

**An Investigation of Contaminant Loadings
from the
Robin Hood Bay Sanitary Landfill**

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Summary

The site of the present day Robin Hood Bay Sanitary Landfill (RHBSL) was initially used by the US Military, first as a training facility and as a waste disposal site since the 1940's. With the closure of the American forces base in Pleasantville, the disposal site became the regional municipal landfill site for the St. John's area in 1963. The plume of waste entering the Atlantic Ocean from the stream of leachate draining from the RHBSL has been a cause for concern for quite some time. Nevertheless, in seeking information on the degree of contamination that the leachate stream is transporting, it became evident that little monitoring has been conducted on this environmental problem.

With this realization in mind, St. John's Harbour ACAP (Atlantic Coastal Action Program) committed to conducting a water and sediment research project to increase our understanding of the contaminant loadings leaching from this landfill and discharging – without any containment or treatment – into the Atlantic Ocean. Five water and sediment sampling sites were selected, including a marine site immediately adjacent to the mouth of the stream, and a nearby reference site used for comparative purposes. A total of four sampling suites were conducted during the summer of 2003.

This research study found that the Robin Hood Bay Sanitary Landfill is adversely affecting the environmental health of the stream draining the landfill site (Skerries Brook). Various polycyclic aromatic compounds (PAHs) and metals are elevated above the Canadian Environmental Quality Guidelines. Likewise, excessive amounts of toxic ammonia and severely limited amounts of dissolved oxygen is extremely deleterious to any aquatic species that may inhabit this stream. Nearshore marine sampling in close proximity to the stream also reveals some contamination to the marine environment. The small wetland situated immediately downstream of the landfill appears to be providing some remediation of the leachate, however, the loadings entering this system are beyond the assimilative capacity of this wetland to handle the volumes of contaminants being discharged into it.

Collection and proper treatment of the leachate is essential to controlling the release of pollutants from the RHBSL and to protect the receiving environment. Likewise, applying a proper landfill cover on a daily basis will both reduce the volume of leachate generated, as well as minimizing the amount of plastic and blown debris that is presently escaping into the coastal forests and the adjacent ocean.

1.0 Introduction

The Robin Hood Bay Regional Landfill Site (RHBSL) has serviced the St. John's municipality and surrounding area for over forty years. The landfill is unlined and exhibit's a semi-permeable soil cover, which allows precipitation to percolate through the ground and into the fill. The conditions of the dumpsite have generated concern relating to environmental risks posed to the immediate environment as well as risks posed to the surrounding area of the site. In particular, there is legitimate concern pertaining to the health of Skerries Brook because it flows directly from the landfill, through the adjacent wooded area, and into the Atlantic Ocean. This landfill has been in use for over 40 years; however, minimal research has been conducted to identify the contaminants leaching from the dump. This study aims to serve as a preliminary investigation of the RHBSL and provide a base report for future work and study pertaining to the conditions and activities of the landfill.

The first section of the report discusses the purpose of completing this project and the intended outcome of the study. The background, scope, methodology, and breakdown of project resources are discussed within this section. Section two provides a general overview of landfills with a focus on leachate composition, accumulation and possible negative effects of leachate when present in the aquatic environment. Within this section, the requirements for proper landfill construction and existing provincial legislation for waste disposal in Newfoundland and Labrador are outlined. Section three details the activities of RHBSL and discusses the site in terms of its history, waste management strategy and site operations. The fourth section of the report includes site selection and observations on abundance of aquatic life within Skerries Brook. Section five provides a summary of the results obtained from both the water and sediment samples and highlights values that exceed the Canadian Environmental Quality Guidelines (CEQG). Section six is a discussion of results, which is then followed by conclusions and recommendations. These sections will be discussed in greater detail in the scope of the report.

1.1 Purpose

The purpose of this study is to conduct both water and sediment sampling from various sites along Skerries Brook to analyze the concentration of leachate from the RHBSL and to provide preliminary discussion on any possible adverse effects the free-flow of leachate might have on surrounding flora and fauna in this area. The main parameters investigated in this report include pH, conductivity, temperature, nutrient loadings, dissolved oxygen, organics, metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls(PCBs), pesticides and the lighter end aromatics, benzene, toluene, ethyl-benzene and xylene (BTEX).

Since RHBSL is the primary depository of solid waste for the City of St. John's and the greater Avalon region, improvements with respect to the treatment, handling and deposition of municipal waste is crucial to the future viability and modernization of this landfill. By undertaking this preliminary investigation, it is anticipated that discussion and research will be stimulated to generate a heightened awareness of the chemical cocktail in this landfill, as well as encourage responsible action with respect to site remediation or site closure.

1.2 Background

The Robin Hood Bay Sanitary Landfill has serviced the City of St. John's as well as the City of Mount Pearl and the Town of Goulds since 1963. In the past fifteen

years, RHBSL has also serviced the Towns of Pouch Cove, Torbay, Logy Bay-Middle Cove-Outer Cove, and Portugal Cove-St. Philips (Kavanagh, 2003). More recently, this landfill has also become a receptacle for municipal wastes from a number of additional communities around Conception Bay as their traditional sites have been closed down. According to a study conducted by the Greater Avalon Regional Waste Management Committee (GARWMC), the RHBSL has been in use since the early 1940's and prior to being used as a landfill, it was utilized by the US Military as a training facility (GARWMC, 2002).

For many years, little to no restriction has been placed on the dumping and sorting of waste in Robin Hood Bay; however, in the past ten years restrictions on what can be dumped as well as different dumping zones have been introduced. This will be discussed more thoroughly later in this report.

The landfill is located in the northeast region of the city and the entrance to the dump is off the newly constructed Outer Ring Road, which runs parallel to the site. The landfill covers an area of approximately 203.36 ha and has a 1.6 km development control zone surrounding the entire perimeter of the dump (Kavanagh & Associates Ltd, 2002). Despite this control zone, development has still taken place. Residential development such as Newfoundland Drive and King William Estates are within this 1.6 km mark.

The general topography of the land around the site is heavily wooded with a gradual sloping of the land towards the ocean (See Appendix A; Figure 1). Within the site there is little vegetation; however, at the lower edge of the main road that circles the landfill there is a small brook that flows through the landfill area (See Appendix F; Figure 2). Vegetation within the marsh is plentiful and consists of varying types of grasses and shrubbery. The brook that flows through the marsh is known as Skerries Brook and is the main visible source of drainage from the dumpsite. The brook flows approximately 2.5 km from the landfill and then flows directly into the Atlantic Ocean (See Appendix A; Figure 3). The landfill is capped by a layer of permeable soil and is unlined, thereby allowing the percolation of precipitation into the landfill. This precipitation flows through the soil and waste materials potentially picking up contaminants which empties into the marshland and Skerries Brook, and from there discharges into the Atlantic Ocean. Since Skerries Brook is the only natural drainage area on this site, in the absence of engineered controls, the likelihood of leachate flowing from the landfill and draining into the surrounding marsh, brook and Atlantic Ocean is high (See Appendix A; Figure 4).

As previously mentioned, the focus of this report is to identify the concentrations of various constituents in the leachate of Skerries Brook and comment on their toxicity by comparing the recorded values to the Canadian Environmental Quality Guidelines developed by Environment Canada. The environmental and health risk posed by this leachate to the surrounding habitat, residents of the area, and hikers of the East Coast Trail is not well understood. A preliminary investigation of the composition and concentration of leachate in this site will serve as a basis to predict possible adverse impacts on the surrounding environment.

Overall, this study is designed to raise awareness of an environmental issue that requires more attention by municipal, provincial and federal authorities in order to correct these impacts and to bring the operation of this landfill within accepted modern standards. St. John's Harbour Atlantic Coastal Action Program (ACAP) received permission and funding to carry out this study to consolidate previous research conducted on the Robin Hood Bay landfill as well as to form a preliminary understanding of possible leachate contamination from this unlined landfill.

This study will not only inform people of the current environmental condition of the waste disposal system that services much of the Avalon region, but should also bring attention to the fact that this dumpsite may pose risks to the health of the local ecosystem.

1.3 Scope

Before summarizing the results obtained from this study, it is necessary to provide a brief overview of landfills in general. Within this section, the problems of leachate are thoroughly reviewed with reference to specific constituents that are of interest to this study. This is followed with a brief discussion on the proper design and construction of landfills to provide the reader with a general overview of what constitutes a poorly constructed and properly constructed landfill. Provincial legislation on landfills is reviewed and some discussion with regards to the *Environmental Protection Act (Waste Disposal Regulations)* is provided. This section closes with a briefing on significant components of the Robin Hood Bay Sanitary Landfill, including the area it services, site description, waste quantities, leachate management, and the present monitoring program.

Following the overview of landfills and RHBSL in particular, a description of the sampling sites is discussed. Within this section, the general topography of the land, geographical placement, conditions of the site and reasoning for specific site selection is provided in detail. General weather conditions of the sampling dates are also provided in this section.

The successive section details the chemical constituents tested in this study. A description of the constituent and why it was analyzed is provided along with a summary table of the concentrations (per site and date), the average concentrations (per site), and the limit of the concentration for aquatic life according to the Canadian Environmental Quality Guidelines. This section is divided into sediment and water samples and further divided into more specific groupings.

The final section of the report discusses the results in terms of their environmental significance to the Robin Hood Bay area, Skerries Brook and the Atlantic Ocean. Only parameters of interest will be discussed in this section. The report closes with some broad conclusions and recommendations for future study in this area.

There are, of course, several limitations that should be discussed to account for any perceived shortcomings of the quality and/or content of the research. When conducting a project of this caliber it is highly unlikely to not encounter any limitations. One large constraint for this project involved time. The sampling took place over the course of a two-month period, but it is recognized that a greater sampling period of a year or more would yield more conclusive findings. Ideally, the results could be based on seasonal variation as concentrations of constituents vary according to precipitation levels. This limitation does not pose any major problems to the quality of the study because sediment samples are not highly affected by seasonal variations and so the results for sediment are analyzed quite confidently.

Another limitation for this project involves financial constraint. Greater finances could support increased technical expertise and equipment to investigate the topography, hydrology and cover permeability of the site. The quantity and flow rate of precipitation permeating through the soil cover of the landfill could be determined through increased knowledge of the hydrology and topography of the area. If the flow and speed of leachate through the dumpsite could be tabulated, the quantity of chemicals flowing through the landfill and into the surrounding environment could be

more accurately predicted. The absence of these complicated, costly and timely procedures does not debilitate the quality or outcome of the study.

1.4 Methodology

The initial phase of the project involved interviewing stakeholders and a literature review. Preliminary information pertaining to previous scientific research and waste disposal practices was gathered mainly through informal interviews and requests. Additional information sources used throughout this project include local studies conducted by groups such as Kavanagh and Associates Limited, The Greater Avalon Region Waste Management Committee, The Department of Municipal and Provincial Affairs, the City of St. John's, and The Department of Environment and Conservation. It should be noted that literature on leachate impact from landfills in the Atlantic region and beyond had been difficult to obtain, although the City of St. John's has recently released a report on the engineering feasibility assessment of Robin Hood Bay that was prepared by Gartner Lee Limited. With respect to exclusive studies pertaining to chemical analysis of leachate in Robin Hood Bay, only one unpublished study conducted by Memorial University in association with the Department of Fisheries and Oceans was found. Unfortunately, this study remains incomplete and could not be used for final comparative analysis.

In addition to acquiring various studies, scholarly literature such as books, journal articles, and research papers were obtained. Other non-scholarly literature including newspapers and internet sources were also used to aid in the execution of this study. Topographic maps were collected from the City of St. John's Engineering and Planning Department and aerial photographs were obtained from the Department of Government Services and Lands; Crown Lands Division. These maps and photographs were used to aid in visual interpretation of the site as well as to assist in understanding the design of the landfill and the most probable path for leachate flow.

The second phase of the project involved a visual assessment of the site. A hike was arranged through St. John's Harbour ACAP and included personnel from Environment Canada and the East Coast Trails Association. The degree of impact from the dumpsite is difficult to determine based on preliminary visual assessment; however, it was apparent through the discoloration of Skerries Brook and scattered debris outside the footprint of the dump that the soil covering of the landfill does not contain the refuse in the designated disposal area. This will be discussed in greater detail in the summary section of the report.

After completing the visual assessment, the sample sites were selected with the help of Environment Canada staff and the ACAP team. The sites were chosen based on the general location of the site relative to the landfill. There were five sites selected in total, with three of the five sites selected in Skerries Brook. A marine site was chosen adjacent to the mouth of the brook and a reference site was chosen in the area, but away from the landfill.

The third phase of the project involved the collection of both sediment and water samples from the designated sampling locations. These five sites were tested on four different occasions throughout the months of July and August and the samples were sent to the EC laboratory in Moncton, New Brunswick for analysis.

The final stage of the project involved interpreting both the sediment and water sample data and final report writing. The results are compared to the Canadian Environmental Quality Guidelines and conclusions and recommendations are developed based on the final results.

1.5 Breakdown of Project Resources

The most important resources provided to this project are in-kind support provided through Environment Canada. Resource personnel including Ron Hunter, Glenn Worthman, and Art Cook of Environment Canada provided invaluable assistance and knowledge during the study. Other resource personnel include Gerri King of the City of St. John's, Toby Matthews with the Department of Environment and Conservation, and Mike O'Connell with the City of St. John's; Maps Division.

In-kind resources also include the provision of EC laboratory equipment such as pH meters, conductivity meters, sampling bottles, coolers, and shovels. The Canadian Coast Guard provided two Boston Whalers for a half-day sampling excursion. St. John's Harbour ACAP provided \$5000, which contributed towards chemical analysis of the leachate in the Environment Canada laboratory in New Brunswick. Considerable in-kind analysis was also provided by this laboratory.

2.0 Landfills: An Overview

Municipal landfills are an issue of increasing concern in today's society. When adequate recycling programs are not in place, the combination of increasing populations and their use of disposable products only exacerbate this concern. In recent decades, the size and number of landfills in Newfoundland and Labrador have increased. Nevertheless, most of these landfills were created prior to implementation of better landfill engineering practices. Older landfills do not provide a means by which to properly confine waste within the landfill footprint. In addition to the increase in waste generation by today's society, the composition of waste is much less organic and far more laden with complex industrial polymers that may jeopardize the health of the environment and communities adjacent to these dumps.

Fortunately, more stringent guidelines and regulations are now in place to regulate the type and quantity of waste entering a landfill. Furthermore, the design and construction of more recent landfills are engineered to handle, treat and dispose of waste in a more environmentally and economically favorable manner. It is no longer acceptable to dispose of waste through a hole in the ground where no lining is used to protect against chemical seepage.

