes, such as organic food scraps, and the second being from moisture introduced after the final disposal of wastes, i.e. precipitation. The characteristics of leachate can vary widely due to a number of site specific factors which include but are not limited to: geography, climate, geology, landfill design, waste composition, and operational aspects such a compaction, cover, and stormwater control measures. The manner in which the resulting leachate is collected, treated, and released are a function of the initial water quality, the design of the overall landfill area, and the desired or regulated effluent water quality standards (Johannessen, 1999).

The standards to which leachate must adhere for landfills within developed nations such as the United States, Canada, Australia, New Zealand, or Western European countries, have all been established by the extensive research performed on solid waste compositions, landfills in general, and the subsequent leachate studied over the past century in these countries. However, for landfills built within developing nations, comparatively little research has been performed in order to justify criteria for leachate effluent and the necessary treatment required to reach those levels. Consequently, the leachate standards that have been set by the few developing nations with the funding to build engineered landfills have been based on developed world standards. Yet, site specific factors that characterize the initial leachate produced are for the most part drastically different in developing nations from that seen amongst the developed nations; in particular, waste composition and climate. Furthermore, the leachate treatment systems available to developing nations are generally more constrained due to financial limitations for installation as well as operation, maintenance, and monitoring of these systems.

In an effort to supplement the existing information on landfill leachate quality in developing nations, information and data was collected on the Naboro Landfill, located in the Republic of the Fiji Islands of the South Pacific. The motivation and ability to collect information and data on the Naboro Landfill was conceived while the author served as a Peace Corps Master’s International Volunteer in Suva, Fiji from August 2007 to July 2009. The Master’s International Program allows students to conduct the research portion of a Masters Degree while serving as a volunteer in the Peace Corps. The Fiji Department of Environment requested a volunteer to assist their Waste and Pollution Control Unit (WPCU) in overseeing the operations of the Naboro Landfill while also building capacity amongst the Unit in the field of solid waste management.

While providing this service to the WPCU, a literature review was undertaken to determine if any information was available on landfill leachate management, typical leachate characterizations, corresponding leachate constituent range of values, and water quality standards in developing countries. The criteria for comparison were sanitary landfills of developing nation status operating within tropical climates similar to that characterizing Naboro. Specifically, any data not meeting the rainfall volume of at least 75% of Naboro's average 4.0 meters or a waste composition as high in organic materials as Naboro Landfill (nearly 85%) were not considered as an appropriate comparison. As a base for global comparison, the same leachate information was searched for developed countries. Scientific journals and reports from accredited sources such as World Bank and United Nations were searched and reviewed. Little information or data was found regarding typical landfill leachate compositions for developing nations and the corresponding levels of treatment needed to be met before discharging the leachate into a surface water stream.

Fiji is also considered a Small Island Developing State. According to the Small Island Developing States Network, Small Island Developing States (SIDS) are "small island and low-lying coastal countries that share similar sustainable development challenges, including small population, lack of resources, remoteness, susceptibility to natural disasters, excessive dependence on international trade and vulnerability to global developments. In addition, they suffer from lack of economies of scale, high transportation and communication costs, and costly public administration and infrastructure." Management of municipal solid waste presents one such challenge.

1.1.1 Objectives of Research

The objectives of this research are to:

- Compile all leachate quality analyses performed on Naboro Landfill leachate treatment system since the commencement of operations and compare to leachate analyses performed in the developed world;
- Analyze and compare leachate sampling results recorded for Naboro Landfill with established standards and values set for leachate being discharged into a surface water;
- Determine if the leachate quality achieved at Naboro Landfill, or any other future landfills located in a similar climate and waste composition, should be required to meet the same standards of water quality as landfills in a developed country such as the U.S.

The following report begins with background information on the Fiji Islands and Naboro Landfill in order to understand all the site specific factors lending towards the leachate composition generated at Naboro Landfill. Chapter 2 defines sanitary landfills and describes how the leachate treatment system at Naboro Landfill was formulated and is currently operated. Chapter 3 outlines the method to which the information and data collected was compiled and analyzed. Chapter 4 displays the results of the leachate sampling events. Chapter 5 provides a discussion of the results and Chapter 6 consists of conclusions and recommendations for future research and use of this information.

1.2 Background of Fiji

1.2.1 Geography and Environment

Officially titled The Republic of the Fiji Islands, Fiji is located in the Western South Pacific Ocean and comprises of 332 islands with a total land area of 18,270 km^2; however, just 110 of the 332 are inhabited. The largest and most populated of the islands is named Viti Levu, where the capital city of Suva is situated at 18^o 08’ South, 178^o 25’ East. The terrain of Fiji is mostly volcanic mountains, the highest point reaching 1,324 km, with clusters of atoll islands and islets. Figures 1 and 2 provide maps of Fiji as a region and as a country, respectively.

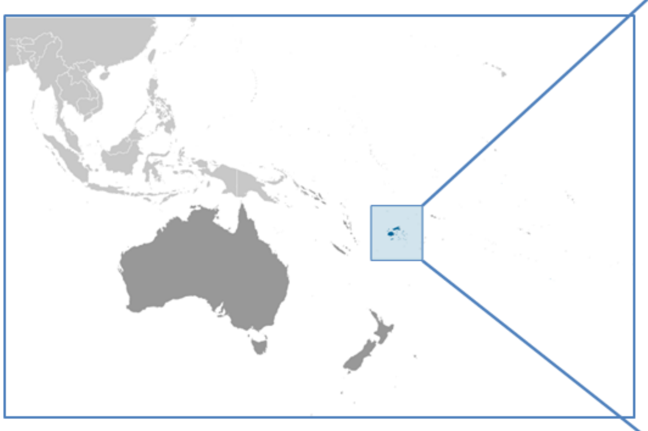

Figure 1: Regional map of Fiji. (CIA, 2009)

Figure 2: Country map of Fiji. (CIA, 2009)

Fiji’s climate is tropical marine with slight seasonal temperature variation; the average low temperature being 18^{o}C during the months of July and August and the average high being 32^{o}C during the months of January and February. Fiji experiences two seasons, wet (November to April) and dry (May to October), and is susceptible to a number of natural hazards including cyclones, earthquakes, tsunamis, floods, and droughts. Annual rainfall in the dry regions average around 2.0 m, whereas in the wet regions, the annual rainfall will range from 3.0 m around the coast to 6.0 m on the mountainous areas. The smaller islands receive various amounts according to their location and size but will generally range between 1.5 m to 3.5 m (Fiji Meteorological Service, 2009).

Arable land covers approximately 11%, permanent crop land only 4.6%, and the remaining land uses, classified as other, at 84.4% as of 2005; and Fiji's natural resources include timber, fish, gold, copper, offshore oil potential, and hydropower (CIA, 2009).

1.2.2 Demographics

The population of Fiji for 2009 is estimated to be 944,720 with a growth rate of 1.4% and net migration rate of -0.3%. The life expectancy at birth is 70.7 years with the median age of the population being 25.5 years. In 2008, 52% of the total population lives within urban centers and the estimated urbanization rate is 1.6% (CIA, 2009). The ethnic distribution of Fiji in 2007 was as follows: Fijian 57.3% (predominantly Melanesian with a Polynesian admixture); Indian 37.6%; and Rotuman, European, other Pacific Islanders, Chinese, and others 5.1%. English is the official language used in legislation, commerce and education; however, Fijian and Hindustani languages are also widely spoken. The literacy rate (definition: people age 15 and over that can read and write) is 93.7% (CIA, 2009).

1.2.3 History

It is believed that thousands of years ago, Melanesians probably from Indonesia, first settled Fiji; followed by a smaller group of Polynesians around 100 A.D. The first recorded

European explorer, Abel Tasman, came in 1643. In 1774, Captain James Cook visited the islands and then throughout the 1800's, Methodist missionaries and escaped Australian convicts settled amongst the islanders. Fijian tribal warfare was common place until Chief Cakobau took over as high chief in 1871 and asked the United Kingdom to include Fiji as a crown colony which was granted in 1874. Fiji remained a British colony for nearly a century (World Book, 2009).

1.2.4 Government and Politics

Fiji gained independence in 1970 with a democratic constitution, after nearly a century as a British colony. The government structure is considered a parliamentary representative democratic republic and consists of three branches. First is the executive branch whereby the President serves as the official Head of State (albeit an honorary role similar to the British monarchy) and is elected by the Great Council of Chiefs with the consultation of the Prime Minister. Actual executive power is in the hands of the Cabinet, presided over by the Prime Minister who obtains this position automatically by being the leader of the political party that controls the majority of the seats in Cabinet. Second is the legislative branch as a bicameral parliament with a House of Representatives and Senate. The third is a judicial branch with a High Court, Court of Appeal, Magistrates' Court, and Supreme Court.

However, this relatively new democracy has been fraught with coup d'états and instability since the late 1980s through today. There were two military coups in 1987 which created a new 1990 constitution that cemented native Melanesian control of Fiji and led to substantial Indian emigration. A new constitution was enacted in 1997 which encouraged multiculturalism and made multiparty government mandatory. Elections in 1999 resulted in a government led by an Indo-Fijian (Fiji citizen of Indian decent), but a civilian-led coup in May 2000 ushered in a prolonged period of political instability. Parliamentary elections held in August 2001 democratically elected a new Prime Minister who was then re-elected in May 2006. Then in a December 2006 military coup led by Commodore Voreqe Bainimarama, the elected Prime Minister was overthrown. Commodore Bainimarama is currently the Interim Prime Minister together with a reduced number of interim ministers (CIA, 2009). When the Fiji Court of Appeals ruled the 2006 coup was illegal in April 2009, the then President abrogated the constitution and reappointed Bainimarama as Prime Minister. The current President is Mr. Epeli Nailatikau and the next elections are slated for the year 2014.

1.2.5 Economy

Fiji relies heavily on their large subsistence sector but has become the economic hub of the South Pacific. Many global and regional companies and organizations have established head offices as well as the University of the South Pacific's main campus in Suva. Sugar exports, remittances from Fijians working abroad, and a growing tourist industry are their major sources of foreign exchange; however, with the political turmoil and inefficient infrastructure particularly with sugar mills, these sources of revenue have suffered loses over the past years (CIA, 2009).

The estimated Gross Domestic Product per capita in Fiji for 2008 was 3,800 USD, down from 4,200 USD in 2006. The most up to date records show the agricultural sector to make up 8.9% of the GDP while industry accounts for 13.5% and the service sector contributes the highest at 77.6% (CIA, 2009).

1.3 Solid Waste Management in the Greater Suva Region

1.3.1 History of Solid Waste Management in Suva

Before the opening of Naboro Landfill, the method of waste disposal was generally localized open dumps around communities. This is the disposal practice still seen in most of Fiji today. The Greater Suva Region includes the following subdivisions: Suva City and Rural Local Authority; Nausori Town and Rural Local Authority; Nasinu Town; Lami Town; and Navua Rural Local Authority. Each of the councils either had individual open dumps or used the City of Suva's very large open dump that operated for more than fifty years before Naboro Landfill opened their gates. Figure 3 shows a map of the Greater Suva Region along with the locations of the various dumps used prior to 2005.