Many landfills are not within current legislative requirements and standards, and often their poor design and ineffective construction are simply no longer appropriate for the types of refuse being deposited in these sites. Unfortunately, the frequent dumping of waste in outdated landfills still continues as population pressures, increased waste, and insufficient funding for proper sites persists. Inevitably, this creates many environmental problems as municipalities are under pressure to maintain aging landfills to support increased disposal of waste that is more exotic and potentially more hazardous compared to years ago. In understanding the merit of this report, it is necessary to inform the reader why a poorly engineered landfill, such as the one in Robin Hood Bay, is increasingly unsuitable to support the expanding population of the Greater Avalon Region. The following section outlines some general issues of leachate; what it is, and why it's not good for the environment. It is essential to understand the negative impacts of leachate as well as some of the negative consequences of free-flowing leachate to appreciate the context of this study.

2.1 Leachates in the Environment

'Leachate' refers to the liquid that has separated from hazardous waste with or without any substance dissolved or suspended in it. Landfill leachates form when liquid originating from rain, melted snow, or the waste material itself percolates through a landfill and moves to the bottom or sides of the fill. It then transports a wide variety of chemicals to the extremities of a landfill (Friends of the Earth, 1999). The quantity of the leachate correlates highly with the amount of precipitation in the area of the landfill site. Moreover, the amount of leachate is also dependent on the amount of liquid waste that is disposed into a landfill, as well as the type and quantity of chemical constituents deposited in the dump. Groundwater also contributes to leachate volume and even though groundwater may dilute the leachate, it still aids in carrying it out of a contained area and into the surrounding environment. For example, if a landfill is built in or near a wetland adjacent to a river, as is the case at Robin Hood Bay, groundwater will flow through the garbage and provide additional liquid to mix with the surface water and waste (See Appendix A; Figure 5).

The quality of municipal landfill leachate varies greatly within individual landfills. Leachate contains hundreds of different chemicals, which are influenced by factors such

as the type of waste deposited and the rate of biological and chemical decomposition taking place (Friends of the Earth, 1999). Landfills contain a variety of potentially hazardous chemical constituents and pathogenic organisms that may have adverse affects on public health, groundwater quality, and the environment. These constituents are not necessarily those classified only as hazardous waste, but also include regulated hazardous chemicals such as heavy metals, volatile organic compounds, chlorinated solvents, and conventional pollutants (Lee & Jones-Lee, 1993). Volatile organic compounds or hydrocarbons can be toxic or carcinogenic and they are not easily broken down during chemical processes in a landfill. In addition to this, they can be highly mobile and capable of migrating with leachate and groundwater far beyond the boundaries of the landfill.

Metal ions can be found within leachate, but they also occur naturally in the environment. These ions move through the environment and may pose problems to plant, animal and human life. Factors affecting metal ion content are pH, temperature, the age of the landfill and types of waste in the site (Alker, 1995). Behavior of metal ion content within leachates is not fully understood and there are many factors that affect the motility of the ions in a landfill. For example, precipitation plays a large role in ionic movement. Another factor relates to the associative properties of metals. Motility of an ion is affected by the concentration and the greater the motility of an ion, the higher its concentration will be (Table 1: Alker, 1995).

Table 1: Examples of Motility and Mechanisms for Metal Ions in a Clay Environment (Alker, 1995).

Metal Ion	Motility in Clay Environment
Cadmium	Moderate
Chromium	Low-High
Copper	Low
Iron	Moderate
Magnesium	Moderate
Zinc	Low

Overall, there is a common misconception that since the materials placed in municipal solid waste landfills are basically household waste, they are relatively “safe” and will not likely affect public health and groundwater quality. In fact our landfills receive waste from a variety of sources including industrial, institutional and household hazardous waste. If an individual could consider the proposition of drinking or even smelling the ooze that develops at the bottom of a garbage can, they would most definitely decline. People do not associate the risk of this ‘ooze’ from a landfill because the associative value of the ooze is diminished once it’s removed from the individual home and placed out of site in a poorly constructed landfill. People must realize that our municipal landfill is like a big garbage can, and the ooze that leaks from the bottom of the bag can be compared to the leachate that flows from the dump. This leachate determines its own fate in the surrounding environment and therefore presents a risk to human health and the environment as it escapes, uncontrolled. This risk can increase depending on the age of the dump as well as the type of waste disposed within the dump. The quantity and quality of leachate from the Robin Hood Bay landfill will be discussed in detail in the summary section of this report.

2.2 Construction of a Secure Landfill

Constructing a landfill requires careful planning, in-depth research and strategic engineering and design. The main objective isolating waste in a landfill is to avoid hydraulic connection between the wastes and the surrounding environment. Preventing the escape of contaminants through the bottom and top of the landfill should be the two primary concerns in construction and design (Daniel, 1995). There are four elements to discuss when securing waste in a landfill, and these include the bottom liner, leachate collection system, covering, and the natural hydrogeologic condition of the land. It is relevant to briefly discuss these elements so their importance can be reflected upon when discussing the current conditions and design of the RHBSL.

2.2.1 Bottom Liner

The bottom liner of a landfill is made of one or more layers intended to inhibit the leachates from penetrating into the groundwater and natural soil underneath. To effectively illustrate their purpose, liners have typically been referred to as a 'bathtub'. The liners are constructed of three main materials including clay, plastic or a composite mixture (Daniel, 1995). Even though liners aim to protect against leachate seepage, they all have their faults. For example, the texture and natural consistency of the clay liners can crack or fracture over time and leachate can eventually seep through these cracks and fractures (Friends of the Earth, 1999).

Plastic liners are a sensible alternative to clay liners; however, they too have their problems. Household products have been reported to break down even the heaviest and most resistant plastics such as high-density polyethylene (HDPE). When these liners degrade, a permeable liner is the result and a pathway for leachate to escape is therefore created. Even household items such as margarine, vinegar, alcohol, shoe polish, and oil can contribute to the degradation of plastic liners (Pellarano, 1995).

The final category is the composite liner, which is made of both plastic and compacted soil. The plastic works together with the soil to prevent or minimize the leaching of chemicals (Pellarano, 1995) and the use of composite materials is perhaps a more efficient alternative to using either one or the other.

A recent study prepared for the City of St. John's by Gartner Lee Limited has raised the issue of whether a liner is required at the Robin Hood Bay Landfill, and claims that the existing bedrock provides containment of the leachate. However, at the time of writing this report, there is still some debate concerning those conclusions and further examination of these findings is continuing.

2.2.2 Leachate Collection System

A leachate collection system is built underneath the landfill. As the name suggests, this system is designed to collect the leachate that accumulates at the bottom of the fill. When designing a landfill, the bottom layer is sloped downward to allow the leachate to flow with the movement of the water. In an ideal system, the water is then pumped to a nearby wastewater treatment plant, where it is purified. The remaining chemicals are then collected and securely stored. Various problems with these systems include pipes that clog from silt and sand, and fouling by microorganisms growing on the inside of the pipes. In addition to this, pipes also become weakened by chemical corrosion (Pellarano, 1995).

2.2.3 Covering

The covering or cap of a landfill is the most complex unit and is responsible for controlling runoff, separating wastes from the surface environment, limiting the

infiltration of precipitation into the fill, and controlling the release of gases (Daniel, 1995).

Landfill covers are usually composed of compacted clay and geosynthetic clay liners. Clay covers demonstrate the greatest problems because the spaces between each particle can sometimes be large enough to promote natural cracking and therefore support the flow of precipitation through the waste. Geosynthetic covers are much more resistant to damage caused by freezing and desiccation. This type of cover uses synthetics to prevent precipitation from entering the waste and is the most common source of covering used for sanitary landfills. In choosing a cover design, many factors such as temperature variations, wet and/or dry seasons, penetration of plant roots, wind/water erosion, and long-term moisture changes must be considered (Daniel, 1995).

Five general layers typically compose the total covering of a landfill and include the surface layer, protective layer, drainage layer, barrier layer and a gas collection/foundation layer. The surface layer of a landfill cover is made primarily of soil and supports vegetation, which minimizes erosion and transpiration of water back into the environment (Daniel, 1995). The protective layer is designed to store any water that has entered the landfill until it is removed by evapotranspiration. This layer also prevents freezing of the water. The drainage layer helps reduce infiltration of water by draining the protective layer into the drainage layer. This layer uses sand or gravel to help drain and filter the collected water. The barrier layer is the most critical layer because it prevents the water from percolating through the cover system by impeding infiltration, and by promoting storage or drainage of water in the overlaying layers. The final layer in a properly capped landfill is the gas collection/foundation layer. This layer acts as a gas collector for discharge as well as serves as a foundation to support the previous layers. Gas collection is only necessary for capping wastes that are volatile. The gas flows into vents naturally or by way of vacuums. This layer is usually made of soil (Daniel, 1995).

2.2.4 Natural Hydrogeologic Setting

When using the natural setting to enhance the function of the landfill site, the geology of the area should be as simple as possible. The directional flow and speed of the leachate into the surrounding environment can be more accurately predicted if the hydrology of the area is not complicated. The natural features of an area such as the topography and geology of land can aid in the effectiveness of a landfill and should not be overlooked when determining the best location for the site.

2.3 Legislative requirements

According to the *Environmental Protection Act (Waste Disposal Regulations)* of Newfoundland and Labrador, there are certain requirements for selecting a site under provincial regulations. The following criteria for waste disposal in the province was developed in an effort to help control, monitor and ensure safe and proper disposal of materials as well as create safe conditions within and around the site:

- The site should be 300 m from a road and not visible from the road
- The site should be 1.6 km away from any residential area
- The site should have a 60-meter wide area around the site of cleared soil to serve as a fire break
- Should have a fence around the entire perimeter of the site
- The site should be 150 m away from brooks, rivers or ponds

- The site should exhibit year-round access with a gate
- The site should have easy access to a body of water for fire control
- A portion of the site should be suitable for car wrecks and scrap metal storage (Griffin & Minty, 1993).

Unfortunately, many of the landfills that exist within the province, including the site under investigation, do not meet all of these requirements. The Department of Environment's consultation paper *Protecting our Environment for Tomorrow Newfoundland* notes that in this province, there are approximately 240 waste sites, and a number of these are at the end of their useful life span. Communities are seeing nuisance problems from poorly or improperly maintained landfill sites and concerns have been expressed that the many unsightly dumps are not in keeping with the expectations of our growing tourism industry. The Greater Avalon Regional Waste Management Committee was formed in 2002 to introduce the feasibility and logistics of a single waste site for the entire Avalon region of the province. The intent of the committee was to devise one waste management site to service approximately half the population of the province. In addition to this, the committee aimed to reduce the number of waste sites currently in operation as well as reduce the amount of material going into the landfill site.

2.4 Robin Hood Bay Sanitary Landfill

Before discussing the results of this study, it is necessary to provide some pertinent information regarding RHBSL, the service it provides and the general operations of the site. Most of the following information was taken directly from a study conducted by Kavanagh & Associates Limited in 2000 on the operation of RHBSL. Within this section, an overall description of the site is provided along with the quantities and types of waste disposed, and how the leachate is presently managed.

2.4.1 Service Area

As of 2000, the area serviced by the RHBSL includes the Cities of St. John's and Mount Pearl and the Towns of Conception Bay South, Paradise, Portugal Cove-St. Phillips, Torbay, Pouch Cove, Logy Bay-Middle Cove-Outer Cove, Flatrock, Petty Harbour-Maddox Cove, and Bauline. According to a 1993 population study for the St. John's Urban Region, the projected population for this region will increase from over 170,000 people in 1996 to over 200,000 people by 2012 and over 230,000 by 2030 (Kavanagh, 2000: 6).

2.4.2 Site Description

As previously mentioned in the background, the RHBL has been in operation for over 40 years. For the first 25 years of operation, there was little restriction on the type of waste that could be disposed of and toxins such as hydrocarbons and effluent from septic tanks were permitted in the fill (Kavanagh, 2000: 6). During this time, much of the waste was burned to reduce its volume and to minimize the space requirement for the dump. In one respect, the burning of waste was beneficial to reduce vermin and gull populations, but the smoke and smell affected residents within miles of the area and forest fires often resulted from blowing debris. Eventually, the burning of waste was prohibited and in order to control the gull problem, a 300 mm thick gravel cap was introduced to help conceal the waste. Gravel is now used to cover the waste dumped at this site and to assist with vector control and blowing debris.

The site has a gross area of approximately 203 ha of which 43 ha are used for waste disposal. This area averages 1.5 km in length and 1.4 km wide. The site is situated in a natural valley making this location ideal for dumping waste. There is a 1.6 km development control zone that extends north to the Ocean Sciences Center, south to Quidi Vidi Harbour and west to the centre of Virginia Lake. It is also presumed that this control zone extends out to the Atlantic Ocean to control ocean related activities (Kavanagh, 2000: 7).

The control zone is within provincial guidelines for landfill use; however, residential development such as Newfoundland Drive, Virginia Waters, King William Estates and Woodlands exists within this zone. Commercial properties in the no-development zone include the Department of Works, Services & Transportation, the White Hills Industrial Park and Crosbie Industrial property (Kavanagh, 2000: 8).

As previously mentioned, the designated fill site is capped with gravel, but the surrounding location is covered in vegetation that includes evergreens and deciduous trees. On the southeast corner of the landfill, there is a marshy area and a culvert that drains water from underneath the landfill into Skerries Brook. For an aerial photographic view of RHBSL, refer to Appendix B.

2.4.3 Waste Quantities

According to Kavanagh & Associates Ltd. (2000), quantities disposed at RHBSL from 1991 to 1999 have been divided into 26 categories. These wastes consisted of substances from bunker oil to hospital waste to harbour sludge. The treatment and handling of waste for the RHBSL has improved over the years. For example, hydrocarbon contaminated soil and septic tank sludge are now taken to a treatment facility in the Conception Bay South area. In addition to this, there is no longer permission to burn waste openly and certain quantities of waste have been reduced through waste diversion programs. For example, metal recycling is available through a metal salvage company located adjacent to the site (Kavanagh, 2000: 13).

It is important to note that the introduction of the metal salvage operation, the treatment facility for hydro-carbon contaminated fill, a septic sludge treatment facility, a commercial cardboard ban, and the collection of various recyclables have contributed to a 21.6% waste quantity reduction from 1992 to 1996. There was a dramatic increase in total waste quantity by 15.6% in 1997 and 23.8% in 1998 (Kavanagh, 2000: 15). This is attributed to the closure of the Conception Bay South Waste Disposal Site. Some points to highlight with respect to the solid waste quantities include the increase in miscellaneous waste from under 3000 tonnes in 1991 to just under 6500 tonnes in 1999 and the introduction of rubber tires to the dump at close to 1000 tonnes in 1999 from very few previous to this year. Of particular interest to this report is the miscellaneous waste water that is disposed of annually. Waste water contributes to leachate accumulation as the water provides a medium for other toxic constituents.

There is no set lifespan for RHBSL, however, it is predicted that if this particular site continues use, the projected quantity of waste will be approximately 8,000,000 tonnes by 2045. The Gartner Lee report (2004) indicates the RHBSL has the potential for 30 more years of life.