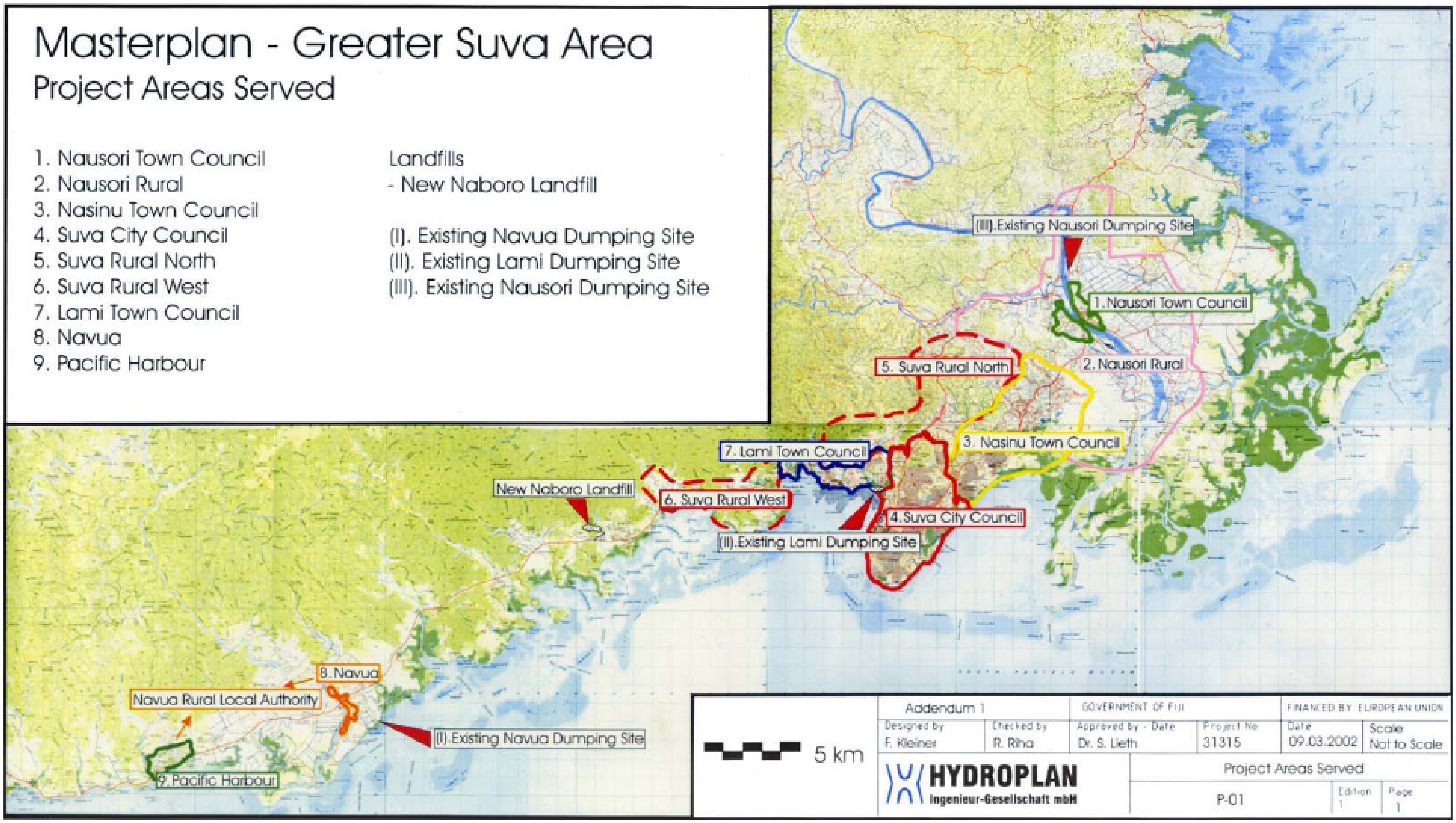

Figure 3: Map of Greater Suva with dump site locations used before 2005 (Hydroplan, 2002).

The Lami dump began operations in 1954 under supervision of the Suva Municipal Council. In 1965 four layers of waste were completed and in 1997 the waste reached a level of 4-6 m above the surrounding terrain. When closed in 2005 the level of the waste reached a height of up to 15 m above the surrounding terrain, covered an area approximately 75,000 m^2, and contained approximately 800,000 tons of mixed wastes. The dump is located on the outskirts of the City of Suva in a swampy area nestled between a large river and a harbor where less than 50% of the original area was above the high water line at the time the dumping of waste started. The soil profile of the area consists of a 6-10 m layer of soft silty sands with some peat on the bedrock. Steep waste slopes fall right down to river and beach. Leachate probably leaks into the marine environment and pollutes both water and sediments. Over the years, the dumpsite was repeatedly on fire, and during the last year of operations, was on fire for at least 5-6 weeks. This caused negative health, environment and social impacts and economic losses to the government. Moreover, the Lami dump is located in a residential area and many children tend to play and swim in the nearby sea and creeks which is why the Fiji Department of Environment has been working towards mitigating these adverse affects by first closing operations and now overseeing a project to rehabilitate the dumpsite (Fiji Department of Environment, 2007).

The planning for a new regional sanitary landfill began in the mid-nineties and the selection of the Naboro site was based on feasibility studies, geological, geotechnical and hydro-geotechnical surveys, and general accessibility conditions. The Naboro Landfill is located approximately 20 km to the west of Suva. The landfill design is based on development of 4 stages in total 31.1 hectares of which Phase 1 (approximately 4 ha) of Stage 1 (7.09 ha) has been constructed and currently in operation. The construction of the Naboro Sanitary Landfill was a multi-million dollar project financed by the European Union (EU). However, the original project budget was reduced and reductions in delivery were made. Substantial technical assistance for environmental impact assessment, design and supervision was also financed from the EU. Since 2005, additional funding was acquired from the Fiji Government to fund the installation of an improved leachate treatment system as well as the construction of the final areas of Stage 1, Phase I (Fiji Department of Environment, 2007).

The design company contracted for the Naboro Landfill project, Hydroplan, performed a waste composition study based on relatively limited information. The Lami dump had a weighbridge for only a short period of time and the records kept are considered to be of doubtful reliability. The breakdown of waste composition for the greater Suva region are given in Table 1; the information was drawn from a variety of sources and assumptions and observations made at the Lami dump (November 2000-April 2001) which was the best approximation available at the time. As a point of reference, Figure 4 illustrates the difference between MSW compositions in developed countries versus developing countries. The waste composition of the Suva region has been superimposed on the graph to compare the findings with those observed around the globe. According to the Hydroplan study, the quantity of domestic waste collected in the greater Suva region is around 91,149 tons in 2004 meaning 379 kg/capita/year. (Watling, 2005) Given this data, the Greater Suva area disposes of nearly 85% organic waste.

Table 1: Waste Composition Generated in the Greater Suva Region (Hydroplan, 2002).

Component	**% by Weight**
Paper cardboard (putrescible free)	16
Putrescible (food, vegetables, market waste, etc)	49.5
Metal (ferrous and non-ferrous)	3.6
Glass	2.5
Plastics	8
Green waste (logs < 150 mm diameter and planks)	9.7
Rubble and fill (brigs, timber, gravel, dirt...)	0.2
Rubber Tires (caoutchouc)	0.1
Timber (> 150 mm diameter and planks)	4
Fiber (cellulose, garments, husks...)	5.5
Hazardous waste	0.2
Others	0.5
Total	**100**

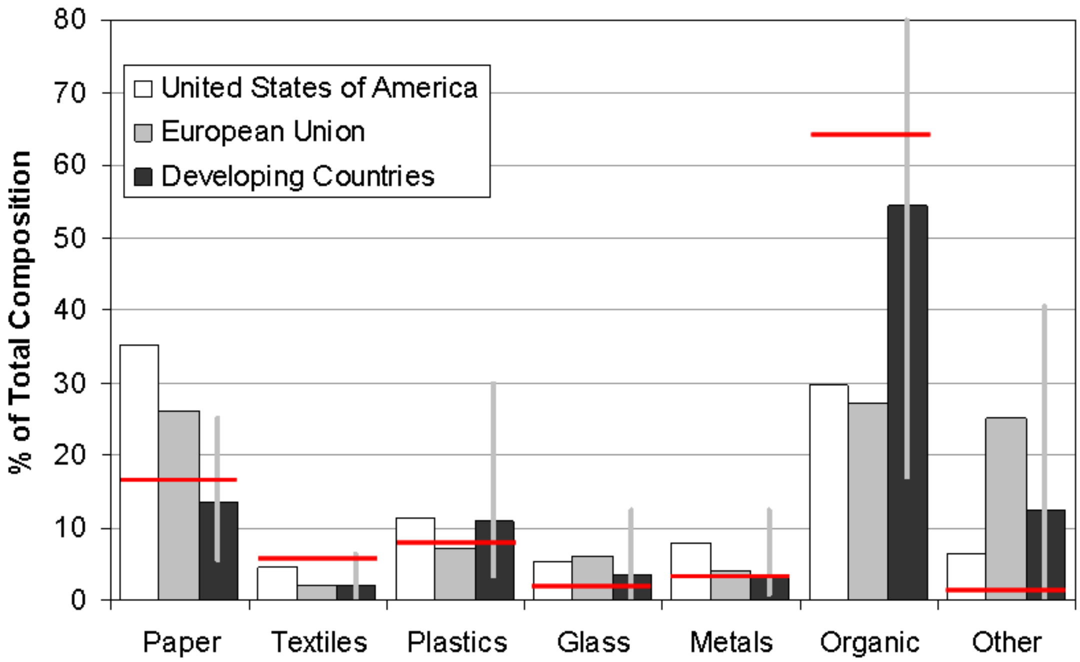

Figure 4: Difference between MSW compositions in developed countries versus developing countries with Suva region values superimposed in red for comparison (Troschinetz and Mihelcic, 2009).

1.3.2 Naboro Landfill

The Naboro Landfill was opened in October 2005 and is operated and managed as a Public-Private Partnership. A solid waste company was contracted by the Fiji Government to operate the landfill; currently H.G. Leach & Co. Ltd, a New Zealand company, is operating Naboro Landfill. HG Leach performs the day to day operations and management of accounts while the Fiji Government (Department of Environment) supervises further development of Naboro Landfill as well as monitors and inspects operations. Fiji has not established their own guidelines and standards for landfill construction or operation but have included in the project contract for the standards to follow the standards set by the country of the contracted operator. Therefore, HG Leach runs the landfill operations in accordance with New Zealand Landfill Guidelines established by the Center for Advanced Engineering (CAE) in 2002. Naboro Landfill only accepts Municipal Solid Waste (MSW) and green waste with some allowance for special wastes but no hazardous or construction and debris wastes are admitted. However, it is speculated that some amount of prohibited materials do pass through the gate unnoticed even with random load inspections and supervision at the tipping face.

More than 50% of the total population lives within urban centers and approximately 60% of these urban dwellers live within the Greater Suva Region; or about 30% of the total population of Fiji (Fiji Islands Bureau of Statistics, 2007). Currently, the Naboro Landfill receives the waste generated by these 241,270 residents; however, that is a theoretical number as it is known that not all residents either can or will take advantage of waste collection offered by the various town councils. After discussions with both residents and councilmen of this region, it was revealed that some residents still do not utilize the waste collection services rendered by the various town councils and the councils themselves have diverted collected waste loads away from Naboro Landfill at times to save money by not having to pay gate fees. Of the waste that does find its way to Naboro Landfill, the contracted operators have recorded the incoming waste loads since opening the gate in October 2005 and for just the year of 2008, over 60,000 tons of waste were received from the Greater Suva Region. Figure 5 provides a summary of the cumulative amount of waste received at Naboro Landfill along with the compaction densities recorded by HG Leach. As of April 2009, Naboro Landfill has received nearly 200,000 tons of waste. The compaction densities were determined by volumes calculated from topographical surveys performed bi-annually by a third party contractor and recorded weight of the waste received through the gate by HG Leach. An April 2009 topographical survey revealed a compaction density of approximately 1.3 tons/m^3 was being achieved by HG Leach.

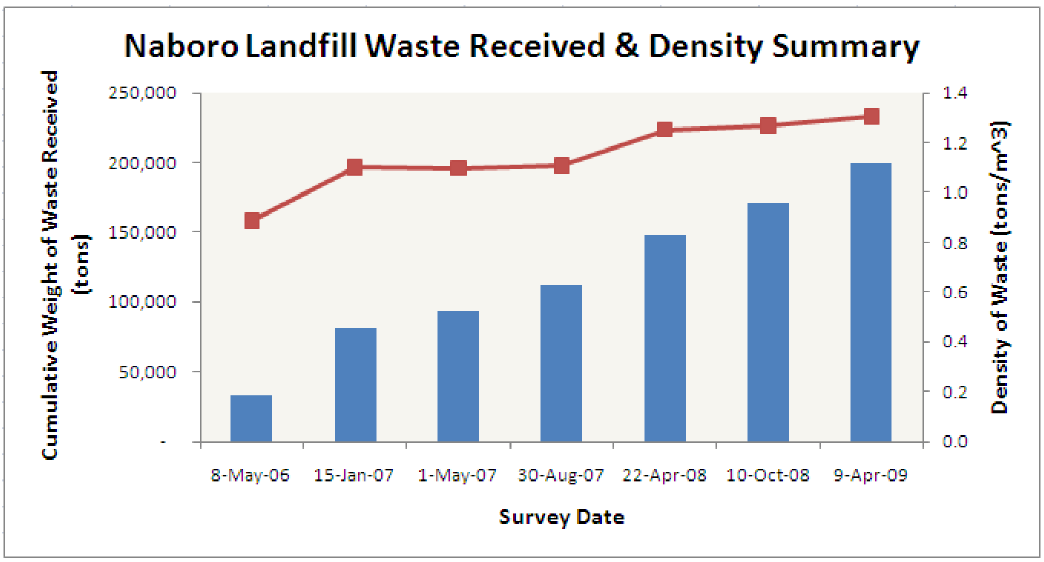

Figure 5: Cumulative tons of waste received at Naboro Landfill from 2006 through 2009 and corresponding compaction densities (HG Leach, 2009).