2.4.4 Leachate Management

During waste disposal operations, surface water inevitably enters the site where it makes contact with exposed waste and becomes leachate. To reduce this problem, Kavanagh & Associates Ltd. and the Gartner Lee Ltd. report have suggested several methods to divert the precipitation away from coming into contact with the waste. They

have proposed the construction of surface water management ditches around the entire waste disposal fill area and proposed the construction of temporary drainage ditches adjacent to each section, or cell boundaries to convey the surface water run-off away from the cell (Kavanagh, 2000; 28).

The current leachate management system for the Robin Hood Bay Landfill is to allow the leachate to discharge from the culvert at the south-east end of the fill and into the marsh area and ultimately into the ocean via Skerries Brook. Since leachate is primarily a function of the quantity of precipitation, RHBSL has the potential to generate high levels of leachate flow because the precipitation for the Avalon region is high (1500 mm/annually). Moreover, the covering for the landfill consists of a highly permeable layer of gravel and soil, which contributes further to the flow of precipitation through the landfill. The topography of the landfill is not sloped enough to support proper drainage and therefore the covering is not conducive to surface run-off. Even though the overall area of Robin Hood Bay slopes downwards towards the ocean, the actual fill area is not sloped enough to promote proper drainage and so water pools and percolates straight down through the dump. As mentioned earlier in this report, groundwater contributes to leachate flow and even though investigating groundwater flow is beyond the scope of the study, the probability that groundwater contributes to the total amount of leachate generated from this site, is high. Overall, it is predicted that approximately one million cubic meters of leachate is generated annually from the RHBSL (Kavanagh, 2000: 46).

In the next section, the report summarizes the procedures and protocols used to determine site selection, and provides relevant discussion on significant parameters tested during this study. The significance of these parameters is discussed with respect to their potential negative environmental impact, and summary tables are provided to highlight results that exceed the values established in the Canadian Environmental Quality Guidelines.

3.0 Sampling Site Selection

An important aspect to any field sampling program is to follow standard protocols to ensure quality results. Equally important is the selection of sampling stations representative of site conditions. There are many methods that can be used when deciding an appropriate sampling protocol; however, there are usually one or two methods that best suit the intentions of the research. In the interest of this study, it was decided that specific sampling locations would be chosen based on their proximity to the landfill and the end point of the effluent. As previously mentioned in the methodology section of this report, five sampling stations were chosen starting with the marine sample at the plume where Skerries Brook emptied into the Atlantic Ocean and ending at the discharge point from the landfill where Skerries Brook begins. A reference site was chosen in a brook located north of the landfill and upgradient of any influence of the site. Figure 1 depicts the locations of the five sample sites used in this study.

3.1 Sampling Protocol

In an effort to determine leachate concentration for water and sediment samples in this area, appropriate sites and methods of sampling were considered. With the collaboration of perspectives from both Environment Canada and St. John's Harbour ACAP, five sampling stations were identified for this study. Water samples were collected in clean glass or plastic bottles and preserved appropriately, depending on the parameter. The PCBs, PAHs and organochlorine pesticides were collected in 1 litre solvent rinsed, amber glass bottles for both water and sediment testing. Samples to test for total phosphorous, total organic carbon (TOC), total nitrogen, and ammonia were collected in 500 ml HDPE bottles and preserved with a 0.2% solution of sulphuric acid. Samples to test for metals were collected in 125 ml bottles preserved with 0.2% nitric acid. Samples to test for BTEX were collected in 20 ml amber glass bottles with no preservatives. The samples were collected in a manner that ensured minimal contact with the air and the bottles were filled completely to the top and stored in a cooler to ensure a relatively constant temperature.

Originally, there was a preference to obtain samples during both wet and dry seasons to account for changes as a result of fluctuations in the water table; however, considering the constraints of time and money, this was not possible. Four sets of samples were collected during the months of July and August and are therefore considered dry season samples.

3.2 Site Selection

RHB Sampling Site 01: This site is located east of the landfill on the downstream side of Skerries Brook. The latitude for this sample site is roughly 47°35.798 N, the longitude is 52°39.595 W and the elevation is at sea level, being the only marine sample site conducted in this survey. The samples were taken in the plume of effluent where the mouth of the river empties into the Atlantic Ocean (See Appendix A; Figure 6). For the first sampling trip, the Canadian Coast Guard supplied two Boston Whalers for the expedition and water samples were taken off the side of the boat by the effluent plume. This plume extends outwards from the shore about 25 - 75m and is very turbid.

The wave action on the first sampling date of July 17, 2004, was low to moderate and did not impede the collection of samples. The sediment sample was unattainable due to the rocky substrate at the bottom of the ocean in this area. The grab sampler was deployed six times in an effort to obtain sediment, but sample trials were

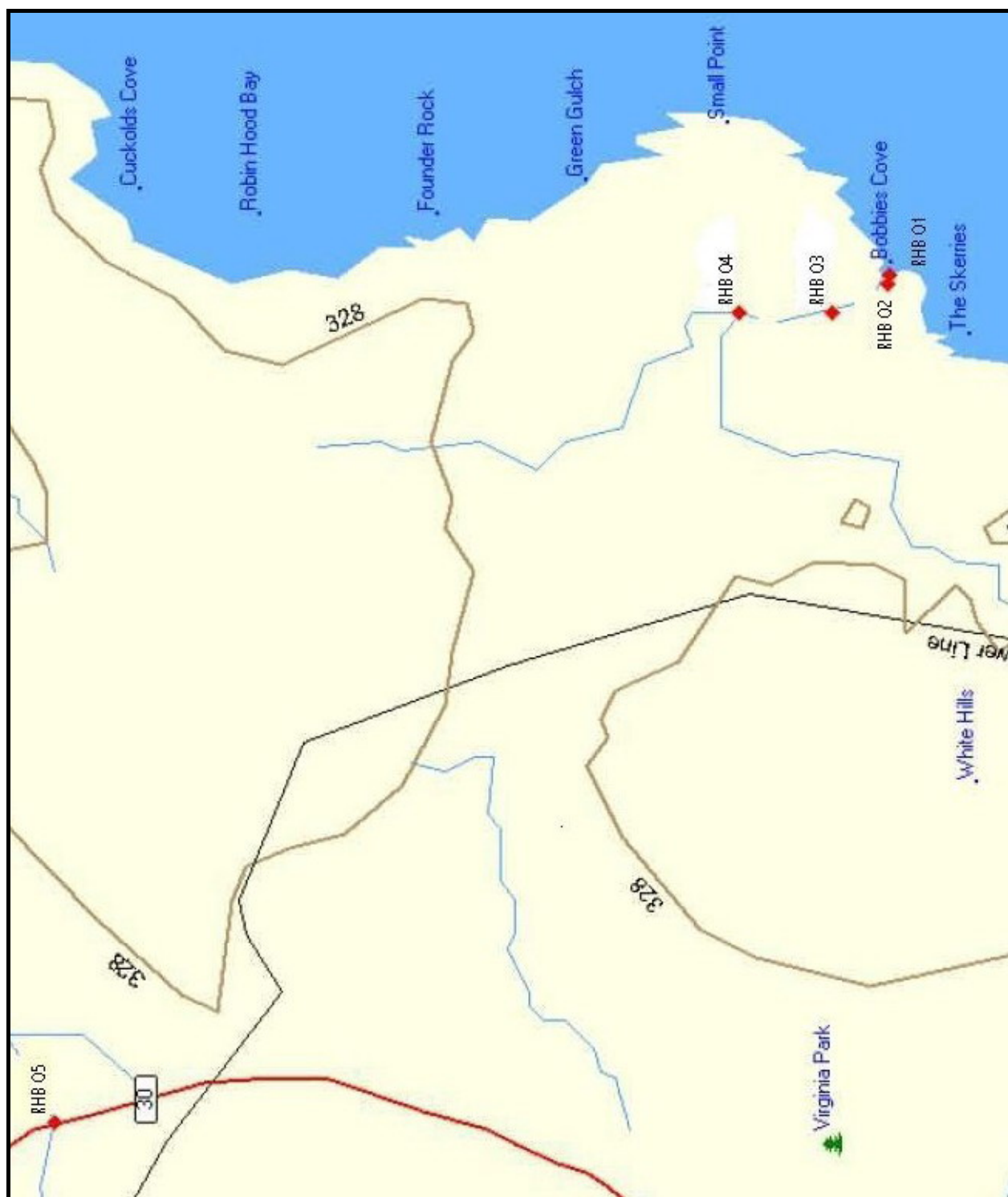


Figure 1: Robin Hood Bay Sampling Site Locations

terminated after realizing the extraction for sediment was unlikely. Should future efforts be attempted to collect marine sediment samples in this area, the aid of a diver would be helpful in locating sediment deposits.

For the remaining four sampling dates RHB-01 water samples were collected using a rod that extended approximately 10m out into the ocean with a sampling cup attached to the end. The sample was then retrieved and brought back to the shoreline where it was deposited into the designated sampling bottles.

RHB Sampling Site 02: This sampling site is located close to the mouth of Skerries Brook before it empties into the ocean. The river exhibited a low flow rate during the sampling period and rocks protruded from the water (See Appendix A; Figure 7). The water displayed a rusty brown coloration and at the time of sampling, the water was very turbid and visibility was zero. This sample site is approximately 50 m from the ocean and was strategically chosen to determine if the quality of leachate from the landfill to the mouth of the river attenuates by dilution. Sediment samples were easily obtained in this area because particles from upstream were deposited in this area. The coloration of the sediment was rusty brown and consisted of very fine particulate. The latitude for this sampling location is 47°35.800 N, the longitude is 52°39.600 W and the elevation is 1 m.

RHB Sampling Site 03: This sampling site is located in Skerries Brook approximately 200 m east of the marsh. The location was strategically chosen “post-marsh” to determine if the wetland contributes any remediation value for the leachate released from the landfill. The river exhibits the same red brown coloration as the other sampling stations along Skerries Brook and the rocks are discolored reddish brown, indicating precipitation of iron oxide from the river (See Appendix A; Figure 8). The water is turbid and displays zero visibility. Sediment was more difficult to collect in comparison to the sediment downstream, but was still attainable. This sampling location was in thick woods and the odor emitted from the brook was pungent. The latitude for this sampling location is 47°35.878 N, the longitude is 52°39.656 W, and the elevation is 31m.

RHB Sampling Site 04: This sampling site is located “pre-marsh” where Skerries Brook flows directly out from the berm roadway at the southeast end of landfill through a culvert and collects in a small pool before flowing through the marsh. The berm roadway is elevated approximately 10 to 15 m above the river and slopes downwards to the marsh on an approximately 60° degree incline or greater. The natural topography of the land in this area consists of the marsh and brook, which is settled in a valley surrounded by a forested area. The elevated landfill above the marsh and brook area is not the natural topography of the land and is the accumulation of waste materials over the years. RHB-04 was chosen based on two factors: one is the fact that this location is the only apparent discharge point from the landfill where Skerries Brook begins, and the other is the fact that it is pre-marsh and there is heightened interest in this study to discover whether the concentration of leachate is greater in the pre-marsh area as opposed to the post-marsh area. The water in this location is reddish brown and a layer of oil was visible on the surface of the water during the sampling period. Quantities of loose garbage surround the brook and waste material including scrap metal, plastics and tires were found in the water (See Appendix A; Figure 9). The stream flows into the marsh, which consists of various forms of vegetation and a family of ducks utilize the river and surrounding marsh, appearing relatively tolerant to the polluted stream and wetland. When walking beyond the sampling area and into the marsh, reddish-orange water remains throughout the entire marsh and oily residue seeped up from the ground. The reddish-brown sediment was

moderately easy to obtain and consisted of more gritty sediment than RHB-02 and RHB-03. Oil residue also appeared in the particulate. The latitude is 47°36.015 N, the longitude is 52°39.657 W, and the elevation is 42 m above sea level.

RHB Sampling Site 05: This sampling location served as the reference site so the site had to be located away from Skerries Brook, preferably before the landfill and away from any activities that might be influenced by the dump. The chosen site was a stream located on the north side of Torbay Road, towards the Oceans Sciences Centre. The reference site is particularly useful where CEQG values are not provided for certain constituents. In these cases, the reference site is used for relative comparison between the concentrations of constituents found in the reference compared to concentrations of constituents found in Skerries Brook. The stream chosen for the reference was very clear during all sampling periods and the sediment was brown and very gritty. The latitude is 47°37.004 N, the longitude is 52°41.399 W, and the elevation is 76 m above sea level.

3.3 Probability for Living Aquatic and Terrestrial Species

It is not apparent through visual observations if aquatic organisms are abundant in Skerries Brook. Since the water is extremely turbid the visibility into the water column was extremely poor. No fish were observed and no aquatic insects were visible through any of the sampling sites on any of the days. Several frogs were heard on July 17th and on every sampling date, ducks were observed swimming around sampling site RHB-04, directly below the landfill area. Vegetation is plentiful in the marsh and flora such as the blue flag iris and other typical marsh inhabiting species were thriving in this area. The river itself exhibits no plant life and algae is absent from the rocks in the brook.

3.4 General Weather Conditions and Sampling Teams

The first sampling trip was conducted on July 17th, 2004 with the assistance of Glenn Worthman of Environment Canada, and Beni Malone and Diana Baird of St. John's Harbour ACAP. General conditions include clear skies with a high temperature of 28°C. The previous night's weather conditions consisted of 30 mm of rainfall and therefore leachate concentration could have been diluted for this sampling date. The second sampling trip was conducted on July 28th, 2004 with the assistance of Andrew Gillingham and Geran Davis of Canadian Parks and Wilderness Society. General weather conditions for this sampling date include clear skies with a high temperature of 23°C. There was no precipitation the previous night. The third sampling effort was conducted on August 8th, 2004 with the assistance of the Newfoundland Conservation Corps. Green Team. General conditions on this sampling date include clear skies with a temperature of 20°C and some precipitation occurred the previous night. The final sampling effort was completed on August 13th, 2004 with the assistance of Beni Malone and Andrew Hennebury of the Torbay Gully Project. Weather conditions on this sampling date were clear skies with a temperature of 20°C. Precipitation was minimal the night before.

4.0 Summary of Results

Environmental conditions such as pH, temperature, conductivity and their relevance to aquatic life are discussed below and tables listing the values for each sample site are provided. The samples taken during the survey are broken down into two matrices that discuss water samples and sediment samples separately. Each matrix is further divided based upon the specific parameters, including nutrient loadings, metals, BTEX, PAHs, pesticides, and PCBs.

The nutrient loadings include nitrate, ammonia, total nitrogen, and phosphorous. Other constituents tested for but not placed in a specific category include chloride, sulphate, total organic carbon, and dissolved oxygen. The metals tested in this study include aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, strontium, titanium, vanadium, zinc, silver, and total mercury. The lighter end aromatic hydrocarbons tested include benzene, toluene, ethyl-benzene, o-xylene, and m+p-xylene. The PAHs measured include naphthalene, acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, and gamma-chlordane. Eighteen organo-chlorine pesticides were measured including O,P'-DDD, P,P'-DDE, O,P'-DDE, P,P'-DDE, O,P'-DDT, P,P'-DDT, alpha and beta-endosulfan, endrin, heptachlor epoxide, alpha and gamma-benzenehexachloride, methoxychlor, mirex, aldrin, alpha and gamma-chlordane and dieldrin. Total PCBs were also tested. It should be noted that because PCBs were detected at very low concentrations and pesticides were not detected at all, discussion about these parameters and summary tables will not be provided in this report.

Descriptions of each constituent and their impact on aquatic life are provided in summary tables that display individual site outcomes, along with the averages for each site. The Canadian Environmental Quality Guidelines (CEQG) values for aquatic life are also provided; elevated concentrations of a particular parameter are highlighted. As previously noted, the CEEQ does not have values for all parameters tested and therefore some of the following tables have no environmental guidelines. In these cases, it is most useful to look at the values for the reference site and assess the relative difference. Some of the results in the raw data are labeled as TC for test cancelled or IN for interference, and in some instances a sample was not obtained successfully. In these instances a slash (/) will be found within the tables to indicate that the sample was either not obtained or was not properly tested. Where only one test result was obtained at a sample site for any given parameter, or the results were below the detection limits, averages would obviously not be calculated. Further interpretation of the results will follow in the discussion section of the report.

4.1 Summary Results for pH, Temperature and Conductivity for Water

Temperature, pH and conductivity measurements for Skerries Brook, Skerries Bight and the reference site were taken in the field using equipment provided by Environment Canada. These parameters are very important to measure for several reasons. Certain species of flora and fauna are pH and temperature sensitive and fluctuations in these levels can result in an adverse impact on the species inhabiting the particular water body. Temperature, pH and conductivity also help to assess the quality of the water in a given area. The average pH levels for all sites were fairly normal with slightly elevated pH levels at RHB-02 (See Table 2). Temperature readings are useful in helping consider the toxicity of other constituents such as ammonia. Values for all sample sites during the sampling period can be viewed in Table 3. High conductivity

levels usually indicate large amounts of ions in the water, and this is not unexpected based on the observed turbidity in Skerries Brook. The average conductivity levels of RHB-01 to RHB-04 are much greater than the reference site (RHB-05) because there is so much more material in the water (See Table 4). It is important to note that since RHB-01 is a marine sample site, conductivity levels would normally be higher than in fresh water samples.

Table 2: Total on-site pH readings and averages.

pH					
Sample Date	Site Location				
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05
17-Jul-04	8.04	8.25	7.77	6.85	6.85
28-Jul-04	7.89	8.3	7.74	6.41	7.1
8-Aug-04	7.23	7.81	7.6	6.91	7.36
13-Aug-04	6.4	7.31	7.4	6.51	7.32
Average	7.39	7.92	7.63	6.67	7.16

Table 3: Total on-site water temperature readings and averages.

Temperature ° C					
Sample Date	Site Location				
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05
17-Jul-04	13.5	15.8	20.5	13.6	20.5
28-Jul-04	14.2	15.1	15.2	14.1	17.3
8-Aug-04	13.8	15.2	15.5	13.8	15.5
13-Aug-04	14.6	16.5	17.1	12.5	15.6
Average	14.0	15.7	17.1	13.5	17.2

Table 4: Total on-site conductivity readings and averages.

Conductivity µS/cm					
Sample Date	Site Location				
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05
17-Jul-04	1890	1219	1330	1915	428
28-Jul-04	1747	1470	1546	1786	425
8-Aug-04	1762	1414	1585	1821	431
13-Aug-04	1897	1873	1930	1825	394
Average	1824	1494	1598	1837	420

Overall, pH, temperature, and conductivity are useful in assessing the quality of the water, aiding with the determination of toxicity of certain chemicals and, in certain cases, evaluating the behavior and associative properties of metals in sediment and water. The values for temperature and pH levels were most useful in this analysis because they help determine the potential toxicity of ammonia, which will be discussed in the following section.

4.2 Summary Results for Nutrient Loadings in Water

An important aspect of chemical analysis is testing for nutrient loadings in the sampling area. High levels of nutrients are useful indicators of environmental integrity and health of an aquatic area. Excess nutrients can have serious deleterious effects on aquatic life, but some constituents are more harmful than others. Within this section nitrate, ammonia, total nitrogen, and phosphorous are discussed.

Nitrate

Nitrate is usually found as a problem in areas of high agricultural activity where the combination of feedlot wastes and excretory products cause this substance to act as a pollutant in water due to nitrification processes. It does not easily bind with soil and therefore passes through the ground with little resistance (Manahan, 1994). Nitrate serves as the primary source of nitrogen for aquatic plants in well oxygenated systems, and as nitrate levels increase, there is an increasing risk of algal blooms and eutrophication in surface waters (CEQG, 1999). While there are no numerical guidelines recommended for control of nitrate levels, the CEQG do caution that excessive amounts of nitrate should be avoided because it may cause prolific weed growth.

Table 5: Total concentrations and averages for Nitrate in mg/L.

NITRATE-NITROGEN mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	0.92	1.94	2.47	0.57	0.05	
28-Jul-04	*	\	\	\	\	
8-Aug-04	\	\	\	\	\	
13-Aug-04	0.20	0.69	0.10	0.02	0.24	
Average	0.56	1.31	1.28	0.29	0.14	NO VALUE

* Results not available. Please refer to Section 4.0 above.

Ammonia

Ammonia is an important component of the nitrogen cycle and it serves as a large source of available nitrogen in the environment (Raven & Johnson, 1989). Determining the fate of ammonia in the environment is very difficult due to the complexity of the nitrogen cycle, its physical behavior and various rate determining environmental conditions for nitrification such as pH and temperature.

Ammonia is highly soluble in water and its speciation is affected by a wide variety of environmental parameters including pH, temperature, and ionic strength.

Ammonia commonly enters the environment as a result of municipal, industrial, agricultural, and natural processes. Natural sources of ammonia include gas exchange with the atmosphere, the decomposition or breakdown of organic waste matter, and nitrogen fixation processes (CEQG, 1999).

Point sources of ammonia include emissions and effluents from a wide variety of industrial plants such as iron and steel mills, fertilizer plants, and oil refineries (Environment Canada 1997; CCREM 1987; WHO 1986). Residential and municipal

sources of ammonia come from the use and disposal of cleansing agents that contain ammonia, improper disposal or accidental spills of ammonia products, and urban runoff (Environment Canada 1997; WHO 1986).

Ammonia can negatively impact plants and animals by stressing carbohydrate metabolism and inhibiting photosynthetic phosphorylation. Overall, the result of excess ammonia uptake is reduced carbohydrate production and therefore, reduced growth (Teshow and Anderson, 1989). Inhalation of ammonia can result in a range of physiological reactions from mild irritation of the mucus membranes to severe corrosion of sensitive membranes of the eyes, nose, throat, and lungs (EC, 1997). Ammonia does not typically exceed levels of more than 0.2 mg/L in Canadian surface waters; however, the results recorded from the sampling events are much higher than this. Because of the well-documented toxic effects of high ammonia concentrations, discharges of municipal and industrial wastewater in Canada have been regulated to avoid acute toxicity to aquatic organisms in receiving waters (EC, 2001:116).

The main factors controlling the toxicity of ammonia in freshwater samples are temperature and pH (Trussell 1972; Haywood 1983). Raising the pH by one unit can cause the un-ionized ammonia concentration to increase nearly tenfold, while a 5°C temperature increase can cause an increase in concentration by 40-50% (Environment Canada, 1999). It should also be noted that higher concentrations of ammonia usually indicate greater organic pollution (McNeely et al., 1979). Since the toxicity of ammonia is dependent on pH and temperature, it is important to understand how these parameters interact with one another. The greater the pH and temperature levels, the more toxic ammonia concentrations will be in the environment.

Using the tables from Trussell (1972), and the total ammonia (NH₃-N) of each sample, Table 6 calculates the amount of undissociated (un-ionized) ammonia that would have been present in the sample at the temperature and pH values provided.

Table 6: Calculations of the Amount of Undissociated (un-ionized) Ammonia Present in the Samples with the Temperature and pH Values Recorded at Time of Sampling.

Sample Date	Parameter	Site Location				
		RHB-01	RHB-02	RHB-03	RHB-04	RHB-05
17-Jul-04	pH	8.04	8.25	7.77	6.85	6.85
	Temperature (°C)	13.5	15.8	20.5	13.6	20.5
	Ammonia-N, mg/L	8.58	48.6	49.7	112	0.03
	Un-ionized ammonia-N, mg/L	0.18	2.70	1.30	0.224	0.0001
28-Jul-04	pH	7.89	8.3	7.74	6.41	7.1
	Temperature (°C)	14.2	15.1	15.2	14.1	17.3
	Ammonia-N, mg/L	No value	No value	No value	No value	No value
	Un-ionized ammonia-N, mg/L	-	-	-	-	-
8-Aug-04	pH	7.23	7.81	7.6	6.91	7.36
	Temperature (°C)	13.8	15.2	15.5	13.8	15.5
	Ammonia-N, mg/L	26.6	92.1	92.9	99.5	0.05
	Un-ionized ammonia-N, mg/L	0.106	1.56	1.08	0.199	0.0004
13-Aug-04	pH	6.4	7.31	7.4	6.51	7.32
	Temperature (°C)	14.6	16.5	17.1	12.5	15.6
	Ammonia-N, mg/L	15.1	77.9	94.3	113	0.2
	Un-ionized ammonia-N, mg/L	0.014	0.483	0.736	0.079	

The toxicity of ammonia to fish and other aquatic life has been reviewed in several scientific publications (e.g.: Russo and Thomann 1978; Haywood 1983; USEPA 1985; International Joint Commission 1986). International Joint Commission (1986) is the most comprehensive reference and tabulates forty-two 96-h LC50 values for rainbow trout, the values for LC50 expressed as undissociated (un-ionized) ammonia range from 0.1 to 1.44 mg/L as summarized in that publication. “Safe” levels for the protection of aquatic life are presented in the CEQG. The guideline level of undissociated ammonia considered protective for freshwater aquatic life in Canada is 0.019 mg/L

An examination of the undissociated (un-ionized) ammonia values presented in the Table above shows:

- All samples taken at RHB-05 (the reference site) were below the CEQG for the protection of freshwater aquatic life and so would not be expected to cause adverse effects on freshwater aquatic life;
- All samples taken at RHB-04 were above the CEQG for the protection of

freshwater aquatic life. Samples taken on 7 July, 2004, and 8 August, 2004 were within the range reported to be acutely lethal to several species of freshwater fish (USEPA 1985; International Joint Commission (1986);

- All samples taken at RHB-03 and RHB-02 exceeded the CEQG for the protection of freshwater aquatic life by a large margin and were within the range reported to be acutely lethal to several species of freshwater fish (USEPA 1985; International Joint Commission (1986);
- Samples taken at RHB-01 on 7 July, 2004 and 8 August, 2004 were above the USEPA ambient water quality criteria for ammonia (saltwater, four-day average concentration) but below the 1-hour average concentration criterion (USEPA 1989). The sample taken at RHB-01 on 13 August, 2004 was below these criteria and the level of undissociated (un-ionized) ammonia in this sample would not be expected to cause unacceptable effects on saltwater aquatic organisms.

Further interpretation of ammonia is provided in the discussion section of this report.

Table 7: Total concentrations and averages for Ammonia in mg/L.

NITROGEN, AMMONIA mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	8.58	48.60	49.70	112.00	0.03	
28-Jul-04	\	\	\	\	\	
8-Aug-04	26.60	92.10	92.90	99.50	0.05	<i>pH/Temp dependent</i>
13-Aug-04	15.10	77.90	94.30	113.00	0.20	
Average	16.76	72.87	78.97	108.17	0.09	

Total Nitrogen

Nitrogen is not considered toxic, but it is still important to highlight elevated values to indicate its presence relative to the reference site. Nitrogen concentrations between RHB-01 to RHB-04 are 8.38 mg/L, 70.25 mg/L, 64.99 mg/L, and 85.58 mg/L, respectively. The reference site is much lower at a concentration of 0.22 mg/L. These values reflect the average concentrations of nitrogen, where RHB-04 is the highest, followed by RHB-03, RHB-02, RHB-01, and finally the reference at RHB-05 (See Table 8).

Table 8: Total concentrations and averages for Total Nitrogen in mg/L.

TOTAL NITROGEN mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	7.98	42.26	40.15	82.08	0.24	
28-Jul-04	2.15	58.59	73.15	76.88	0.07	
8-Aug-04	15.73	77.23	68.45	89.41	0.25	
13-Aug-04	7.65	102.90	78.22	93.95	0.32	
Average	8.38	70.25	64.99	85.58	0.22	NO VALUE

Phosphorous

Although phosphorous is not directly toxic in the forms found naturally in the environment, plants supplied with a small excess of phosphorous often develop purple to rusty-brown lesions on their dark green lower leaves (Jones, 1998). Growth of flora is not impaired when excess amounts of phosphorous are supplied in small amounts. The most common source of phosphorus levels in the receiving environment is from detergents. Any concentrations in the environment would contribute to nitrification, which is usually the limiting nutrient value for plant growth. The values between RHB-02 to RHB-04 are greater than the marine and reference site with average concentrations of 0.161 mg/L, 0.397 mg/L, and 0.227 mg/L, respectively. The average concentration for the marine sample is 0.071 mg/L and the average concentration at the reference site is even lower at 0.014 mg/L (See Table 9).

Table 9: Total concentrations and averages for Phosphorous in mg/L.

PHOSPHOROUS mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	0.045	0.172	0.484	0.243	0.018	
28-Jul-04	0.067	0.126	0.309	\	0.015	
8-Aug-04	0.125	0.186	\	0.211	0.013	
13-Aug-04	0.048	\	\	\	0.010	
Average	0.071	0.161	0.397	0.227	0.014	<i>NO VALUE</i>

4.3 Summary Results for Chloride, Sulphate, TOC, and DO

The following results are for chloride, sulphate, total organic carbon and dissolved oxygen.

Chloride

Chloride levels for RHB-02, RHB-03, and RHB-04 are elevated compared to the reference with average values of 244.3 mg/L, 249.3 mg/L, and 307 mg/L, respectively. The reference site at RHB-05 is slightly lower with an average value of 148.6 mg/L. The marine sample (RHB-01) is much higher at 15,368 mg/L (See Table 10).

Table 10: Total concentrations and averages for Chloride in mg/L.