The method of waste collection in the greater Suva region varies between the councils. Both Suva City and Lami Town operate with their own fleet of collection trucks while Nasinu Town and Navua Rural contract all collection services to private companies and Nausori Town operates with a combination of public and private waste collection services. Collection in the councils with larger populations tends to be two to three times per week while the smaller councils offer one to two times per week collection. The infrastructure utilized by all councils now is the same as what was used when more localized dumps were available; old, low mileage, small capacity collection trucks with an average of three laborers per truck. Newer, higher capacity trucks are desired but are not affordable and the implementation of transfer stations is still under discussion.

Figure 6 shows the layout of the Naboro Landfill compound. The solid waste collection trucks arrive at the gate and proceed to the weigh station for their incoming load measurement. After weighing in, the trucks drive past the administration building, mechanic workshop, and leachate treatment system area, to arrive at the landfill tipping area. The trucks unload their waste into the designated tipping area that is being supervised by the operating company. The trucks are then given the opportunity to rinse their truck beds and wheels before exiting the tipping area. Once the trucks leave this area, they drive back to the weigh station where the exit weight is recorded before they depart the landfill compound.

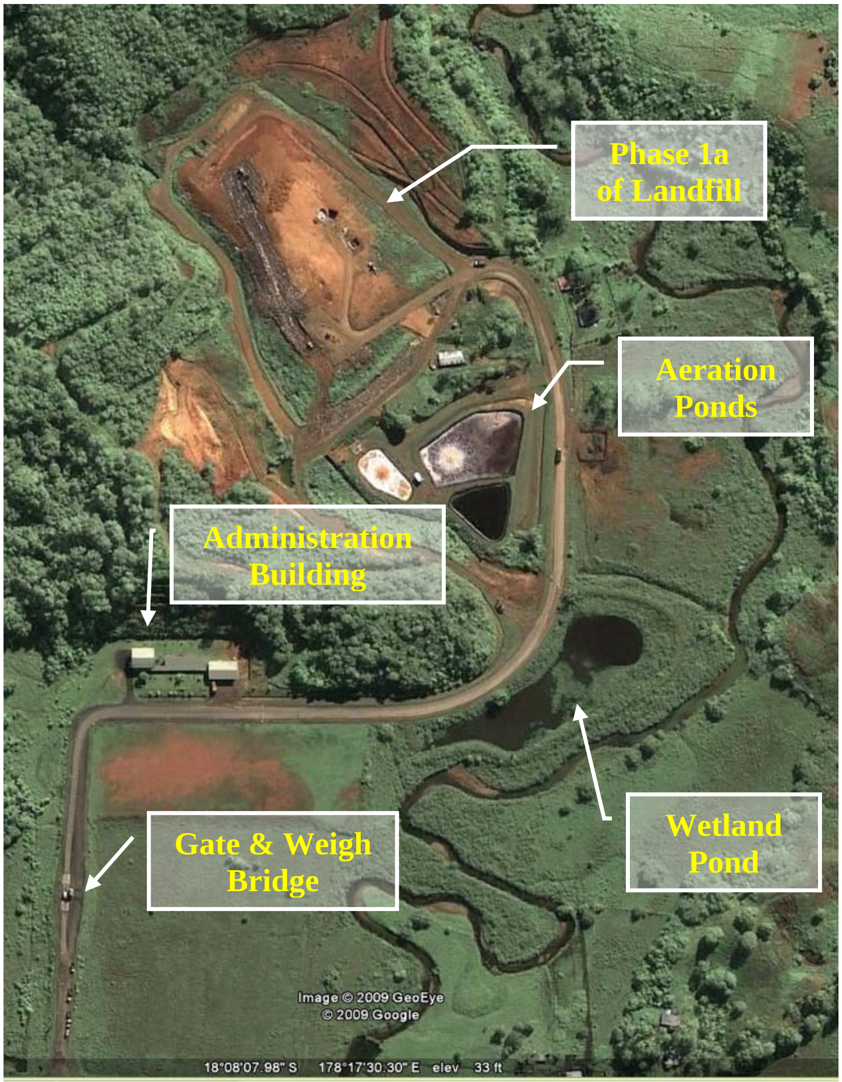

Figure 6: Naboro Landfill compound layout (Google Earth, 2009).

Chapter 2 Naboro Landfill Leachate Treatment

2.1 Sanitary Landfills

For a landfill to be considered a "Sanitary Landfill," certain design criteria must be met. The landfill must be designed and operated so as to isolate the wastes from the environment until it may be rendered innocuous through biological, chemical and physical degradation processes in the landfill (Rushbrook and Pugh, 1999). In general, a sanitary landfill will be characterized by the following: site chosen based on environmental risk assessment; planned capacity; designed cell development; extensive site preparation; full leachate management; full gas management; daily and final cover; compaction; fence and gate; record kept of waste volume, type, and source; and no waste picking and trading (UNEP, 2002). A major component of isolation is in the management and treatment of leachate. A number of techniques can be utilized to achieve isolation of leachate from the surrounding environment, depending on available resources. The techniques range from prevention of leachate generation, to sophisticated leachate treatment systems, to controlled release of leachate into the environment (Johannessen, 1999).

Table 2 displays the range of values for typical leachate constituent observed at landfills in developing countries. This table comes from a 2005 Solid Waste Management publication from the United Nations Environment Programme. This publication looks at the use of technologies that are environmentally sound for managing municipal solid wastes in developing countries. The range incorporates both the acidogenic and methanogenic phases of the waste decomposition within the landfill. This table provides an indication of the relative strength of leachate being produced at any landfill.

Table 2: Characteristics of leachate generated from decomposition of municipal solid wastes in developing countries (UNEP, 2005).

Parameter	**Range of Values (mg/L)**
pH	4.5 to 9
Alkalinity ($CaCO_3$)	300 to 11,500
BOD (5 day)	20 to 40,000
Calcium	10 to 250
COD	500 to 60,000
Copper	4 to 1,400
Chloride (Cl^-)	100 to 5,000
Hardness ($CaCO_3$)	0 to 22,800
Iron - Total	3 to 2,100
Lead	8 to 1,020
Magnesium	40 to 1,150
Manganese	0.03 to 65
Ammonia - NH_3	30 to 3,000
Organic N	10 to 4,250
Nitrite Nitrogen - NO_2^-	0 to 25
Nitrate Nitrogen - NO_3^-	0.1 to 50
Nitrogen - Total	50 to 5,000
Potassium	10 to 2,500
Sodium	50 to 4,000
Sulphate (SO_4^{-2})	20 to 1,750
TDS	0 to 42,300
TSS	6 to 2,700
Total Phosphate	0.1 to 30
Zinc	0.03 to 120

For developed countries, Figure 7 depicts relative expected landfill leachate constituent concentrations over time.

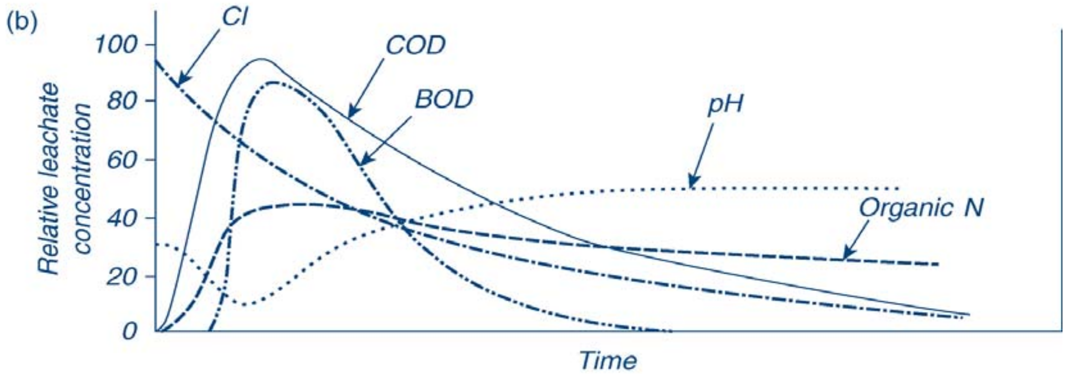

Figure 7: Relative expected leachate composition concentrations for developed countries over time as the organic waste decomposes within the landfill. (Mihelcic and Zimmerman, 2010)

The time for landfill leachate to progress along these trend lines varies between landfills. The peaks of the BOD and COD concentrations correlate to the maturation of the landfill leachate. This maturation can occur anywhere from two to twenty years, depending on the site characteristics of the landfill. During the earlier stages of decomposition, the oxygen content is being consumed and carbon dioxide and organic acids are being produced. This creates a low pH and a high oxygen demand as a result of organic particulates being converted to a dissolved phase; high oxygen demand correlates to high BOD/COD concentrations. As time progresses, the oxygen is depleted and the waste undergoes anaerobic decomposition. Microorganisms convert the BOD organic acids to methane gas thus creating a weakened leachate because the dissolved constituents convert to gaseous phase and readily leachable constituents become less prevalent (Mihelcic and Zimmerman, 2010).

2.2 Naboro Landfill Leachate Treatment System Formulation

The landfill site at Naboro has a high average annual rainfall of nearly 4 m with higher rainfall intensity occurring during October to April, without any significant dry periods. Infiltration of rainfall into the landfill has become the main driver of leachate production. Additionally, Naboro Landfill receives a waste composition with nearly 85% organic waste. The waste composition from the US and European Countries, shown in Figure 4, each have less than 30% organic waste. This higher organic waste composition correlates to higher intrinsic moisture content, thus producing a higher volume of leachate. As a “greenfield” site, there was not any data available on leachate flows or composition to use for treatment system design at Naboro. Detailed lysimeter studies carried out under tropical, monsoon conditions show that leachate generation and composition is strongly affected by rainfall and top-fill characteristics, as well as waste composition and age. Due to budget reallocations during the construction of the entire landfill compound, the design and construction of the leachate treatment system was handed over to HG Leach. The budget and timeframe available to develop a suitable treatment system at Naboro precluded hydrological modeling options.

The following information was collected and used in the design of the initial leachate treatment system and subsequent upgrades made by HG Leach. Substantiating the lack of information found during the literature review done while working at the Department of Environment and for this research, Mr. Chris Tanner and Mr. Andrew Dakers (contracted parties responsible for the Leachate Management Conceptual Design report) found that the majority of leachate composition data reported in the literature was for temperate regions. Temperate climates produce considerably less annual rainfall than that of tropical climates thereby providing inappropriate information for their study. Furthermore, Tanner and Dakers discovered the scattered studies available for tropical regions often apply to unlined and/or mature landfill sites and commonly provide insufficient background information to make them useful in other situations. The most comprehensive and relevant information found by Tanner and Daker when researching the most appropriate technology for leachate treatment was monitoring data from nine young (1-4 years) lined landfills operating in subtropical/tropical climatic regions of Taiwan with annual average rainfall of 2.5 m (Chen, 1996). Table 3 shows the leachate characteristics recorded in the central region of Taiwan; the information was used to formulate Naboro Landfill's leachate treatment system.

Table 3: Leachate characteristics in the central region of Taiwan (Chen, 1996).

Items / Sites	BOD mg/L	COD mg/L	NH_4^+-N mg/L	TKN mg/L	SS mg/L	VSS mg/L	pH	P mg/L	Fe mg/L	Zn mg/L	Cr mg/L	Age y
Touwu, Miaoli Co.	967	1214	133	162	102	96	6.7	6.7	28.6	1.0	0.3	0.67
Tatun, Taichung Co.	414	1944	866	1054	120	109	8.0	10.6	6.6	5.6	5.0	0.92
Tienchung, Changhua Co.	743	3641	1452	1605	66	58	7.8	27.5	11.8	ND	1.3	1.00
Peitou, Changhua Co.	247	1311	379	452	54	42	7.7	8.9	0.8	ND	ND	1.00
Puyen, Changhua Co.	43	825	13	75	10	8	8.0	21.7	9.8	ND	0.3	1.25
Tienwei, Changhua Co.	70	1456	47	544	20	16	8.5	23.5	21.8	0.6	0.5	1.58
Hsichou, Changhua Co.	386	2282	962	1029	110	78	8.4	7.9	8.4	ND	0.3	1.92
Fangyuan, Changhua Co.	18	204	29	102	5	4	8.2	5.2	1.0	ND	0.2	2.08
Taichung City	620	3447	2505	2648	194	160	8.2	15.4	7.7	3.4	1.1	4.50

Expected contaminant concentrations in the Naboro leachate were estimated based on 80-90 percentile values calculated from the annual average data reported for these nine Taiwanese landfills. Concentrations were checked against ranges given in general guidelines. Given the greater amount of rainfall at Naboro, which results in greater dilution, these were likely to provide a conservative (over-) estimate of contaminant concentrations. Expected contaminant concentrations were combined with predicted maximum leachate flows to provide estimated contaminant mass loading rates for design of the treatment system. Given the expected buffering of leachate flows during passage through the land-filled materials, design of the treatment system was based on the maximum daily flow able to be generated from average recorded flows for the wettest month of the year (April). The April data were based on recorded rainfall at Naboro Prison adjacent to the Landfill site, acquired by the Fiji Meteorological Service from 1963 to 1991 (Tanner and Daker, 2005).

2.3 Naboro Landfill Leachate Treatment System

The proposed leachate management system was developed in stages. The first stage was to design a system with a capacity to treat the leachate volume and characteristics anticipated for the third year of operation; the following stages were to be based on monitoring during the first three years. HG Leach project manager for Naboro Landfill, Mr. Eric Souchon, and operations manager on site, Mr. Mark Hirst, provided the design specifications of the leachate treatment system which was formulated.

The current leachate treatment system flow diagram is shown in Figure 7. The initial leachate treatment system passively collects the leachate generated into lateral leachate collectors connected to a leachate collector with an internal diameter of 400 mm. The leachate collector then discharges the leachate into a leachate storage tank where it continues to a series of sedimentation ponds, provided by two partially aerated lagoons. The first pond has a water surface area of about 740 m^2 and a hydraulic detention time of three days (design flow of 301 m^3/day). The following pond has a water surface area of about 2,350 m^2 and corresponding hydraulic retention time of twelve days. The effluent flows into a one hectare surface-flow wetland. The vegetated zones of the wetlands have a depth of 0.3 m and free-space porosity of 90%, with deeper (1.5-2 m) open-water zones to provide for enhanced settling, re-aeration, and flow redistribution. The wetland system has a nominal residence time of over twelve days under predicted average wet season flows. The wetland was constructed in existing wet fields to the south of the landfill site with side bunds to retain flow through the wetland and exclude normal flood-flows from the stream. The wetland discharges directly into the stream feeding a creek which empties into an estuary.

Once operations began, monitoring was performed to check the design assumptions made in developing the treatment system and adaptation were implemented in order to meet appropriate water quality standards. As the waste deposition progressed, it became apparent from the health of the wetlands and the leachate sample results that this level of treatment was no longer sufficient enough for release into the stream and further funding was granted to improve the leachate treatment system. To begin, the sedimentation process was expanded with the addition of a third pond with a surface area of approximately 1,720 m^2 and a hydraulic detention time of thirty days. Then, 1.5-mm High Density Polyethylene (HDPE) single side textured liners were placed below all three sedimentation ponds. Finally, mechanical aerators were installed in the first two sedimentation ponds for increased re-aeration. An Aqua Lator Model 6011-MSC aerator with a 40-kW motor was installed in Pond 1 and two Aqua Lator Model 3011-MSC aerators with 20-kw motors were installed in Pond 2. No mechanical aeration is performed in Pond 3. The aerators are operated on a fixed schedule, providing sufficient time for dissolved oxygen concentrations in each of the ponds to be kept above 4 mg/l. The aerators are powered by an on site power panel fed by the local power company with the capacity to control two 30-hp and one 60-hp aerators at 380 V and 50 hz. Construction for the improvements began in April 2008 and was finished by January 2009 when the aerators were switched on.

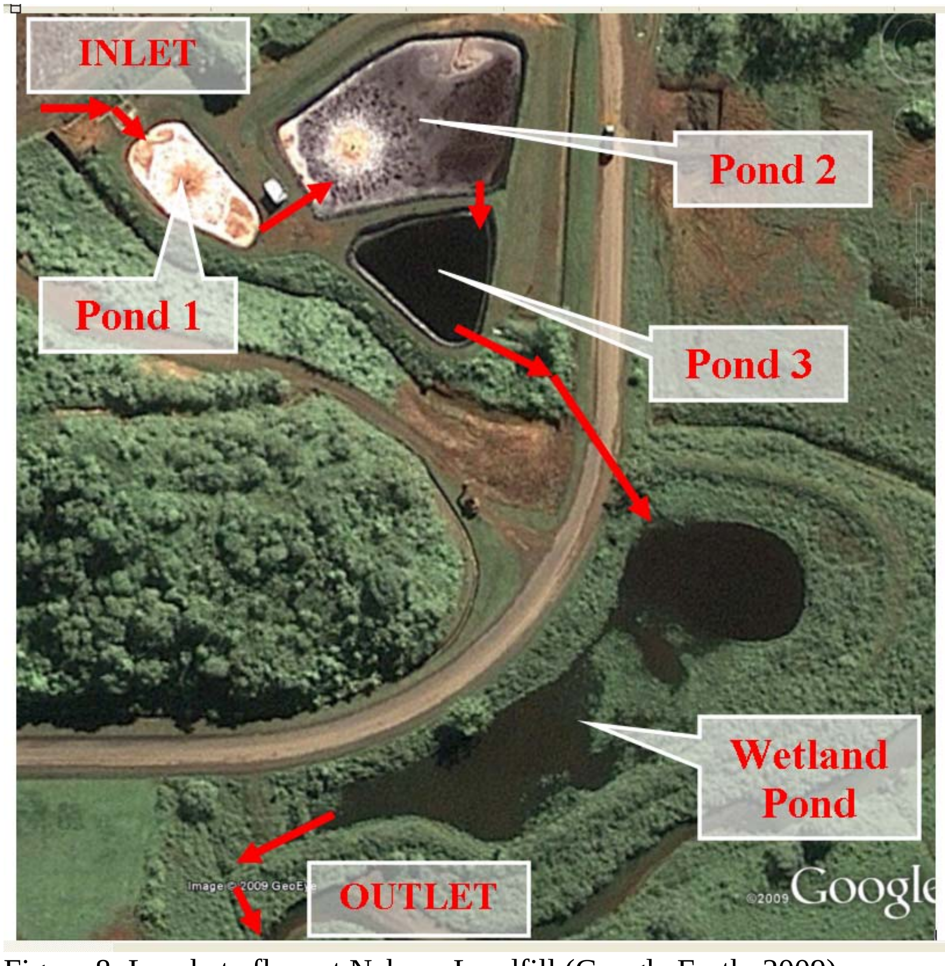

Figure 8: Leachate flow at Naboro Landfill (Google Earth, 2009).

2.4 Leachate Effluent Standards

The eventual discharge of leachate produced at a landfill is typically accomplished in one of two ways: collection and transfer to a wastewater treatment plant (with or without pre-treatment) or discharge into water bodies after on-site treatment. Naboro Landfill utilizes the latter.

The Fiji Government recently passed new regulations for liquid waste discharge limitations in 2008. These new regulations do not specifically mention landfill leachate as a liquid waste discharge source but since the leachate is a discharged liquid, the limitations can be applied. Table 4 outlines a selected list of these new regulations for liquid waste dischargers.

Table 4: National Liquid Waste Discharge Limitations for Fiji (EMA Regulations, 2008).

Parameters	Unit	General
pH		7 to 9
Oil & Grease		No visible
BOD	mg/L	40
SS	mg/L	60
TDS	mg/L	1000
Fecal Coliform	c/100mL	400
Sulphate	mg/L	500
Total N	mg/L	25
Ammonia	mg/L	10
Total P	mg/L	5
Iron	mg/L	5
Arsenic	mg/L	0.05
Cadmium	mg/L	0.05
Lead	mg/L	0.05
Mercury	mg/L	0.02
Zinc	mg/L	1

The US Environmental Protection Agency (USEPA) passed a "Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Landfills Point Source Category" regulation in January 2000 that came into law in February 2000. This new regulation establishes technology based effluent limitations for wastewater discharges associated with the operations and maintenance of new and existing hazardous and non-hazardous landfill facilities regulated, respectively, under Subtitle C and D of the Resource Conservation and Recovery Act (USEPA, 2000). These limitations guidelines set a minimum standard for landfill facilities that discharge their leachate into federal water bodies to abide by. These values are based on "Best Practicable Control Technology Currently Available" or BPTs. For leachate discharge into surface water bodies, the chosen BPT for non-hazardous MSW landfills is a combination of biological treatment and multi-media filtration. Additional and/or more stringent effluent standards for the leachate can be applied by the individual states, on a case by case basis, under the National Pollutant Discharge Elimination System (NPDES). Table 5 provides the list of effluent limitations guidelines for non-hazardous MSW landfills.

Table 5: Effluent Limitations for Non-Hazardous MSW Landfills in the US (USEPA, 2000).

Parameter (mg/L)	**Max Daily**	**Max Monthly Average**
BOD	140	37
TSS	88	27
Ammonia-N	10	4.9
alpha-Terpineol	0.033	0.016
Benzoic acid	0.12	0.071
p-cresol	0.025	0.014
phenol	0.026	0.015
Zinc (total)	0.2	0.11
pH	6 to 9	6 to 9

Chapter 3 Methods

A number of leachate quality sampling events were performed on the leachate treatment train since the start of operations. Table 6 provides a summary of the various leachate sampling events with the date and specific water quality parameters tested for each event.

Table 6: Summary of leachate sampling events and parameters tested at Naboro Landfill.

Date Sampled/Received	**16-Jan-06**	**25-May-06**	**1-Jun-06**	**8-Apr-08**	**1-Aug-09**
pH	x	x	x	x	x
Conductivity		x			
Electrical Conductivity	x		x	x	x
Dissolved Oxygen		x	x		x
Total Dissolved Oxygen	x				
Turbidity					x
Ammonia				x	x
Nitrate					x
Nitrite					x
Phosphate					x
Sulphate					x
Chemical Oxygen Demand				x	
Biochemical Oxygen Demand	x				
Arsenic	x				
Cadmium	x				
E.coli	x				
Lead	x				
Mercury	x				
Oil & Grease	x				
Total Coliforms	x				
Zinc	x				

The first sampling event was performed on January 16, 2006; three months after operations at Naboro Landfill began. The Fiji Department of Environment (DOE) contracted the

University of the South Pacific – Institute of Applied Sciences Analytical Laboratory (USP-IAS) to collect and analyze each of the leachate samples. Two sites were chosen for analysis, Site 1 and Site 2, located at the inlet pipe of Pond 1 and the outlet point of Pond 1, respectively.

The following parameters were tested (Table 6): Biochemical Oxygen Demand; arsenic; electrical conductivity; cadmium; E.coli; lead; mercury; oil and grease; pH; total coliforms; total dissolved oxygen; and zinc. The validity of these sample results was investigated for credibility by acquiring the laboratory's credentials. USP-IAS is accredited through the NZS/ISO/IEC 17025 requirements for the competence of testing and calibration laboratories. The results were done through the methods outlined in APHA's Standard Methods 20th Edition (1998). The individual method reference numbers were listed alongside the leachate sampling results. Asterisks applied to the parameters tested indicate these tests are outside the laboratory's scope of accreditation.

The next sampling events occurred on May 25, 2006 and June 1, 2006 (Table 6); undertaken by HG Leach who contracted USP-IAS as well for the collection and analysis. Each event included four sample points representing the progressive treatment points along the system. Figure 8 shows the Naboro leachate sampling points used for each sampling event performed in May and June 2006. The sampling points are labeled L1, L2, L3, and L4; the "L" representing leachate. L1 was located at the influent pipe from the leachate storage tank into Pond 1. L2 was located at the influent point of Pond 2. L3 was taken at the effluent point of Pond 2. L4 was taken at the effluent point of the wetlands.

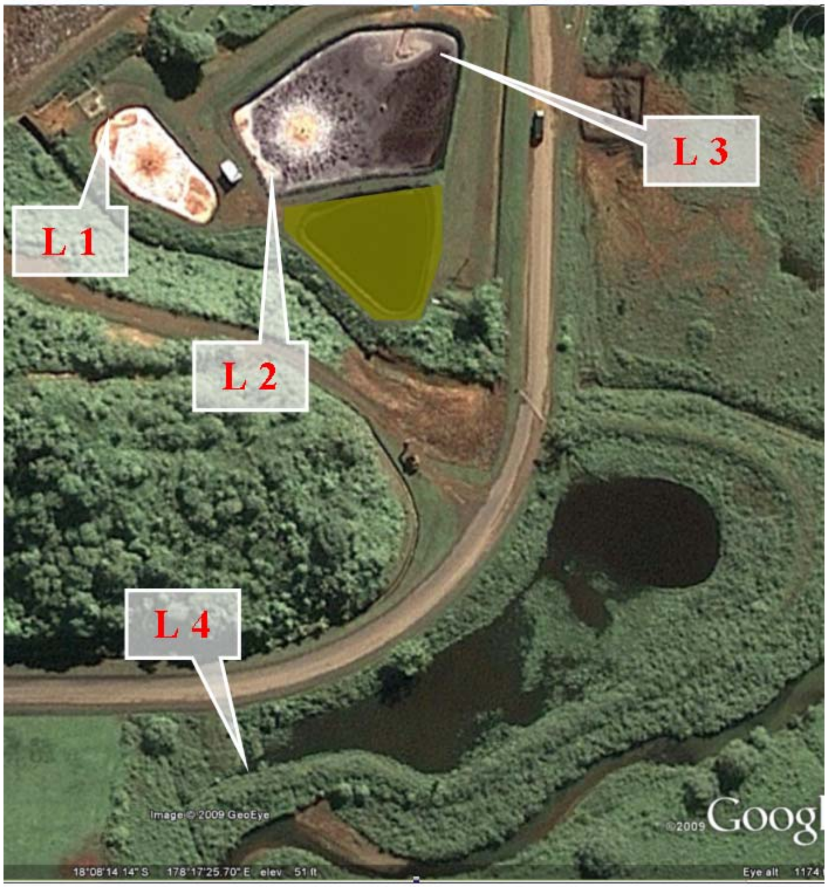

Figure 9: Naboro leachate sampling points for tests done in May and June 2006 (Google Earth, 2009).