CHLORIDE mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	13675.0	193.6	201.1	293.3	159.8	
28-Jul-04	\	\	\	\	\	
8-Aug-04	\	\	\	\	\	
13-Aug-04	17061.0	295.0	297.5	320.7	137.4	
Average	15368.0	244.3	249.3	307.0	148.6	<i>NO VALUE</i>

Sulphate

Sulphate levels are elevated in sites RHB-01 to RHB-04 with average concentrations measured at 2166 mg/L, 20.6 mg/L, 32.0 mg/L, and 55.5 mg/L, respectively. The reference site was significantly lower with an average of 3.79 mg/L (See Table 11). Since sulphate naturally has higher concentrations in the marine environment, the marine sample is expectedly high.

Table 11: Total concentrations and averages for Sulphate in mg/L.

SULPHATE mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	1908.00	35.20	59.55	107.50	4.46	
28-Jul-04	\	\	\	\	\	
8-Aug-04	\	\	\	\	\	
13-Aug-04	2424.00	5.92	4.48	3.58	3.11	
Average	2166.00	20.56	32.01	55.54	3.78	<i>NO VALUE</i>

Total Organic Carbon

TOC for RHB-02, RHB-03, and RHB-04 are significantly higher than RHB-01 and RHB-05 with average concentrations at 22.2 mg/L, 20.4 mg/L, and 47.8 mg/L, respectively. Average values for sites RHB-01 and RHB-05 are much lower at 7.75 mg/L and 6.73 mg/L, respectively (See Table 12). These values indicate a significantly greater nutrient concentration along Skerries Brook compared to the marine sample and the reference site.

Table 12: Total concentrations and averages for Total Organic Carbon in mg/L.

TOTAL ORGANIC CARBON mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	5.5	24.3	26.5	45.4	9.0	
28-Jul-04	6.9	27.3	24.1	10.5	8.8	
8-Aug-04	12.1	9.4	1.7	83.8	4.1	
13-Aug-04	6.5	27.9	29.4	51.4	5.0	
Average	7.8	22.2	20.4	47.8	6.7	<i>NO VALUE</i>

Dissolved Oxygen

Dissolved Oxygen (DO) is the most fundamental parameter in water because it is essential to the metabolism of all aerobic aquatic organisms (CEQG, 1999). The solubility of oxygen in water is dependent on such factors as turbulence, temperature, salinity, and other biological processes (Wetzel, 1983). Major sources of DO in water are the atmosphere and photosynthesis by aquatic vegetation. The amount of oxygen available for aquatic life; however, depends on the factors that affect its solubility (CEQG, 1999). DO should be relatively consistent in shallow moving water such as Skerries Brook because the air-water interface allows for rapid saturation. The greater the temperature of the air and water, the less soluble the DO will be in the upper surface, known as the epilimnion. In shallow waters like Skerries Brook, the bulk of oxygen loss can be attributed to oxidation occurring at the sediment-water interface, where bacterial activity and organic matter are concentrated. Oxygen depletion also occurs by direct chemical oxidation of dissolved organic matter. Since Skerries Brook is relatively shallow and the dissolved organic matter is high, oxygen levels are expected to be low for this water body.

The depletion of DO in receiving waters is usually an indication that wastewater is being emitted via anthropogenic sources. Unlike the values for other parameters, the lower the level of DO, the worse it is for the aquatic environment. The threshold at which an organism responds to insufficient oxygen is referred to as the 'critical level.' Hypoxia, or oxygen starvation, sets in at this level and the organism must adjust its available energies to counteract the oxygen deficiency. This stress can have an effect on long-term survival as freshwater organisms suffer lethal consequences when DO levels are insufficient (Doudoroff & Shumway, 1970; Alabaster & Lloyd, 1982 p. 2-3).

The negative impacts of low DO levels are heightened in the presence of other metals such as zinc and nickel. These metals interfere with respiration and when they are found in larger quantities, they can reduce the diffusing capacity of the gills, which reduces oxygen supply to fish tissue (Hughes, 1981). This sort of analysis is beyond the scope of the current research, but could be explored in greater depth in future studies.

The Canadian Water Quality Guidelines for DO in colder waters are 9.5 and 6.5 mg/L for early and other life stages, respectively (CEQG, 1999). According to the CEQ Guidelines, the level of DO must be between 5.5-9.5 mg/L in order for aquatic species to survive. Below 5.5 mg/L, the risk of physiological and behavior malfunctions increase. The level of DO is within acceptable limits, except for RHB-04, which exhibits a concentration of less than 0.5 mg/L. RHB-01, RHB-02, RHB-03, and RHB-05 are within the CEQG values at 10.8 mg/L, 9.5 mg/L, 8.0 mg/L and 8.6 mg/L, respectively (See Table 13). A quick review of the difference in the DO results from each sample site would suggest there is demonstrable effectiveness for the wetland to recover oxygen levels in the stream.

Table 13: Total concentrations and averages for Dissolved Oxygen in mg/L.

DISSOLVED OXYGEN mg/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	10.8	9.5	8.0	<0.5	8.6	
28-Jul-04	\	\	\	\	\	
8-Aug-04	\	\	\	\	\	
13-Aug-04	\	\	\	\	\	
Average						<i>Freshwater: 5.5-9.5 mg/L</i>

4.4 Summary Results for Metals in Water

As previously discussed, leachate consists of many types of metals that have varying effects on human and aquatic health. They are problematic in both water and sediment and therefore the concentrations of specific metals were tested for in both medians. The following is a brief description of the metals tested in water and their significance with respect to the CEGQ values. There are no results for copper or mercury as the tests for copper were cancelled due to interference and the test for mercury showed no significant values.

Aluminum

With respect to aquatic species, increased levels of aluminum can obstruct gill function through the precipitation of aluminum on the gill surface. Furthermore, aluminum causes mucus production of fish to increase, which creates fusion and thickening of the gill lamellae (McDonald & Wood, 1993). The toxicity of aluminum is pH dependent, but since the average pH levels were all greater than 6.5, the allowable limit is 100ug/L. RHB-02 and RHB-03 showed elevated averages of 163 ug/L and 426 ug/L respectively (See Table 14).

Table 14: Total concentrations and averages for Aluminum in ug/L.

ALUMINUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	58.3	246.3	601.3	96.3	33.8	
28-Jul-04	19.6	152.0	333.1	53.7	34.8	
8-Aug-04	76.7	148.7	649.2	38.4	27.8	
13-Aug-04	13.0	104.5	118.7	37.1	28.6	<i>5 ug/L if pH <6.5</i>
Average	41.9	162.9	425.6	56.4	31.3	<i>100 ug/L if pH >6.5</i>

Arsenic

Arsenic is an odorless, tasteless, and insoluble metal that is used in wood preservatives, herbicides, pharmaceuticals, and glass manufacturing (Government of Canada, 1993). The largest natural source of arsenic entering surface waters is from weathered rocks and soils (Nriagu, 1989). In rivers, approximately two thirds of the total arsenic is soluble and one third is adsorbed to suspended solids (Reuther, 1986). Arsenic is sorbed by colloidal humic material under conditions of high organic contents, low pH, low phosphorus, and low mineral content (Thanabalasingam and Pickering, 1986). There is no indication that arsenic biomagnifies in freshwater food chains and the degree and rate of uptake depends on the level of phosphorus, which interacts with arsenic and competes for sorption sites, thus reducing the surfaces available for arsenic to bind (Reuther, 1992). The levels of arsenic for the sampling period were all below the CEQG of 12.5 ug/L for marine, and 5.0 ug/L for freshwater (See Table 15).

Table 15: Total concentrations and averages for Arsenic in ug/L.

ARSENIC ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04		<3.0	<3.0	3.6	<3.0	
28-Jul-04	\	<3.0	<3.0	<3.0	<3.0	
8-Aug-04	\	<3.0	<3.0	<3.0	0.5	
13-Aug-04	\	3.2	3.2	3.8	<3.0	12.5 ug/L Marine
Average	\					5.0 ug/L Freshwater

Cadmium

Cadmium occurs naturally in the environment and is typically found in rocks and the earth's crust. Cadmium is mainly used in industrial applications such as batteries, pigments, coatings, stabilizers in plastics and synthetic products, and alloys. Most cadmium entering water bodies eventually becomes associated with bottom sediments (CEQG, 1999).

The most important factors determining the fate of cadmium in aquatic systems include such factors as pH, hardness, and redox potential. Consequently, cadmium tends to be removed rapidly from solution and accumulate in bottom sediments in both marine and freshwater systems (CEQG, 1999). Sediment, suspended solids, and colloidal particles may contain various components that can complex with cadmium and influence its fate in aquatic systems. Absorption and ion exchange can occur with clay, silica, or organic matter. Changes in environmental factors such as pH can enable cadmium to become remobilized and transported to other compartments of the ecosystem (CCME, 1996).

Cadmium is considered highly toxic and several studies have indicated the bioaccumulation potential of cadmium in fish tissues (CEQG, 1999). The marine and freshwater CEQG limits for cadmium are lower than the detection limit set for this metal during analysis. Unfortunately, with a freshwater limit of 0.017 ug/L and a marine limit of 0.12 ug/L, the detection limit of <2.0 ug/L is far too high to determine if the levels of cadmium are significant. One detection limit for RHB-04 on Aug 13th was set at <0.2 and even though this is lower than the others, it is still too high to determine significant

values for cadmium in Skerries Brook (See Table 16). This parameter should be tested in future surveys.

Table 16: Total concentrations and averages for Cadmium ug/L.

CADMIUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<2.0	<2.0	<2.0	<2.0	<2.0	
28-Jul-04	<2.0	<2.0	<2.0	<2.0	<2.0	
8-Aug-04	<2.0	<2.0	<2.0	<2.0	<2.0	<i>DL too high</i>
13-Aug-04	<2.0	<2.0	<2.0	<0.2	<2.0	<i>0.12 ug/L Marine</i>
Average						<i>0.017 ug/L Freshwater</i>

Chromium

Chromium exists naturally in the environment and large chromium-containing ore deposits are located in Newfoundland (CEQG, 1999). Anthropogenic sources include municipal waste and sewage sludge as well as waste from tanning beds, metal finishing and plating operations, wood treatment facilities, and paint and chemical works, to name a few. Chromium is widely used by many small industries, and can be responsible for as much as 75% of the level found in sewage. It is difficult to test for chromium because standard testing methods are subject to contamination and ultra-clean techniques must be validated (CEQG, 1999). While chromium can bioconcentrate in some aquatic plants, it does not seem to bioaccumulate in fish or invertebrates, and levels remain low even in contaminated water (Environment Canada 1997; Pawlisz et al., 1997). The values for chromium are all below the limits outlined by CEQG (See Table 17).

Table 17: Total concentrations and averages for Chromium in ug/L.

CHROMIUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	6.0	<3.0	<3.0	4.0	<3.0	
28-Jul-04	6.6	<3.0	<3.0	3.2	<3.0	
8-Aug-04	5.2	<3.0	4.8	3.9	<0.3	
13-Aug-04	5.3	<3.0	<3.0	3.6	<3.0	<i>56.0 ug/L Marine</i>
Average	5.8			3.7		<i>8.9 ug/L Freshwater</i>

Iron

The mobility of iron is increased when ferric iron is converted to ferrous iron from reducing conditions created by anaerobic growth. The levels of iron in all sampling events exceed the limit of 300 ug/L. Average results were recorded at a high of 44,140 ug/L in RHB-04 followed by 40,760 ug/L in RHB-04, 20,660 ug/L in RHB-02, 4,133 ug/L

in RHB-01, and 563 ug/L in RHB-05 (See Table 18). In fact, concentrations of iron were found at such high levels to indicate that the quantities being leached from the landfill are equivalent to the leaching of a car every two or three days. As seen in the photographic depictions of the area, the water is very turbulent, rusty-brown, and protruding rocks were reddish-brown in colour. The visual assessment of the site clearly indicates very high concentrations of iron; however, the chemical testing supports this base assessment.

Table 18: Total concentrations and averages for Iron in ug/L.

IRON ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	3440	15320	31970	52670	500	
28-Jul-04	1800	14690	27330	4450	730	
8-Aug-04	9500	30190	76990	58950	360	
13-Aug-04	1790	22440	26750	60490	660	
Average	4133	20660	40760	44140	563	<i>300 ug/L Freshwater</i>

Molybdenum

Molybdenum is an essential nutrient for all nitrogen-fixing organisms and occurs regularly in all plant and animal tissues. High dietary concentrations of molybdenum are harmful to several animal species. The total concentrations for molybdenum are far lower than the CEQG allowable limit (See Table 19).

Table 19: Total concentrations and averages of Molybdenum in ug/L.

MOLYBDENUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	7.4	<7.0	<7.0	<7.0	<7.0	
28-Jul-04	9.4	<7.0	<7.0	<7.0	<7.0	
8-Aug-04	7.0	<7.0	<7.0	<7.0	<0.7	
13-Aug-04	9.1	<7.0	<7.0	<7.0	<7.0	
Average	8.2					<i>73 ug/L Freshwater</i>

Nickel

The CEQG values for nickel are calcium carbonate (CaCO₃) dependent and range between 25-150 ug/L. All levels were measured below even the lowest limit and therefore the levels of nickel in Skerries Brook are all below the CEQG values (See Table 20).

Table 20: Total concentrations and averages for Nickel in ug/L.

NICKEL ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	11.2	8.6	10.4	18.2	<7.0	
28-Jul-04	13.0	10.8	11.8	14.9	<7.0	
8-Aug-04	12.3	12.6	14.7	15.2	1.0	
13-Aug-04	12.7	11.5	13.8	15.3	<7.0	<i>[CaCO₃] dependent</i>
Average	12.3	10.9	12.7	15.9		<i>25-150 ug/L Freshwater</i>

Zinc

Zinc is one of the most abundant essential trace elements in the human body, but moderately elevated zinc concentrations in water can affect metabolism. Attenuation of zinc reaches its maximum level in the pH range of 6-8. It also precipitates with a variety of anions including carbonate, sulfate, silicate, phosphate and other organic matter (Quasim & Chiang, 1994: 162). The levels for zinc in the water samples were significantly greater than the CEQG limit of 30 ug/L and elevated sites include RHB-02 at 30.8 ug/L, RHB-03 at 64.2 ug/L, and RHB-04 at 44.5 ug/L (See Table 21).

Table 21: Total concentrations and averages for Zinc in ug/L.

ZINC ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<20.0	52.7	96.3	95.0	<20.0	
28-Jul-04	<20.0	30.4	39.6	42.8	21.3	
8-Aug-04	21.0	<20.0	101.0	<20.0	4.3	
13-Aug-04	27.2	<20.0	<20.0	<20.0	<20.0	
Average						<i>30 ug/L Freshwater</i>

Other Metals

Antimony, Barium, Beryllium, Cobalt, Manganese, Strontium, Titanium, and Vanadium were also tested, but no CEQG limits exist for these metals. To observe relative amounts of these metals in Skerries Brook, it is useful to compare their averages to the reference site at RHB-05 to assess the concentrations in Skerries Brook relative to this site (See Tables 22-29). Manganese, strontium and vanadium are elevated as compared to concentrations at our reference site.