As shown in Table 6, the pH, conductivity, and dissolved oxygen were tested in the May 2006 event. The June 1, 2006 event tested for pH, electrical conductivity, dissolved oxygen, and commented on the appearance of the water and weather conditions at each sampling point.

Further testing of the leachate quality was performed on behalf of the DOE and the author on April 8, 2008, just before the upgrade of the leachate treatment system. The same four sampling points, L1-L4, were used in this event. The sampling equipment was provided by USP-IAS but the samples were taken by DOE staff, the author, and the HG Leach supervisor to save on costs, and then given to USP-IAS for analysis for the April 2008 event.

The following four parameters were chosen to be tested, based on their ability to determine the effectiveness of the treatment and available funding for the analysis: electrical conductivity; pH; ammonia (NH_3); and chemical oxygen demand. A test for Ammonia-N (NH_3-N) was originally requested but USP-IAS had to change to a NH_3 test due to the high levels of ammonia received in the samples. However, NH_3-N was calculated using the relationship provided by USP-IAS laboratory:

$$NH_3\text{-}N = NH_3 / 1.214$$

In order to determine as many typical leachate constituent values for comparison to accepted range of values in the literature, TDS and BOD were determined from other measured parameters. TDS was calculated based on the electrical conductivity readings using a combination of two equations (Mihelcic and Zimmerman 2010):

$$TDS = 1.6 * EC / 2.5$$

BOD values were determined from the COD values using the assumption that BOD is between forty to sixty percent of COD for domestic waste water.

Another leachate sampling event occurred in August 2009, after the upgrade was complete and in operation for six months. Figure 9 points out the locations of the leachate samples taken after the leachate treatment system was upgraded in December 2008. The sampling points are labeled in the same manner as before but additional points are included to accommodate the third pond. The sampling points remained the same from the previous samplings aside from point L3 moving from the outlet of Pond 2 to the outlet of Pond 3 at the weir. A sampling point was added, L5, at a point just downstream of the stormwater creek and wetland pond outflow confluence.

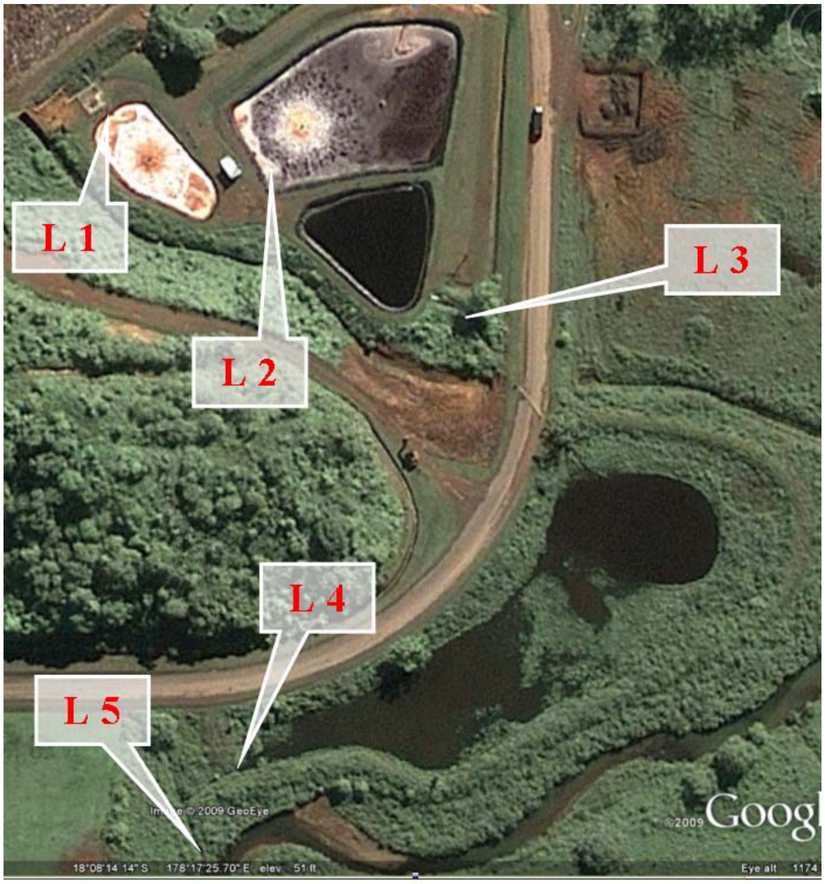

Figure 10: Naboro leachate sampling locations in August 2009 (Google Earth, 2009).

This sampling event occurred as part of an environmental health audit performed on the whole of the landfill compound. The event was commissioned by the DOE at the request of the Fiji Central Board of Health after numerous complaints were received over concerns of odor and water quality. A local consulting firm, Coreréga Environmental Consultants (CEC), was contracted to perform an analysis of the leachate, among other tasks. CEC chose to use their own sampling instruments and limited their data collection to only conductivity measurements of the leachate at the five sampling points. However, CEC did take a more extensive analysis at the L4 sampling point.

The following parameters were analyzed from the L4 sampling location: pH, electrical conductivity, dissolved oxygen, turbidity, ammonia-N, nitrate, nitrite, phosphate, and sulphate. It could not be determined when these tests were performed by the consultants but it was done sometime in August 2008. Similarly, the instruments used to test these parameters are unknown as they were never reported in the Audit report.

All results were compiled from DOE and HG Leach records and placed in an excel spreadsheet. The leachate results from sample point L1 were then related to the observed range of values for the leachate characterization parameters listed in Table 2 to determine Naboro's overall leachate strength before treatment begins. Based on the available results, only five leachate parameters were able to be compared for determining the leachate strength. TDS and pH for all sampling events except for 2009 were compared to the range of leachate constituents. Ammonia, BOD, and COD values could only be compared for the April 2008 sampling event. For each of these comparisons, the Naboro value was plotted as a point over the sampling date while the range of values is displayed as a block of values in shading within the graph area.

In order to understand how Naboro Landfill's leachate corresponds to leachate generation in developed countries, the results were compared to Figure 7. Figure 7 illustrates the expected relative leachate composition concentrations for developed countries over time as the organic waste decomposes. The BOD, COD, pH, and Chloride (Cl^-) trend lines of this figure were able to be compared to the BOD, COD, pH, and TDS concentrations at sampling point L1. Chloride has been considered a relative approximation of the TDS concentrations and therefore used as an acceptable comparison.

The results from sampling point L4 were then correlated to the standards established for the discharge of leachate into surface waters in Fiji and the US for applicability of these standards to Naboro Landfill leachate. When comparing the results to the USEPA standards, the "Maximum Daily" standards were used because the leachate samplings were "grab samples" and most appropriate for comparison to the Max Daily standards, not the Maximum Monthly Average standards. The sampling point L4 was chosen as it is the discharge point from the wetland pond into the creek. Based on the available results, four leachate parameters were able to be compared for applicability of effluent standards using the values listed in Tables 4 and 5. TDS and pH for all sampling events except for January 2006 (no L4 sampling point) were compared to the leachate effluent standards. Ammonia values were compared for the April 2008 and August 2009 sampling events. BOD values were available only from the April 2008 sampling event. Again, the Naboro values were plotted as a point above the sample date while the effluent standards were displayed as a bar of reference within the graph area.

Chapter 4 Results and Discussion

4.1 Naboro Landfill Leachate Test Results

The data compiled from each leachate sampling event can be viewed in Appendix A.

The amount of data available for Naboro Landfill on leachate sampling events was minimal and inconsistent. However, enough data were present to make some comparisons and analyses. As illustrated in Table 6 of the Methods chapter, the leachate constituents tested were never all the same or included slight variations between the sampling events. More extensive and consistent sampling events were desired for the period in which the author worked for the DOE but the lack of funds available for such monitoring projects made this unfeasible. For these reasons, only a few constituents found in the leachate could be compared on an individual basis.

4.2 Measured Naboro Leachate Concentration Compared with Range of Values for Leachate Characterization in Developing Countries

When comparing the Naboro leachate values to the leachate characterization range of values for developing countries, a rough idea of the leachate strength can be formulated as well as its comparableness to other developing country leachate.

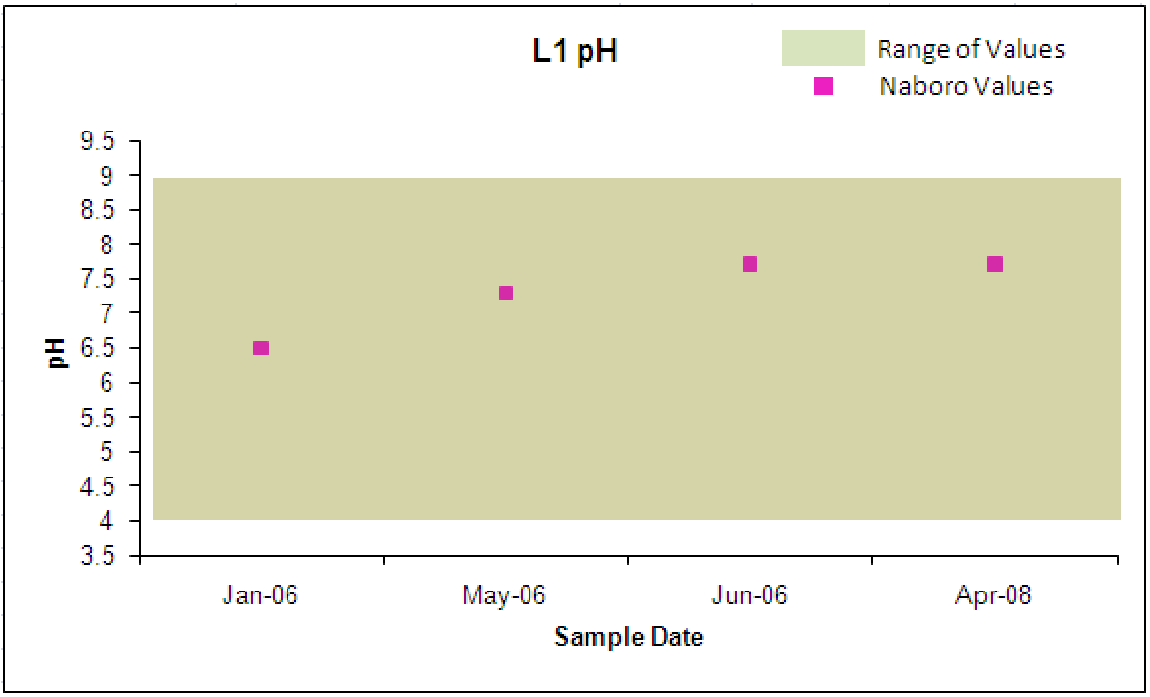

Figure 11: Measured pH values from sample point L1 compared to observed range of values for developing country leachate.

Figure 11 shows that pH values remained well within the range of expected values 4 to 9.