Table 22: Total concentrations and averages for Antimony in ug/L.

ANTIMONY ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5.0	<5.0	<5.0	<5.0	<5.0	
28-Jul-04	<5.0	<5.0	<5.0	<5.0	<5.0	
8-Aug-04	<5.0	<5.0	<5.0	<5.0	<0.5	
13-Aug-04	<5.0	<5.0	<5.0	<5.0	<5.0	
Average						<i>NO VALUE</i>

Table 23: Total concentrations and averages for Barium ug/L.

BARIUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	96.7	401.7	586.6	779.6	94.7	
28-Jul-04	57.6	436.6	524.5	694.6	96.4	
8-Aug-04	164.3	551.1	907.8	782.2	81.8	
13-Aug-04	44.6	31.1	39.3	42.2	71.6	
Average	90.8	355.1	514.6	574.7	86.1	<i>NO VALUE</i>

Table 24: Total concentrations and averages for Beryllium ug/L.

BERYLLIUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<4.0	<4.0	<4.0	<4.0	<4.0	
28-Jul-04	<4.0	<4.0	<4.0	<4.0	<4.0	
8-Aug-04	<4.0	<4.0	<4.0	<4.0	<0.4	
13-Aug-04	<4.0	<4.0	<4.0	<4.0	<4.0	
Average						<i>NO VALUE</i>

Table 25: Total concentrations and averages for Cobalt ug/L.

COBALT ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<4.0	<4.0	<4.0	4.8	<4.0	
28-Jul-04	<4.0	<4.0	<4.0	<4.0	<4.0	
8-Aug-04	<4.0	<4.0	<4.0	<4.0	<4.0	
13-Aug-04	<4.0	<4.0	<4.0	<4.0	<4.0	
Average						<i>NO VALUE</i>

Table 26: Total concentrations and averages of Manganese in ug/L.

MANGANESE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	233.0	1087.0	1341.0	2431.0	252.0	
28-Jul-04	137.7	1250.0	1558.0	1952.0	1382.0	
8-Aug-04	345.5	1490.0	2040.0	2018.0	431.8	
13-Aug-04	95.8	1316.0	1922.0	2092.0	501.1	
Average	203.0	1285.8	1715.3	2123.3	641.7	<i>NO VALUE</i>

Table 27: Total concentrations and averages for Strontium in ug/L.

STRONTIUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	5910.0	632.2	729.9	1297.0	229.4	
28-Jul-04	7239.0	820.7	882.5	1204.0	237.4	
8-Aug-04	5475.0	1012.0	1184.0	1282.0	210.9	
13-Aug-04	7026.0	949.4	1084.0	1227.0	200.0	
Average	6412.5	853.6	970.1	1252.5	219.4	<i>NO VALUE</i>

Table 28: Total concentrations and averages for Titanium in ug/L.

TITANIUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	26.9	7.7	9.3	6.5	<3	
28-Jul-04	28.8	3.3	9.2	5.1	<3	
8-Aug-04	26.4	6.7	15.0	5.6	1.1	
13-Aug-04	\	\	\	\	\	
Average	27.4	5.9	11.2	5.7		<i>NO VALUE</i>

Table 29: Total concentrations and averages for Vanadium in ug/L.

VANADIUM ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	66.1	8.3	10.4	9.7	<5.0	
28-Jul-04	80.0	10.0	12.0	10.5	<5.0	
8-Aug-04	64.2	11.8	16.8	11.5	1.7	
13-Aug-04	79.2	11.1	9.8	12.0	<5.0	
Average	72.4	10.3	12.3	10.9		<i>NO VALUE</i>

4.5 Summary Results for Polycyclic Aromatic Hydrocarbons in Water

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds that contain two or more benzene rings in their structure. PAHs are constituents of petroleum and oil spills and refinery effluents are a major source of PAH contamination in freshwater and marine environments (Neff, 1979). Landfills, such as RHBSL can be considered a major anthropogenic source of PAHs and are of significant concern to this study.

Factors such as microbial degradation, volatilization, and adsorption help determine the fate of PAHs in the environment (Southworth, 1979). PAHs tend to adsorb onto solid phases in aquatic environments because of their hydrophobic nature and low water solubilities (Neff 1979; NRCC 1983; Eisler 1987; Slooff et al., 1989). It would therefore be anticipated that the majority of PAHs would be found within the sediment samples rather than in the water. PAHs degrade through photodegradation, especially for PAHs with a high molecular weight. Photooxidation can chemically transform PAHs, and the resulting products may be more carcinogenic and toxic than the parent compounds (Suzuki et al. 1982; USEPA 1982b, 1982c; NRCC, 1983). Microbial degradation of PAHs is one of the main processes responsible for removing these substances from bottom sediments and the water column (CEQG, 1999), and the rate of biodegradation depends on factors such as the number of aromatic rings. For example, two and three ringed PAHs such as naphthalene, phenanthrene, and anthracene, are readily degraded and may be used as primary substrates by PAH-degrading organisms (Herbes and Schwall, 1978). Higher molecular weight compounds, such as pyrene and benzo(a)pyrene degrade more slowly.

Aquatic organisms may remove a significant fraction of PAHs from a body of water. Pelagic organisms may take up PAHs directly from the water column and benthic organisms may absorb these substances from contact with bottom sediments (CEQG, 1999). Aquatic organisms can accumulate PAHs from water, sediment, and food. The uptake of PAHs depends on the physical and chemical properties of the PAH, the environmental variables, and other biological factors. The movement of PAHs in a body of water, its interaction with external variables, and the ability to degrade in the environment are all related. These factors can consequently make their fate and toxicity in the aquatic environment difficult to assess.

The values derived through the CEQG were developed based on the CCME protocol to determine the lethal concentration range for selected freshwater and marine species. The following summary tables outline the PAHs analyzed for water samples and the limits indicated by the CEQG (See Tables 30-41). The tables are grouped together and any significant reference regarding a particular PAH can be viewed by referring to the table.

Some significant values to note include the elevated value of naphthalene in RHB-04 with an average value of 12.7 ug/L compared to the CEQG limit of 1.4 ug/L for marine and 1.1ug/L for freshwater (See Table 30). The average value for phenanthrene in RHB-04 was also over the limit at 0.71 ug/L compared to the limit of 0.4 ug/L (See Table 34). The detection limit for anthracene was set at 0.2 ug/L for most samples; however, the guideline limit is 0.012 ug/L. The actual amount of anthracene in the water compared to its allowable limit is therefore difficult to determine from this analysis. The only conclusive test was at RHB-04 where the values were detected at an average of 0.06 ug/L, which is still above the guideline for aquatic life (See Table 35). The detection limit for pyrene was also set too high and the values were analyzed at a detection limit of less than 0.02 ug/L, where the allowable guideline for aquatic life is 0.025 ug/L (See Table 37). The same situation holds for benz(a)anthracene where the

allowable limit is set at 0.018 ug/L, but the detection limit was set at less than 0.02 ug/L (See Table 38).

Table 30: Total concentrations and averages for Naphthalene in ug/L.

NAPHTHALENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	0.20	0.10	0.14	17.80	0.15	
8-Aug-04	<0.04	<0.04	<0.04	<0.04	<0.04	
13-Aug-04	0.05	<0.04	<0.04	20.30	0.15	1.4 ug/L Marine
Average						1.1 ug/L Freshwater

Table 31: Total concentrations and averages for Acenaphthylene in ug/L.

ACENAPHTHYLENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	0.09	<0.04	0.5	2.52	<0.04	
8-Aug-04	<0.04	<0.04	<0.04	<0.04	<0.04	
13-Aug-04	<0.04	<0.04	0.3	2.49	<0.04	
Average						NO VALUE

Table 32: Total concentrations and averages for Acenaphthene in ug/L.

ACENAPHTHENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	0.09	<0.04	0.5	2.52	<0.04	
8-Aug-04	<0.04	<0.04	<0.04	<0.04	<0.04	
13-Aug-04	<0.04	<0.04	0.3	2.49	<0.04	
Average						5.8 ug/L Freshwater

Table 33: Total concentrations and averages for Fluorene in ug/L.

FLUORENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	0.04	<0.03	0.28	1.76	<0.03	
8-Aug-04	<0.03	<0.03	0.03	<0.03	<0.03	
13-Aug-04	<0.03	<0.03	0.25	1.81	<0.03	
Average			0.19			<i>NO VALUE</i>

Table 34: Total concentrations and averages for Phenanthrene in ug/L.

PHENANTHRENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	0.02	0.01	0.02	1.01	0.01	
8-Aug-04	<0.01	<0.01	<0.01	0.02	<0.01	
13-Aug-04	<.01	<0.01	0.01	1.09	<0.01	
Average				0.71		<i>0.04 ug/L Freshwater</i>

Table 35: Total concentrations and averages for Anthracene in ug/L.

ANTHRACENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	<0.02	<0.02	<0.02	0.07	<0.02	
8-Aug-04	0.02	0.03	0.03	0.03	0.02	
13-Aug-04	<0.02	<0.02	<0.02	0.09	<0.02	<i>*DL too high</i>
Average				0.06		<i>0.012 ug/L Freshwater</i>

Table 36: Total concentrations and averages for Fluoranthene in ug/L.

FLUORANTHENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	<0.01	<0.01	0.03	0.05	<0.01	
8-Aug-04	0.01	0.01	0.02	0.03	0.01	
13-Aug-04	<0.01	<0.01	0.02	0.05	<0.01	
Average			0.02	0.04		<i>0.04 ug/L Freshwater</i>

Table 37: Total concentrations and averages for Pyrene in ug/L.

PYRENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	<0.02	0.02	0.04	0.05	<0.02	
8-Aug-04	<0.02	<0.02	<0.02	0.09	<0.02	
13-Aug-04	<0.02	0.02	0.03	0.06	<0.02	<i>*DL too high</i>
Average				0.07		0.025 ug/L Freshwater

Table 38: Total concentrations and averages for Benz(a)anthracene in ug/L.

BENZ(A)ANTHRACENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	<0.02	<0.02	<0.02	<0.02	<0.02	
8-Aug-04	<0.02	<0.02	<0.02	0.02	<0.02	
13-Aug-04	<0.02	<0.02	<0.02	<0.02	<0.02	<i>*DL too high</i>
Average						0.018 ug/L Freshwater

Table 39: Total concentrations and averages for Benzo(b)fluoranthene in ug/L.

BENZO(B)FLUORANTHENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	<0.03	<0.03	<0.03	<0.03	<0.03	
8-Aug-04	<0.03	<0.03	<0.03	<0.03	<0.03	
13-Aug-04	<0.03	<0.03	<0.03	<0.03	<0.03	
Average						NO VALUE

Table 40: Total concentrations and averages for Benzo(k)fluoranthene in ug/L.

BENZO(K)FLUORANTHENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	<0.02	<0.02	<0.02	<0.02	<0.02	
8-Aug-04	<0.02	<0.02	0.02	0.02	0.02	
13-Aug-04	<0.02	<0.02	<0.02	<0.02	<0.02	
Average						NO VALUE

Table 41: Total concentrations and averages for Chrysene in ug/L.

CHRYSENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	\	\	\	\	
28-Jul-04	<0.01	<0.01	<0.01	<0.01	<0.01	
8-Aug-04	0.02	0.02	0.02	0.04	0.02	
13-Aug-04	<0.01	<0.01	<0.01	<0.01	<0.01	
Average						<i>Insufficient Data</i>

4.6 Summary Results for Benzene, Toluene, Ethyl-benzene, O and M+P-Xylene (BTEX) in Water

Benzene

Benzene is a highly volatile substance that is produced through industrial processes such as coal tar distillation and production and combustion of fossil fuels (Buikema and Hendricks 1980; Fishbein 1984). When Benzene enters the water, it is usually removed rapidly through degradation by a variety of aquatic microorganisms and is not expected to bio-concentrate in aquatic organisms. The levels of benzene found in these samples are well below the CEQG limit of 370 ug/L (See Table 42).

Table 42: Total concentrations and averages for Benzene in ug/L.

BENZENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<1	<1	/	6	<1	
28-Jul-04	<1	<1	<1	4	<1	
8-Aug-04	\	<1	<1	7	\	
13-Aug-04	<1	<1	1	7	<1	
Average				6.5		<i>370 ug/L Freshwater</i>

Toluene

Toluene is a volatile and flammable aromatic hydrocarbon that occurs naturally in coal and crude oil (Nielson and Howe 1991; Government of Canada 1993). It is also a by-product of the petroleum refining process and is present in many consumer products including gasoline, cosmetics, and cleaners (OMOEE 1994).

Toluene is non-persistent in the environment and can be rapidly biodegraded. It is removed from water through volatilization and biodegradation and can remain for days or weeks depending on the temperature, mixing conditions and the existence to acclimated microorganisms (CEQG, 1999). The interim water quality guideline for toluene according to the CEQG for the protection of freshwater life is 2.0ug/L and marine life is 215 ug/L. Toluene concentrations analyzed for all sample sites over the sampling period were below the CEQG guidelines (See Table 43).

Table 43: Total concentrations and averages for Toluene in ug/L.

TOLUENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	4	<1	\	2	<1	
28-Jul-04	<1	<1	<1	1	<1	
8-Aug-04	\	<1	<1	2	\	
13-Aug-04	<1	<1	<1	1	<1	215 ug/L Marine
Average				1.5		2.0 ug/L Freshwater

Ethyl-Benzene, O-Xylene, M+P-Xylene

Ethylbenzene occurs naturally in coal, tar, and petroleum and is found in many consumer products such as paint, ink, pesticides, and gasoline (ATSDR, 1990).

When released into the aquatic environment, ethylbenzene may volatilize within a few hours, but can remain for a few weeks, depending on local conditions (Howard 1989). As is the case with the other light end hydrocarbons tested, the level of ethylbenzene in the sample area is low with all values under the CEQG guideline of 25 ug/L in marine waters and 90 ug/L in freshwater (See Table 44).

There are no limits indicated by CEQG for o-xylene and m+p-xylene but it is significant to note that RHB-04, which is adjacent to the landfill, is greater than the concentrations found in the other samples including our reference site (See Table 45 & 46).

Table 44: Total concentrations and averages for Ethyl-Benzene in ug/L.

ETHYL-BENZENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<1	<1	\	2	<1	
28-Jul-04	<1	<1	<1	1	<1	
8-Aug-04	\	<1	<1	2	\	
13-Aug-04	<1	<1	<1	2	<1	25 ug/L Marine
Average				1.8		90 ug/L Freshwater

Table 45: Total concentrations and averages for O-Xylene in ug/L.

O-XYLENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	1	<1	\	5	<1	
28-Jul-04	<1	<1	<1	4	<1	
8-Aug-04	\	<1	<1	6	\	
13-Aug-04	<1	<1	1	5	<1	
Average				5		NO VALUE

Table 46: Total concentrations and averages for M+P Xylene in ug/L.

M+P XYLENE ug/L						
Sample Date	Site Location					CEQG value
	RHB-01	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	\	3	<1	12	<1	
28-Jul-04	<2	<2	<2	10	<2	
8-Aug-04	\	<2	<2	13	\	
13-Aug-04	<2	<2	2	13	<2	
Average				12		NO VALUE

4.7 Summary Results for Metals in Sediment

Metals leaching from anthropogenic influences can have deleterious effects on the environment and not only end up in surrounding water bodies, but can also be deposited and accumulate in riverbed sediment. Unlike water, sediment is sedentary and can therefore serve as a fairly good indication of the type of exposure that aquatic species will be exposed to over a particular time period. Sediments are an important route of exposure for aquatic organisms; therefore it is important to analyze the quantity and subsequent toxicity level of metals in sediment to get an indication of the health of the water body.

The concentrations for the following metals are in ug/g except for iron, which is given as a percentage. The values are once again compared to the CEQG, which include the interim sediment quality guideline or ISQG and the probable effect limit or PEL. The PEL is the limit by which adverse biological effects are likely to occur as a result of exposure to a certain metal (CEQG, 1999). The PEL is substantially higher than the ISQG; however the measured value for the samples retrieved for RHBSL should still be below the ISQG.

Cadmium

Cadmium can enter aquatic systems through runoff and accumulate in bed sediments by association with particulate matter such as organic matter and iron (CEQG, 1999). High levels of cadmium can result in adverse biological effects including decreased benthic invertebrate abundance, increased mortality, and behavioral changes (Environment Canada, 1997). All the samples collected are below the PEL for cadmium of 3.5 ug/g; however the detection limit of less than 1.0 ug/g was set too high for the ISQG limit of 0.6 ug/g and as a result, definitive assessment cannot be stated for this metal (See Table 47).

Table 47: Total concentrations and averages for Cadmium in ug/g.

CADMIUM ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<1.0	<1.0	<1.0	<1.0	
28-Jul-04	<1.0	<1.0	<1.0	<1.0	
8-Aug-04	<1.0	<1.0	<1.0	<1.0	
13-Aug-04	<1.0				<i>ISQG: 0.6 ug/g PEL: 3.5 ug/g</i>
Average					

Chromium

Chromium is an essential trace element that can be toxic to aquatic biota at elevated concentrations and can enter the environment through surface runoff. Adverse biological effects for chromium in the environment include reduced mortality, and behavioral changes of benthic organisms (CEQG, 1999). The concentrations for chromium are all below the ISQG limit of 37.3 ug/g (See Table 48).

Table 48: Total concentrations and averages for Chromium in ug/g.

CHROMIUM ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	4.3	24.9	17.2	11.4	
28-Jul-04	5.8	26.4	17.1	13.2	
8-Aug-04	6.6	24.5	17.5	18.3	
13-Aug-04	26.5	\	\	\	<i>ISQG: 37.3 ug/g PEL: 90.0 ug/g</i>
Average	10.8	25.3	17.3	14.3	

Copper

Copper is an essential trace element that can be toxic to aquatic biota at elevated concentrations. It can enter the aquatic environment through surface runoff and can accumulate in sediments (CEQG, 1999). Copper can become problematic for benthic organisms that continually are in contact with this metal. Adverse biological effects include decreased benthic invertebrate diversity, reduced abundance, increased mortality, and behavioral changes (Environment Canada, 1998). The concentrations for copper are all below the ISQG limit of 35.7 ug/g and (See Table 49).

Table 49: Total concentrations and averages for Copper in ug/g.

COPPER ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	3.3	28.6	6.9	11.3	
28-Jul-04	5.1	34.4	29.2	11.6	
8-Aug-04	5.9	21.7	25.2	22.7	
13-Aug-04	32.1	\	\	\	<i>ISQG: 35.7 ug/g PEL: 197ug/g</i>
Average	11.6	28.2	20.4	15.2	

Lead

Lead is a nonessential trace element that is toxic to biota at elevated concentrations. Lead entering aquatic environments is usually deposited in bed sediments in association with particulate matter, such as iron and manganese oxides. Alternatively, lead can be precipitated out of solution with carbonate or sulphide (Eisler 1988; Prosi, 1989). Sediments can therefore act as an important route of exposure to lead for aquatic organisms since it can easily precipitate out of solution with the presence of other metals. Adverse biological effects for lead include increased

mortality, decreased benthic invertebrate abundance and diversity, and abnormal development (Environment Canada 1998).

The concentrations of lead found in this study are significant in sites RHB-02, RHB-03, and RHB-05. RHB-02 on Aug 13th exhibited an elevated concentration of 51.7 ug/g compared to the guideline of 35.0 ug/g. RHB-03 exhibited concentrations of 76.8 ug/g and 96.4 ug/g on August 8th and August 13th, respectively. RHB-04 did not show any elevated levels of lead, while RHB-05 showed an elevated level of 66.5 ug/g on August 8th. These levels are greater than the ISQG value, but do not exceed the PEL value of 91.3 ug/g (See Table 50). Elevated levels of lead at our reference site may be attributable to the proximity to the roadway or an error in analytical workup.

Table 50: Total concentrations and averages for Lead in ug/g.

LEAD ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	2.8	31.9	6.1	17.5	
28-Jul-04	16.6	76.8	28.1	12.1	
8-Aug-04	8.1	96.4	31.4	66.5	
13-Aug-04	51.7	\	\	\	ISQG: 35.0 ug/g PEL: 91.3 ug/g
Average	19.8	68.4	21.9	32.0	

Zinc

Zinc is an essential trace element that can be toxic to aquatic biota at elevated concentrations. Like the other metals discussed, it can enter the aquatic environment through surface runoff and because of zinc's strong affinity for particulate matter, it is readily deposited in bed sediments (Campbell and Tessier, 1996). Adverse biological effects for zinc include decreased benthic invertebrate diversity and abundance, increased mortality, and behavioral changes (Environment Canada, 1998). Levels for zinc were elevated in sampling sites RHB-02, RHB-03, and RHB-04 with average concentrations of 249 ug/g, 561 ug/g, and 359 ug/g, respectively, compared to the ISQG level of 123 ug/g. RHB-03 and RHB-04 are the only sites that exceed the PEL limit of 315 ug/g (See Table 51).

Table 51: Total concentrations and averages for Zinc in ug/g.

ZINC ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	67.4	545.2	201.2	58.7	
28-Jul-04	171.0	586.7	234.8	67.4	
8-Aug-04	131.5	551.8	641.6	78.8	
13-Aug-04	625.0	\	\	\	ISQG: 123 ug/g PEL: 315 ug/g
Average	248.7	561.2	359.2	68.3	

Iron

There is no guideline set for iron within the CEQ Guidelines; however it is important to observe the total concentration of iron in the sediment sample. Since the values of iron are extremely high, average results for the sampling sites were tabulated

in percentage form as opposed to ug/g. 27.4% of the sediment sample obtained for RHB-03 was iron, followed by 17.1% for RHB-04, and 12.7% for RHB-02. When compared to the reference sample of 2.4%, it is clear that the amount of iron in the sediment of Skerries Brook is exceedingly high (See Table 52).

Table 52: Total concentrations and averages for Iron in percentage.

IRON %					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	8.54	37.08	43.08	1.81	
28-Jul-04	4.40	24.81	5.18	2.68	
8-Aug-04	8.45	20.29	3.02	2.60	
13-Aug-04	29.24	/	/	/	
Average	12.66	27.39	17.09	2.36	<i>NO VALUE</i>

Mercury

Mercury is a nonessential trace element that can be toxic to aquatic biota at elevated concentrations and is complex, existing in both inorganic and organic forms (CEQG, 1999). Mercury is easily transported to bed sediments from the water column and it can settle in the sediment and act as a good source of exposure to aquatic organisms. Adverse biological effects for mercury include lethality, reduced fertilization, and impaired development of early life stages of benthic organisms (CEQG, 1999). The average values for mercury were detected below the ISQG limit of 0.170 ng/kg (See Table 53).

Table 53: Total concentrations and averages for Mercury in mg/g.

MERCURY mg/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	0.02	0.08	0.03	0.03	
28-Jul-04	0.02	0.10	0.06	0.04	
8-Aug-04	0.02	0.11	0.05	0.04	
13-Aug-04	0.11	0.05	0.04	0.02	<i>ISQG: 0.170 mg/kg PEL: 0.486 mg/kg</i>
Average	0.04	0.09	0.04	0.03	

Other Metals

The other metals analyzed with the ICP-MS analysis include cobalt, manganese, molybdenum, nickel, tin, and vanadium (See Tables 54-59). These metals do not have limits developed by the Canadian Environmental Quality Guidelines; however, to determine the significance of their concentrations, the results can be compared to the reference value at sample site RHB-05.

Some metals of interest include manganese concentrations, which were elevated in sites RHB-02 and RHB-03 with average values of 5238 ug/g and 2648 ug/g, respectively. The reference site at RHB-05 measured 729 ug/g (See Table 55). It is of

interest to note that the level of manganese for RHB-04 measured 553 ug/g. For molybdenum, the only site that seems to have a higher concentration than the control site is RHB-03 at 2.5 ug/g, compared to the reference at less than 1 ug/g (See Table 56). For nickel, RHB-03 and RHB-04 have slightly elevated concentrations at 12 ug/g and 14 ug/g, respectively, compared to 8 ug/g at the reference site (See Table 57). Similarly, both tin and vanadium have elevated concentrations for RHB-03 and RHB-04, compared to the reference site. For tin, RHB-03 and RHB-04 is recorded at 4.3 ug/g and 2.8 ug/g, respectively, compared to the reference site at 2.0 ug/g (See Table 58). For vanadium, RHB-03 and RHB-04 are recorded at 88 ug/g and 71 ug/g, respectively, compared to the reference site at 39 ug/g. RHB-02 is slightly elevated compared to the reference at 46 ug/g (See Table 59).

Table 54: Total concentrations and averages for Cobalt in ug/g.

COBALT ug/g					
	Site Location				CEQG value
Sample Date	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	1.4	6.0	5.5	5.5	
28-Jul-04	1.6	6.7	5.3	7.0	
8-Aug-04	2.2	8.5	6.3	6.9	
13-Aug-04	7.0	\	\	\	
Average	3.1	7.1	5.7	6.5	<i>NO VALUE</i>

Table 55: Total concentrations and averages for Manganese in ug/g.

MANGANESE ug/g					
	Site Location				CEQG value
Sample Date	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	7671.0	2442.0	521.6	663.4	
28-Jul-04	5540.0	1841.0	510.5	767.0	
8-Aug-04	5876.0	3662.0	626.5	756.1	
13-Aug-04	1865.0	\	\	\	
Average	5238.0	2648.3	552.9	728.8	<i>NO VALUE</i>

Table 56: Total concentrations and averages for Molybdenum in ug/g.

MOLYBDENUM ug/g					
	Site Location				CEQG value
Sample Date	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<1.0	1.3	1.3	<1.0	
28-Jul-04	<1.0	2.8	<1.0	<1.0	
8-Aug-04	<1.0	4.3	<1.0	<1.0	
13-Aug-04	2.3	\	\	\	
Average		2.8			<i>NO VALUE</i>

Table 57: Total concentrations and averages for Nickel in ug/g.

NICKEL ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	2.0	11.1	6.9	7.3	
28-Jul-04	3.7	16.7	16.6	8.5	
8-Aug-04	1.2	14.3	13.2	8.6	
13-Aug-04	15.9	\	\	\	
Average	5.7	14.0	12.2	8.1	NO VALUE

Table 58: Total concentrations and averages for Tin in ug/g.

TIN ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<1	4.4	3.2	1.6	
28-Jul-04	1.1	4.5	2.6	2.0	
8-Aug-04	1.0	3.9	2.7	2.3	
13-Aug-04	4.3	\	\	\	
Average		4.3	2.8	2.0	NO VALUE

Table 59: Total concentrations and averages for Vanadium in ug/g.

VANADIUM ug/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	25.7	92.3	102.1	33.6	
28-Jul-04	23.6	101.8	55.1	39.6	
8-Aug-04	27.0	69.9	55.9	43.9	
13-Aug-04	106.1	\	\	\	
Average	45.6	88.0	71.0	39.0	NO VALUE

4.8 Polycyclic Aromatic Hydrocarbons (PAHs) in Sediment

PAHs are a diverse group of organic compounds that contain two or more fused aromatic rings that can be toxic to aquatic biota at elevated concentrations (CEQG, 1999). The *Canadian Environmental Protection Act* has concluded that PAHs are entering the environment in concentrations that may have, or are having a harmful effect on the environment (CEPA, 1985).

The fate and behavior of PAHs in aquatic systems is influenced by a number of physical, chemical, and biological processes that are responsible for cycling these substances throughout the aquatic environment (for a more detailed discussion on these influences refer to the PAH fact sheet in the CEQG booklet for sediment samples). The importance of these processes is dependent on the characteristics of the sediments and on the properties of the individual PAH under consideration. PAHs are relatively nonvolatile and poorly soluble and therefore become incorporated into bottom sediments when they are removed from the water by association with other

particulate matter (CEQG, 1999). PAHs tend to be hydrophobic and have a high potential for adsorption to suspended particles in air and water (NRCC, 1983; Sloof et al., 1989). This means that they can show up in relatively high concentrations in sediments.

Known to be carcinogenic, adverse biological effects associated with PAHs in sediments include decreased benthic invertebrate abundance, diversity, and growth, and adverse physiological and behavioral changes (Environment Canada, 1998). Mortality is the most common acute toxicological effect; however the toxicity of PAHs depends on factors such as species, route of exposure, and structure of the PAH (CEQG, 1999).

Organic carbon content is one of the most important factors affecting the bioavailability of PAHs (Environment Canada, 1998). In addition to this, the type and size of sediment can directly affect particle size distribution and may also contribute to the sorption of organic chemicals to bed sediment (Neff 1984; Rodgers et al., 1987).

The following summary tables outline the concentrations of PAHs in sediments along with the CEQG values.

Naphthalene

Naphthalene is a low molecular weight (LMW) PAH, meaning that the substance is considered to be acutely toxic and non-carcinogenic to aquatic organisms (CEQG, 1999). The CEQG limits for naphthalene include an ISQG value of 34.6 ng/g and a PEL value of 391 ug/g. Results for RHB-03 and RHB-04 were over these limits at 143.7 ng/g for RHB-03 and 370 ng/g at RHB-04. In addition to being over the ISQG limit, RHB-04, which is directly adjacent to the landfill, is very close to the PEL limit (See Table 60).

Table 60: Total concentrations and averages for Naphthalene in ng/g.