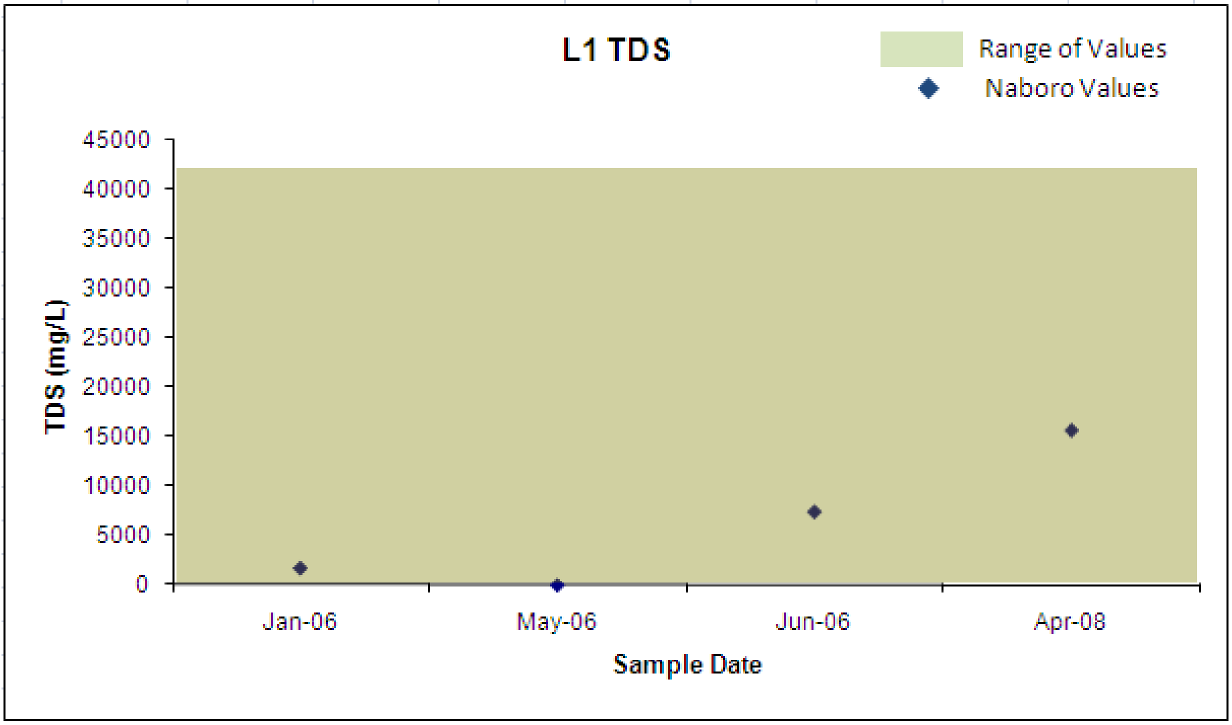

Figure 12: Measured TDS concentrations from sample point L1 compared to observed range of values for developing country leachate.

Figure 12 shows Naboro TDS concentrations were in the lower range of the 0 to 42,300 mg/L concentrations listed in Table 2. The smallest concentration was reported on May 2006 with a TDS of only 6 mg/L and the highest concentration in April 2008 of 15,616 mg/L. A low TDS indicates a low mobilization of dissolved ions that includes metals which is positive for the overall leachate system.

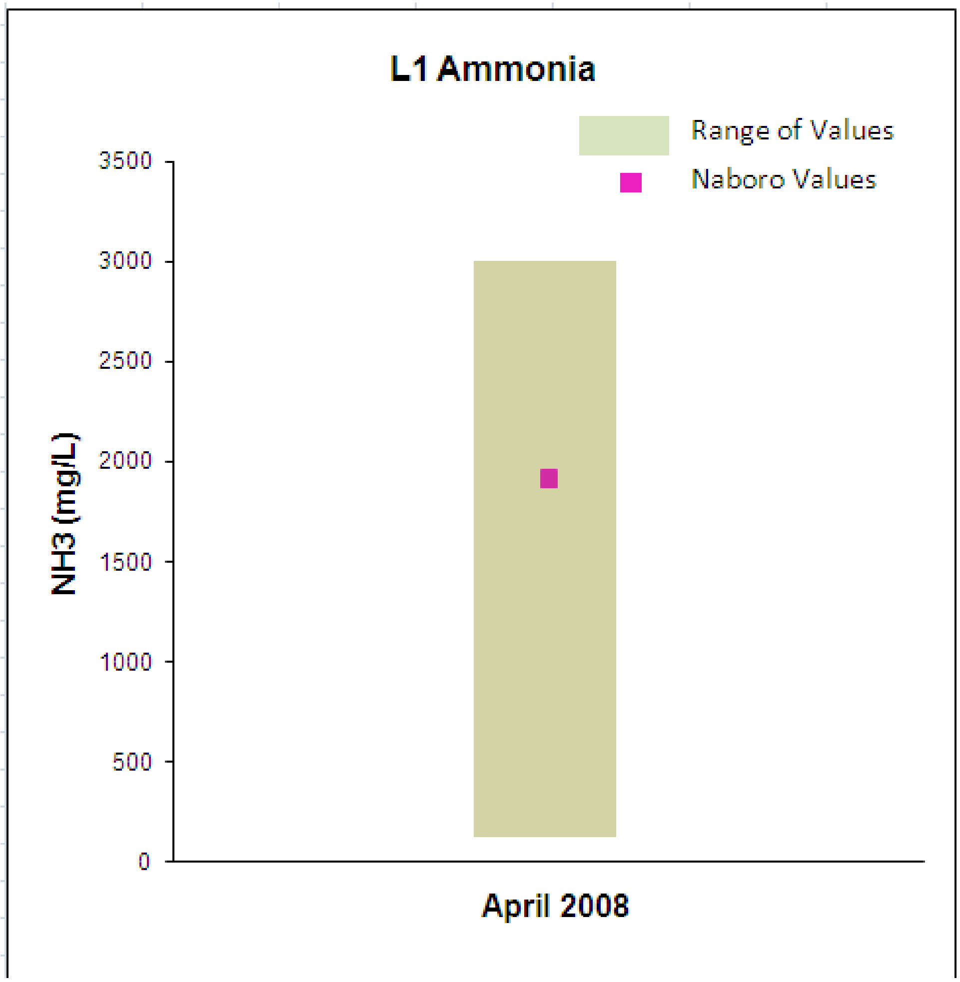

Figure 13: Measured Ammonia concentrations from sample point L1 compared to observed range of values for developing country leachate.

The ammonia concentration at Naboro was reported just above the mid-range values (1,914 mg/L) in Table 2, as shown in Figure 13. This is not surprising in that the values for Ammonia were from samples collected prior to the installation of the aerators. The increased oxygen and turbulence created by these new aerators should increase the removal of ammonia by stripping and oxidation to nitrate by biological nitrification.

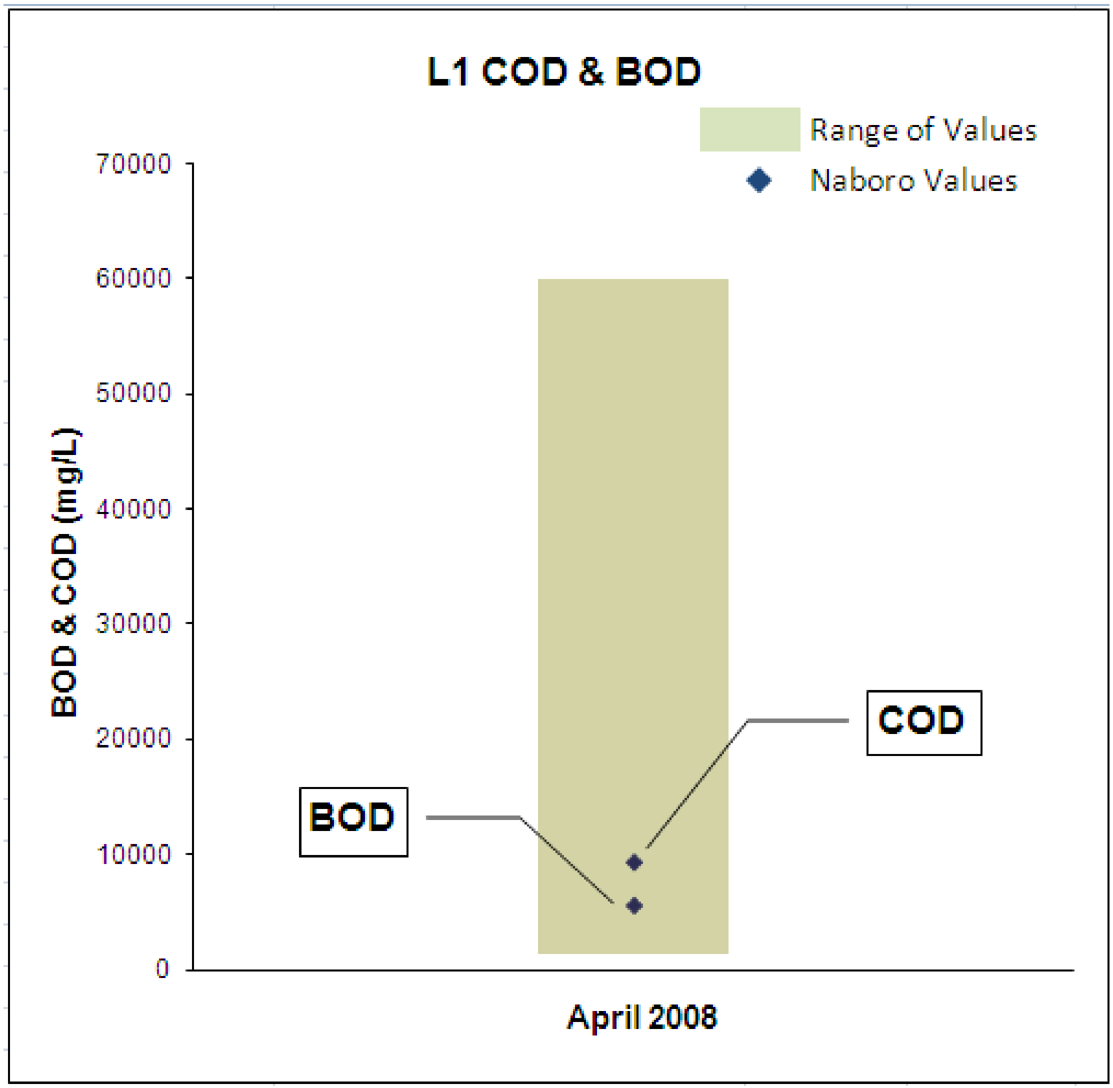

Figure 14: Measured BOD and COD concentrations from sample point L1 compared to observed range of values for developing country leachate.

Figure 14 provides the measured COD concentrations of 9,416 mg/L and the calculated BOD (60%) value of 5,650 mg/L from Naboro. Table 2 lists the range for COD as 20-40,000 mg/L and the range for BOD as 500-60,000 mg/L. The concentration of leachate entering Pond 1 is in the low range of values listed in Table 2 which indicates few aerobic microorganisms are present at this point. This is to be expected in that these values come at the inlet sample point to the leachate treatment system.

4.3 Measured Naboro Leachate Concentration Compared with Relative Leachate Concentrations Expected in Developed Countries

To compare influent Naboro leachate to developed world values, Figure 7 and Figures 11-14 should be referenced in order to follow the ensuing discussion. Figure 7 depicts the relative constituent concentrations of leachate; hence, absolute concentration ranges such as displayed in Table 2 were not available for comparison. The amount of available data on leachate generated at Naboro Landfill is insufficient in providing information on where Naboro lies within the graph shown in Figure 7. However, Figure 7 can provide an understanding of what can be expected of Naboro landfill's leachate over time.

Figure 7 shows pH values that dip just before the BOD and COD concentrations peak. The Naboro pH values reported at the L1 sampling points have remained relatively constant, with no noticeable dip.

The Chloride concentration (correlates to TDS) shown in Figure 7 begins high and steadily decreases over time. However, the Naboro leachate TDS concentrations at L1 started low and mostly increased over the different sampling events.

The BOD and COD concentrations data at Naboro do not provide enough information to understand where it lies along these trend lines of Figure 7. The BOD and COD concentrations of Figure 7 increase exponentially early in the decomposition stages of the waste then decline at a slower exponential rate as time progresses.

Overall, the initial leachate produced at Naboro Landfill is relatively weak when compared to leachate in other developing countries. This is likely due to the dilution affect the high rainfall contributes to the system, the waste composition, and the age of the landfill. However, it must be noted that these values may still increase before eventually decreasing over time. Therefore, the leachate should be monitored as more waste is disposed at Naboro and the existing waste has a chance to decay.

4.4 Naboro Leachate Unit Comparisons with Leachate Effluent Standards

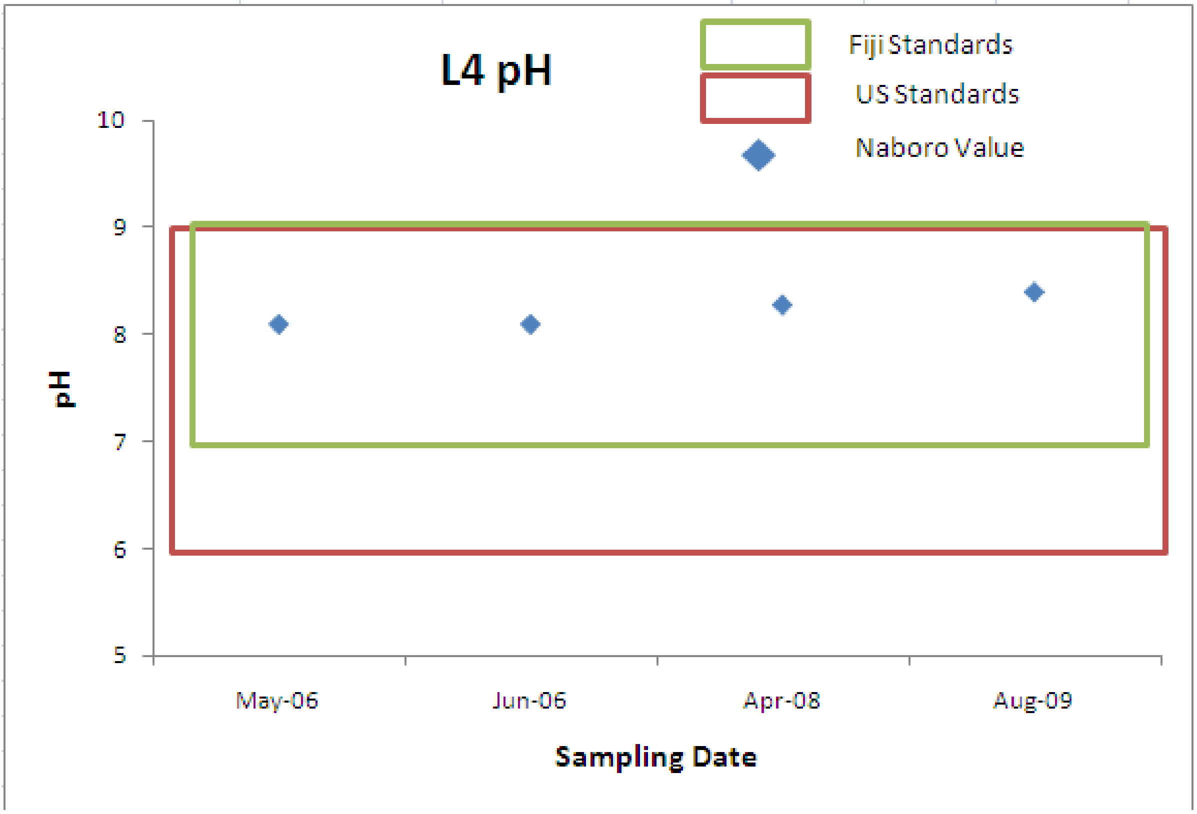

Figure 15: Measured pH values from sample point L4 compared to US and Fiji effluent standards.

The measured pH values, provided in Figure 15, at the outlet of the wetland pond have remained steady over the sampling events and well within the 6 to 9 and 7 to 9 effluent standards set by the US and Fiji, respectively.

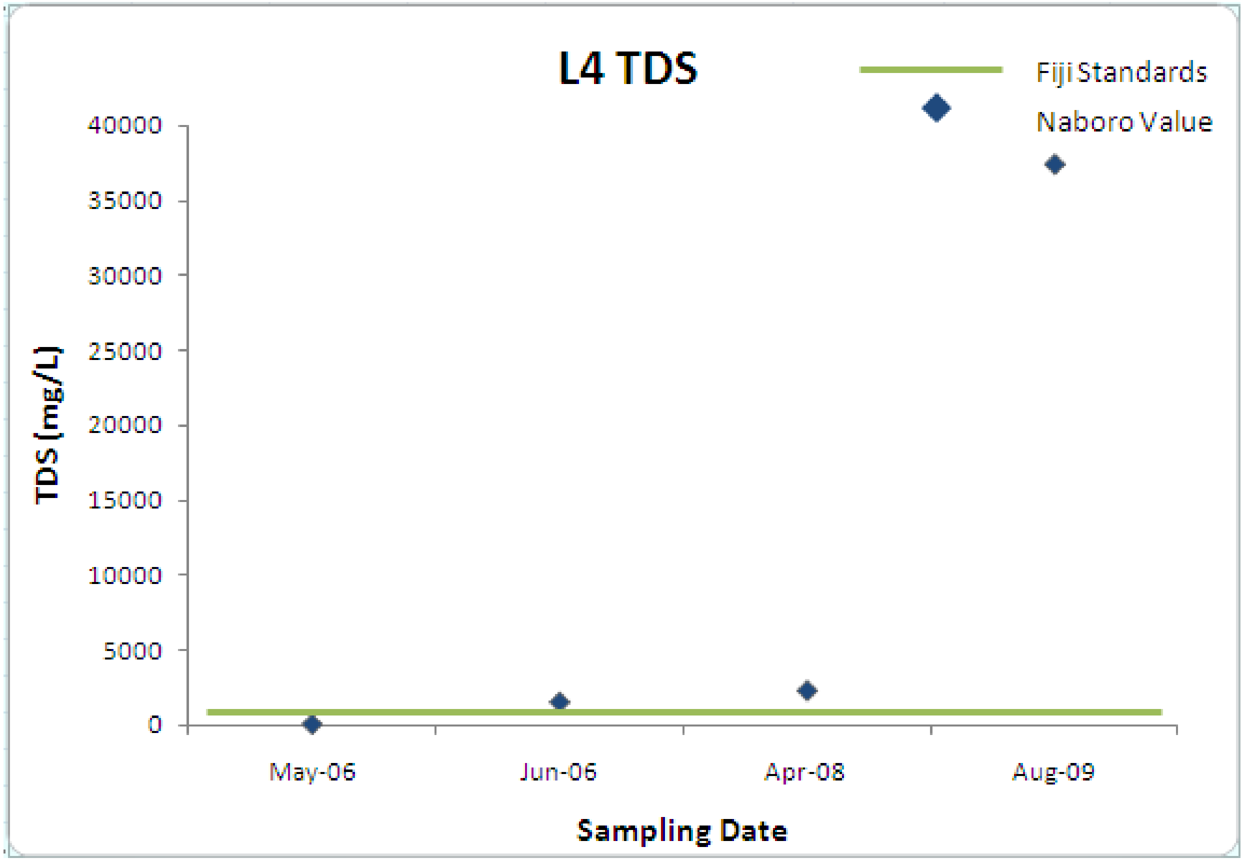

Figure 16: Measured TDS concentrations from sample point L4 compared to Fiji effluent standards.

The TDS trend over the sampling dates, displayed in Figure 16, started off low with a concentration of 2 mg/L but has increased significantly over the leachate testing period. The resulting differential from the effluent standards set by Fiji is higher by 478 mg/L in June 2006, 1,240 mg/L in April 2008, and 36,376 mg/L in August 2009. It must be noted though that the Fiji National Liquid Waste standards are not meant for landfill leachate specifically. Landfill leachate will typically report higher TDS values than a wastewater treatment system. Therefore, it is understandable why this effluent standard is set so much lower than what the effluent leachate at Naboro is achieving. The US EPA did not specify an effluent standard for TDS but this value could be included in the NPDES permit given to a similar landfill facility in the US.

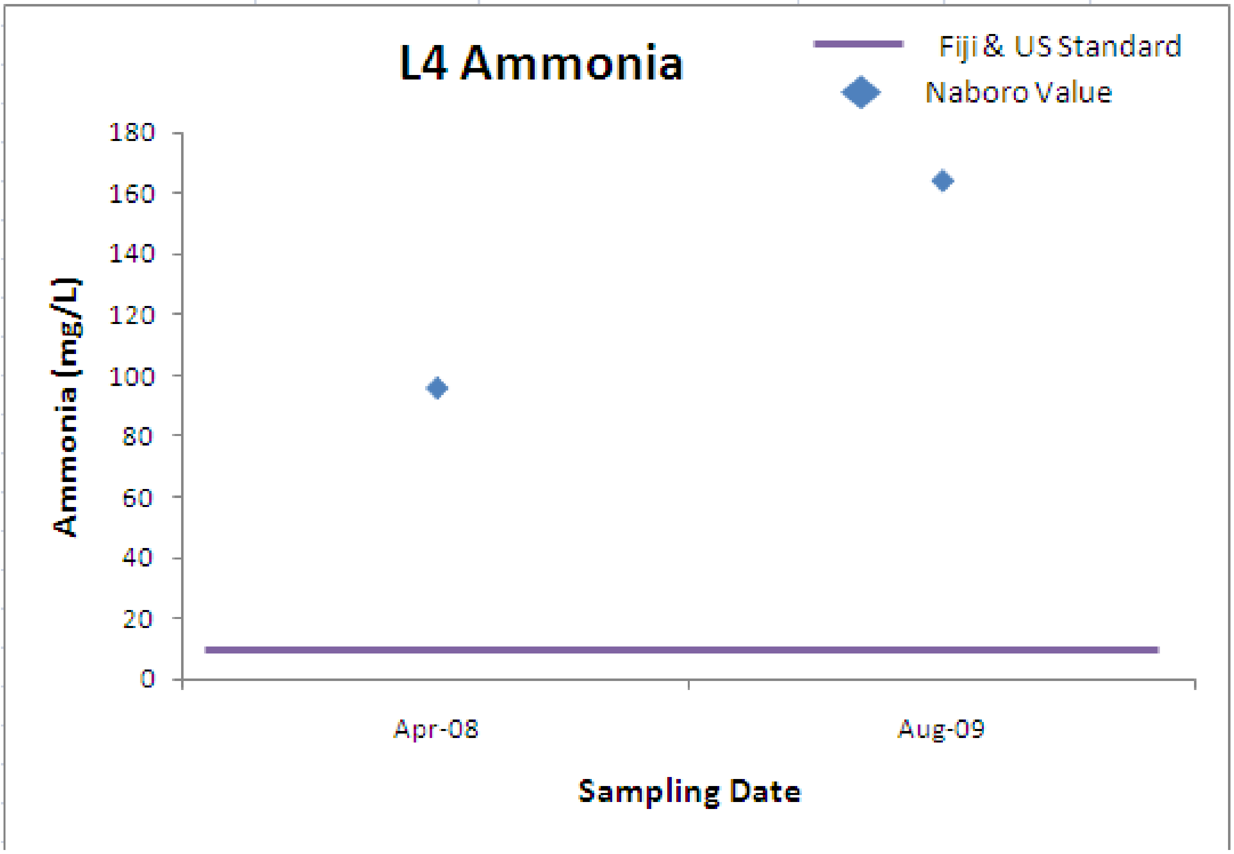

Figure 17: Measured Ammonia concentrations from sample point L4 compared to US and Fiji effluent standards.

The Ammonia content at Naboro was far above the effluent standards established by both the US EPA and Fiji, as shown in Figure 17. Fiji requires an Ammonia concentration no greater than 10 mg/L. The US EPA requires an Ammonia-N concentration no greater than 10 mg/L. Naboro reported Ammonia-N concentrations of 96 and 164 mg/L in April 2008 and August 2009, respectively. It is understandable for high records prior to the leachate system upgrade in late 2008 but this value is even higher for the sampling date in August 2009, six months after the installation of the mechanical aerators.

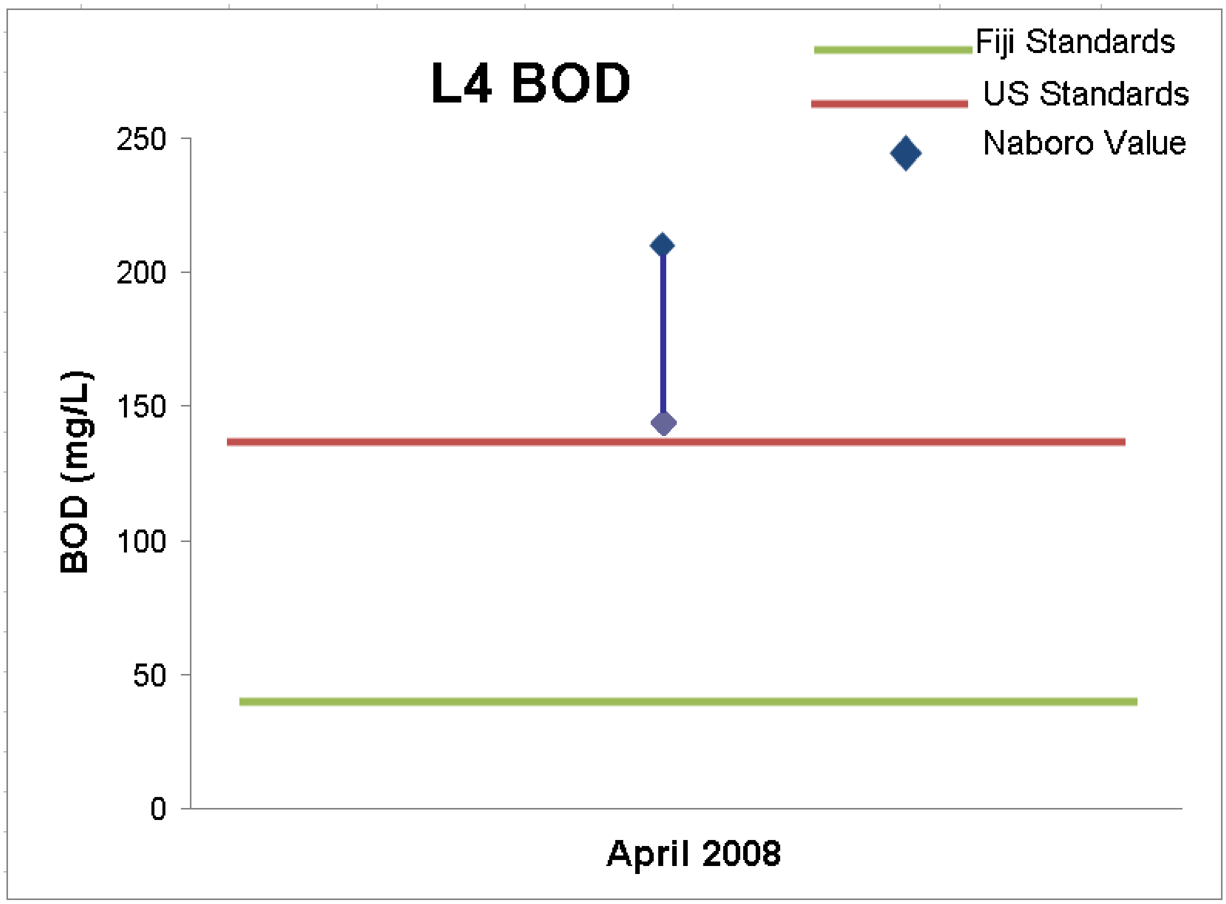

Figure 18: Measured BOD concentrations from sample point L4 compared to US and Fiji effluent standards.

Figure 18 shows the BOD calculated for the effluent sampling point range from 217 mg/L at 60% of COD to 144 mg/L at 40% of COD. These concentrations are lower than the inlet leachate value of 5,650 mg/L recorded on the same date but are still above both Fiji and US EPA's set effluent standards of 40 mg/L and 140 mg/L, respectively. This parameter should continue to be monitored at Naboro Landfill.

An idea of the effectiveness of the leachate treatment system was calculated using the April 2008 values. Table 7 provides an understanding of the percent removal of leachate constituents after each phase of the leachate treatment process as well as the total percent removal from the influent to effluent concentrations.

Table 7: Percent Removal of Leachate Constituents after each Treatment Pond and Total Percent Removal from Inlet to Effluent concentrations calculated for April 2008 Samples.

	Parameters (mg/L)		
Sample Location	**TDS**	**Ammonia-N**	**BOD**
[Inlet] L1	15616	1914	5650
L2	11968	1294	3409
% Removal (L1-L2)	**23%**	**32%**	**40%**
L3	5248	433	770
% Removal (L2-L3)	**56%**	**67%**	**77%**
[Outlet] L4	2240	96	217
% Removal (L3-L4)	**57%**	**78%**	**72%**
Total % Removal (L1-L4)	**86%**	**95%**	**96%**

Even before the treatment system upgrade, the total removal efficiencies were high. A sampling of all leachate points (L1-L4) should be done to understand the upgraded treatment system's removal efficiencies.

As far as Naboro Landfill leachate meeting the effluent standards set by both the Fiji government and the US EPA, it is not yet but could in the future with further treatment techniques incorporated in the treatment train. As mentioned above, the Fiji effluent standards are not leachate specific and so should be kept in mind that wastewater is the more likely candidate for these standards to apply. The US EPA has set these limitation guidelines to be met by landfill leachate treatment systems utilizing a combination of biological treatment and multi-media filtration. Naboro Landfill's leachate treatment system primarily uses biochemical treatment without any multi-media filtration device(s). Therefore, the effluent standards for treated leachate into surface waters can only be roughly compared to the case at Naboro Landfill.

Chapter 5 Conclusions and Recommendations

The leachate data has been compiled for analysis but the sampling events that were available were minimal and inconsistent in the constituents tested. Due to a limited working set of data, a few leachate constituents were chosen for comparisons on an individual basis. In comparing the overall strength of the initial leachate produced at Naboro Landill, pH, TDS, Ammonia, BOD and COD were compared to a range of values observed in developing countries' leachate. The leachate being generated at Naboro Landfill is considered to be weak which is likely a result of the dilution factor provided by the high annual rainfall. When applying the effluent standards of the US EPA and Fiji to Naboro's treated effluent leachate, it was found the standards were not being achieved for most of the effluent concentrations being reported at Naboro. The water quality constituents, TDS, Ammonia, and BOD, are all reporting concentrations above the regulations.

The data collected and analyzed for this research was not done solely by the author and so occurrences of error are uncertain but none the less, highly likely. Errors may have occurred in the collection of leachate samples and respective laboratory analyses. Additionally, some leachate information that may be applicable to this research could have been overlooked or never found and therefore not included.

Further research on this topic is recommended. A broader study on acceptable effluent leachate standards should be completed that includes more developed and developing countries for a more comprehensive comparison of standards applicability for any developing nation. A database of all NPDES permits issued in the US and their respective effluent standards for discharge into surface waters from landfill leachate treatment systems should be compiled. And lastly, more regular and extensive monitoring of the landfill leachate at the Naboro Landfill would be greatly beneficial to the Fiji DOE as well as the contracted operators of the landfill.

References

Chen, Paris Honglay. "Assessment of Leachates From Sanitary Landfills: Impact of Age, Rainfall, and Treatment" *Environment International*, Vol. 22, No. 2, pp. 225-237, 1996.

[CIA, 2009] Central Intelligence Agency. Accessed November 11, 2009. http://www.cia.gov/library/publications/the-world-factbook/geos/fj.html

Fiji Islands Bureau of Statistics 2007 Census Report. Accessed November 11, 2009. http://www.statsfiji.gov.fj/index.htm

Fiji Department of Environment. Project Formulation Mission: Fiji Solid Waste Management Project. Final Report. Pages 31 and 55. April 23, 2007.

Fiji Meteorological Service. Accessed November 11, 2009. http://www.met.gov.fj/climate_fiji.html

[EMA Regulations, 2008] Fiji Islands Government Gazette Supplement. Environmental Management (Waste Disposal and Recycling) Regulations 2007. No. 1. January 4, 2008.

[Google Earth, 2009] Google Earth Imagery. Accessed December 8, 2009.

[HG Leach, 2008] Hirst, Mark and Souchon, Eric. H.G. Leach (Fiji) Ltd. Interviewed August 2007 through December 2009.

Hydroplan. Naboro Landfill Project: Master Plan. Final Report. 2002.

Johannessen, Lars Mikkel. Guidance Note on Leachate Management for Municipal Solid Waste Landfills. Urban Development Division. The World Bank. Urban Waste Management Working Paper Series No.5. November 1999.

Mihelcic, James R. and Zimmerman, Julie Beth. Environmental Engineering: Fundamentals, Sustainability, Design. Chapter 13. 2010.

Rushbrook, Phillip and Pugh, Michael. Solid Waste Landfills in Middle- and Lower- Income Countries: A Technical Guide to Planning, Design, and Operation. World Bank Technical Paper No. 426. 1999.

Tanner, Chris and Daker, Andrew. Naboro Landfill: Leachate Management Concept Design. Final Report. September 6, 2005.

Troschinetz, A.M. and Mihelcic, J.R. "Sustainable Recycling of Municipal Solid Waste in Developing Countries." *Waste Management*. Vol. 29 No.2. Pages. 915-923, 2009.

[UNEP, 2002] United Nations Environment Programme. A Directory of Environmentally Sound Technologies for the Integrated Management of Solid, Liquid and Hazardous Waste for Small Island Developing States (SIDS) in the Pacific Region. July 2002.

[UNEP, 2005] United Nations Environment Programme - Division of Technology, Industry, and Economics. Solid Waste Management. 2005. Accessed March 3, 2008. http://www.unep.or.jp/ietc/Publications/spc/solid_waste_management/index.asp

[USEPA, 2000] United States Environmental Protection Agency. Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Landfills Point Source Category. Federal Register Environment Documents. Rules and Regulations. Vol. 65, No. 12. Pages 3007-3051. January 19, 2000.

Watling, Dick. Final Report: Naboro Landfill – Technical Assistance to the National Authorising Officer. Volume 1: Main Report. Page 18. February 20, 2005.

[World Book, 2009] World Book Encyclopedia. Fiji. Vol.7, Pages 98-99. World Book, Inc. 2009.

Appendices

Appendix A: Naboro Landfill Leachate Sampling Test Results

Appendix B: Rainfall Data and Outflow Measurements at Naboro Landfill

Appendix A: Naboro Landfill Leachate Sampling Test Results

Date Sampled			**16-Jan-06**		**25-May-06**				**1-Jun-06**				**8-Apr-08**				**1-Aug-09**				
Sample Location			**L1**	**L2**	**L1**	**L2**	**L3**	**L4**	**L1**	**L2**	**L3**	**L4**	**L1**	**L2**	**L3**	**L4**	**L1**	**L2**	**L3**	**L4**	**L5**
Parameters Tested	pH	(units)	6.5	7.1	7.3	7.3	7.8	8.1	7.7	7.7	8.2	8.1	7.71	7.91	8.31	8.28				8.4	
	Conductivity	(μS/cm)			9.97	9.77	5.77	3.25													
	EC	(mS/cm)	2.71	1.71					11.6*	11.3*	4.07*	2.31*	24.4	18.7	8.2	3.5	123.2	82.2	81.4	58.4	52.2
	DO	(mg/L)			0.1	0.1	0.13	0.19	0.12*	0.12*	0.19*	3.28*								0.64	
	Turbidity																			20	
	Ammonia	(mg/L)											2324*	1571*	526*	116*					
	Ammonia-N	(mg/L)																		164	
	Nitrate	(mg/L)																		0.074	
	Nitrite	(mg/L)																		0.055	
	Phosphate	(mg/L)																		3.54	
	Sulphate	(mg/L)																		5	
	COD	(mg/L)											9416	5681	1284	361					
	BOD	(mg/L)	n.deter.	n.deter.																	
	Arsenic	(μg/L)	1.4	0.7																	
	Cadmium	(μg/L)	<0.4	<0.4																	
	E.coli		n.detect.	n.detect.																	
	Lead	(μg/L)	<2.5	<2.5																	
	Mercury		<0.3	<0.3																	
	Oil & Grease	(mg/L)	4	2																	
	Total Coliform	(c/100ml)	1.70E+06	1.10E+06																	
	Zinc	(mg/L)	68.5	55.9																	
Parameters Calculated	Ammonia-N	(mg/L)											1914	1294	433	96					
	TDS	(mg/L)	1734	1094	6	6	4	2	7398	7213	2605	1478	15616	11968	5248	2240	78848	52608	52096	37376	33408
	BOD (60%)	(mg/L)											5650	3409	770	217					
	BOD (40%)	(mg/L)											3766	2272	514	144					

Notes: n.deter. = not determined due to available volume of sample being insufficient. n.detect. = not detectable. *Tests were outside the accreditation of the laboratory.

Appendix B: Rainfall Data and Outflow Measurements at Naboro Landfill

The following information is provided as a supplemental resource in understanding the leachate treatment system at Naboro Landfill. Rainfall data is collected every morning of each day, except on Sundays and Holidays, by HG Leach personnel and recorded in millimeters. The outflow measurements were started on May 2009 by measuring the height of the water level over the "cease to flow point" over the v-notch weir at the outlet point of Pond 3. The available data was collected and recorded by HG Leach. An Advanced Control Engineering (ACE) Quick Ref Table for V-Notch Weir of 90^o was used to determine the flow of the leachate, given the measured height above the v-notch. The values shown for the outflow measurements were converted from litres per second, as provided by the ACE table, to cubic meters per month. It was assumed the outflow was constant during the entire day, as real time data was not available.

Month	**Rainfall (mm)**	**Month**	**Rainfall (mm)**	**Month**	**Rainfall (mm)**	**Month**	**Rainfall (mm)**	**Outflow (m^3)**
Jan-06	307.2	Jan-07	172	Jan-08	453.5	Jan-09	314.5	no data
Feb-06	377.4	Feb-07	539	Feb-08	65	Feb-09	218.5	no data
Mar-06	311	Mar-07	635.5	Mar-08	128.5	Mar-09	389.5	no data
Apr-06	228	Apr-07	692	Apr-08	126	Apr-09	398	no data
May-06	357.5	May-07	84	May-08	248.5	May-09	451	37.7
Jun-06	270	Jun-07	149.5	Jun-08	248.5	Jun-09	206.5	11.5
Jul-06	182	Jul-07	216	Jul-08	85.5	Jul-09	244	11.2
Aug-06	327	Aug-07	377	Aug-08	230	Aug-09	135.5	2.2
Sep-06	537	Sep-07	393	Sep-08	112	Sep-09	432	46
Oct-06	401	Oct-07	826	Oct-08	262	Oct-09	114	5
Nov-06	32	Nov-07	429	Nov-08	334.5	Nov-09	no data	no data
Dec-06	139	Dec-07	111	Dec-08	194	Dec-09	no data	no data
Total 2006	**3469.1**	**Total 2007**	**4624**	**Total 2008**	**2488**			