NAPHTHALENE ng/g					
Sample Date					CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5	61	1014	12	
28-Jul-04	<5	57	65	<5	
8-Aug-04	7	313	31	<5	
13-Aug-04	\	\	\	\	ISQG: 34.6 ng/g
Average		143.7	370.0		PEL: 391 ng/g

Acenaphthylene

Acenaphthylene is a LMW-PAH with an ISQG limit of 5.87 ng/g and a PEL of 128 ng/g. Averages for sites RHB-03, RHB-04, and RHB-05 were all above the ISQG value at 15.5 ng/g, 18.5 ng/g, and 9.0 ng/g, respectively (See Table 61).

Table 61: Total concentrations and averages for Acenaphthylene in ng/g.

ACENAPHTHYLENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5	\	\	17	
28-Jul-04	8	21	26	<5	
8-Aug-04	<5	10	11	<5	
13-Aug-04	\	\	\	\	<i>ISQG: 5.87ng/g PEL: 128 ng/g</i>
Average		15.5	18.5		

Acenaphthene

Acenaphthene is a LMW-PAH with an ISQG limit of 6.71 ng/g and a PEL limit of 88.9 ng/g. RHB-02, RHB-03, and RHB-04 were all above the ISQG limit at 11.7 ng/g, 205 ng/g, and 329 ng/g, respectively. These concentrations all exceed the ISQG limit and sites RHB-03 and RHB-04 are both above the PEL limit for this PAH (See Table 62).

Table 62: Total concentrations and averages for Acenaphthene in ng/g.

ACENAPHTHENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5.0	95.0	847.0	\	
28-Jul-04	13.0	116.0	90.0	<5.0	
8-Aug-04	17.0	404.0	49.0	<5.0	
13-Aug-04	\	\	\	\	<i>ISQG: 6.71 ng/g PEL: 88.9 ng/g</i>
Average		205.0	328.7		

Fluorene

Fluorene is a LMW-PAH with an ISQG limit of 21.2 ng/g and a PEL limit of 144 ng/g. Sites RHB-03 and RHB-04 both exceed the ISQG and the PEL limits for this PAH (See Table 63).

Table 63: Total concentrations and averages for Fluorene in ng/g.

FLUORENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5	190.0	1075.0	38.0	
28-Jul-04	19.0	152.0	94.0	<5.0	
8-Aug-04	24.0	744.0	55.0	<5.0	
13-Aug-04	\	\	\	\	<i>ISQG: 21.2 ng/g PEL: 144 ng/g</i>
Average		362.0	408.0		

Phenanthrene

Phenanthrene is a LMW-PAH with an ISQG limit of 41.9 ng/g and a PEL limit of 515 ng/g. Sites RHB-03, RHB-04, and RHB-05 all exceed the ISQG limit and RHB-03 and RHB-04 exceed the PEL value as well. It should be noted that at sampling site

RHB-05 on July 17th, phenanthrene was recorded at 385 ng/g, which caused the overall average to increase. This value is irregularly high for a reference site and it is significant to highlight this point (See Table 64). Further interpretation of the possibilities as to why this value is greater will be provided in the discussion section of the report.

Table 64: Total concentrations and averages for Phenanthrene in ng/g.

PHENANTHRENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	9.0	245.0	2026.0	385.0	
28-Jul-04	28.0	343.0	533.0	<5.0	
8-Aug-04	49.0	1282.0	198.0	40.0	
13-Aug-04	\	\	\	\	<i>ISQG: 41.9 ng/g PEL: 515 ng/g</i>
Average	28.7	623.3	919.0		

Anthracene

Anthracene is an LMW-PAH with an ISQG limit of 46.9 ng/g and a PEL of 245 ng/g. RHB-02 and RHB-04 both exceed the ISQG value at 88.3 ng/g and 135.5 ng/g, respectively, but do not exceed the PEL value (See Table 65).

Table 65: Total concentrations and averages for Anthracene in ng/g.

ANTHRACENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5.0	43.0	229.0	69.0	
28-Jul-04	8.0	111.0	121.0	<5.0	
8-Aug-04	11.0	111.0	56.0	7.0	
13-Aug-04	\	\	\	\	<i>ISQG: 46.9 ng/g PEL: 245 ng/g</i>
Average		88.3	135.3		

Fluoranthene

Fluoranthene is a high molecular weight (HMW) PAH, meaning that this group of PAH's are generally not acutely toxic to aquatic organisms, but a number of them can be more carcinogenic than the low molecular weight PAHs (Neff, 1979; Moore and Ramamoorthy 1984; Goyette and Boyd, 1989). The ICQG limit for fluoranthene is 111 ng/g and the PEL limit is 2355 ng/g. RHB-03, RHB-04, and RHB-05 were all detected at values greater than the ISQG limit at 345 ng/g, 655 ng/g and 289 ng/g, respectively. None of the values exceed the PEL limit, but once again the reference site at RHB-05 on July 17th exhibited an elevated concentration of 792 ng/g (See Table 66).

Table 66: Total concentrations and averages for Fluoranthene in ng/g.

FLUORANTHENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	19.0	235.0	561.0	792.0	
28-Jul-04	24.0	382.0	1065.0	10.0	
8-Aug-04	49.0	418.0	340.0	66.0	
13-Aug-04	\	\	\	\	ISQG: 111ng/g PEL: 2355 ng/g
Average	30.7	345.0	655.3	289.3	

Pyrene

Pyrene is a HMW-PAH with an ISQG limit of 53 ng/g and a PEL limit of 875 ng/g. RHB-02, RHB-03, RHB-04, and RHB-05 all exceed the ISQG limit with concentrations of 54.3 ng/g, 623 ng/g, 761 ng/g, and 235 ng/g, respectively. No average values exceeded the PEL limit; however on July 17th, RHB-04 was over the PEL limit of 875 ng/g with a concentration of 1072 ng/g (See Table 67).

Table 67: Total concentrations and averages for Pyrene in ng/g.

PYRENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	35.0	289.0	1072.0	640.0	
28-Jul-04	41.0	786.0	897.0	10.0	
8-Aug-04	87.0	795.0	314.0	55.0	
13-Aug-04	\	\	\	\	ISQG: 53 ng/g PEL: 875 ng/g
Average	54.3	623.3	761.0	235.0	

Benzo(a)pyrene

Benzo(a)pyrene is a HMW-PAH with an ISQG limit of 21.9 ng/g and a PEL limit of 782 ng/g. Sites RHB-03, RHB-04 and RHB-05 were above the ISQG limits at 147 ng/g, 247 ng/g, and 123 ng/g, respectively. None of the values were above the PEL limit. Once again on July 17th, RHB-05, which is the reference site, was well above the limit with a concentration of 332 ng/g (See Table 68).

Table 68: Total concentrations and averages for Benzo(a)Pyrene in ng/g.

BENZO(A)PYRENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	11.0	82.0	99.0	332.0	
28-Jul-04	21.0	247.0	491.0	7.0	
8-Aug-04	29.0	111.0	152.0	31.0	
13-Aug-04	\	\	\	\	ISQG: 31.9 ng/g PEL: 782 ng/g
Average	20.3	146.7	247.3	123.3	

Chrysene

Chrysene is a HMW-PAH with an ISQG value of 57.1 ng/g and a PEL limit of 862 ng/g. Sites RHB-03, RHB-04, and RHB-05 were above the allowable limits at 244 ng/g,

276 ng/g, and 120 ng/g, respectively but no values were greater than the PEL limit. RHB-05 on July 17th was again above the limit at a concentration of 316 ng/g (See Table 69).

Table 69: Total concentrations and averages for Chrysene in ng/g.

CHRYSENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	7.0	108.0	211.0	316.0	
28-Jul-04	28.0	397.0	467.0	7.0	
8-Aug-04	46.0	227.0	150.0	38.0	
13-Aug-04	\	\	\	\	ISQG: 57.1ng/g
Average	27.0	244.0	276.0	120.3	PEL: 862 ng/g

Dibenz(a,h)anthracene

Dibenz(a,h)anthracene is a HMW-PAH with an ISQG value of 6.22 ng/g and a PEL limit of 135 ng/g. All sites exhibited elevated concentrations with RHB-02 at 8.7 ng/g, RHB-03 at 37.3 ng/g, RHB-04 at 32.7 ng/g, and RHB-05 at 19.3 ng/g. None of these values exceed the PEL limit and RHB-05 for July 17th was again high relative to the other sampling dates for this location (See Table 70).

Table 70: Total concentrations and averages for Dibenz(a,h)Anthracene in ng/g.

DIBENZ(A,H)ANTHRACENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5.0	14.0	13.0	44.0	
28-Jul-04	9.0	55.0	78.0	<5.0	
8-Aug-04	12.0	43.0	7.0	9.0	
13-Aug-04	\	\	\	\	ISQG: 6.22 ng/g
Average		37.3	32.7	19.3	PEL: 135 ng/g

Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeo(1,2,3-C,D)pyrene, and Benzo(g,h,i)perylene

The following compounds did not have ISQG or PEL limits so the values are compared relative to the reference site. However, the range of concentrations found for these compounds indicate that fuels as volatile as gasoline, to bunker fuels, have been disposed of in this landfill, and are continuously leaching. For benzo(b)fluoranthene, RHB-03 and RHB-04 are significantly elevated from the reference site (excluding the July 17th value), with concentrations of 164 ng/g and 224 ng/g, respectively, compared to 19 ng/g for the reference (See Table 71).

For benzo(k)fluoranthene, the average concentration for RHB-04 was significantly greater than the reference site (excluding July 17th), with a value of 190 ng/g compared to 15 ng/g for the reference (See Table 72).

For indeo(1,2,3-c,d)pyrene, the average concentrations for RHB-03 and RHB-04 exceed the reference site (excluding July 17th), with values of 135 ng/g and 189 ng/g, respectively, compared to 15 ng/g for the reference (See Table 73).

For benzo(*G,H,I*)perylene, average concentrations for RHB-03 and RHB-04 exceed the reference site (excluding July 17th), with values of 278 ng/g and 290 ng/g, respectively compared to 20 ng/g for the reference (See Table 74).

Table 71: Total concentrations and averages for Benzo(*b*)Fluoranthene in ng/g.

BENZO(<i>B</i>)FLUORANTHENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	12.0	82.0	92.0	344.0	
28-Jul-04	22.0	239.0	455.0	9.0	
8-Aug-04	30.0	170.0	126.0	28.0	
13-Aug-04	\	\	\	\	
Average	21.3	163.7	224.3	127 (19)	<i>NO VALUE</i>

Table 72: Total concentrations and averages for Benzo(*K*)Fluoranthene in ng/g.

BENZO(<i>K</i>)FLUORANTHENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	<5.0	49.0	46.0	264.0	
28-Jul-04	12.0	147.0	410.0	5.0	
8-Aug-04	21.0	83.0	115.0	26.0	
13-Aug-04	\	\	\	\	
Average	12.7	93.0	190.3	98.3 (15)	<i>NO VALUE</i>

Table 73: Total concentrations and averages for Indeo(1,2,3-*C,D*)Pyrene in ng/g.

INDEO(1,2,3-<i>C,D</i>)PYRENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	9.0	67.0	56.0	264.0	
28-Jul-04	23.0	193.0	390.0	8.0	
8-Aug-04	31.0	145.0	123.0	31.0	
13-Aug-04	\	\	\	\	
Average	21.0	135.0	189.7	101 (15)	<i>NO VALUE</i>

Table 74: Total concentrations and averages for Benzo(*G,H,I*)Perylene in ng/g.

BENZO(<i>G,H,I</i>)PERYLENE ng/g					
Sample Date	Site Location				CEQG value
	RHB-02	RHB-03	RHB-04	RHB-05	
17-Jul-04	14.0	88.0	80.0	237.0	
28-Jul-04	25.0	397.0	395.0	5.0	
8-Aug-04	37.0	350.0	124.0	34.0	
13-Aug-04	\	\	\	\	
Average	25.3	278.3	199.7	92 (20)	<i>NO VALUE</i>

5.0 Discussion

The discussion chapter of this report is divided into five sections covering nutrient loadings in the water of Skerries Brook, metals in both water and sediment, and PAHs in both water and sediment. Organochlorine pesticides and BTEX compounds will not be discussed further because concentrations of these substances were not measured at levels to suggest adverse effects on aquatic life. While concentrations for PCB's also fall within the guidelines and will not be discussed further, it should be noted that any PCB accumulations in the environment should be considered to be unacceptable due to their persistence. The interpretation of the results is based on the Canadian Environment Quality Guidelines and where guidelines are not set, the reference station is used for comparative purposes. Graphs are used to help demonstrate substances that greatly exceed the CEQG limit, or in some cases, greatly exceed the reference value.

5.1 Nutrient Loadings and Additional Parameters

Ammonia, Nitrate, and Nitrogen

There are extremely high levels of ammonia present in all Skerries Brook sample sites. As previously mentioned, ammonia can enter the environment in many different ways; however, the most probable source of ammonia from the RHBSL would be organic waste and waste that includes household cleaning agents. The reason for these high values of ammonia would be the anaerobic decomposition of the municipal waste. The levels of ammonia found in sites RHB-02, 03, and 04 far exceed the guidelines when interpreted within the context of the temperature and pH levels recorded at these sites.

The levels of ammonia present in Skerries Brook are a concern because not only do they exceed the CEQ Guidelines, but they are present at concentrations that in all likelihood prohibit any productive functioning of aquatic species in this environment. We recall from the site surveys that from casual observation we did not encounter any evidence to indicate the presence of fish or aquatic insects in Skerries Brook; the high levels of ammonia may be directly related to this observation. Since the leachate is not contained, high levels of ammonia contaminated water flow down through Skerries Brook and into the marine environment.

As previously mentioned throughout this report, it was in the interest of St. John's Harbour ACAP to consider the natural remediation that might be provided by the marsh, situated directly adjacent to the landfill and where its leachate is discharged via the culvert. According to the samples, the concentration of ammonia is greater in the pre-marsh sample than post-marsh as well as at the mouth of the brook. The vegetation in the marsh might help with the uptake of ammonia; however, its presence is found in such large quantities that the overall concentrations are only marginally reduced.

Levels of nitrogen and nitrate are less of a concern, but as indicated in the summary tables, their concentrations reflect the excess amounts of nitrogen found in Skerries Brook compared to the reference, with higher concentrations at RHB-04 and decreasing concentrations further down stream.

Total Organic Carbon, Sulphate, Chloride, Phosphorous

There are no guidelines for TOC, sulphate, chloride, and phosphorus for the protection of aquatic life; however, it is relevant to mention that the average results for these constituents were greater in Skerries Brook than in the reference, therefore

supporting the observation that the amount of organic matter in Skerries Brook is greater than at the reference site.

Chloride and sulphate values were expected to be greater in the marine sample because they exist naturally in much larger concentrations in seawater. However, we notice in this case the conductance for both the freshwater and marine samples are of similar value, but the chloride values for the freshwater samples are an order of magnitude lower than the marine samples at RHB-01. This indicates that there are high dissolved solids in the leachate. Nitrogen helps with the uptake of phosphorous and so the high values for nitrogen can help account for the relatively low values recorded for phosphorous. The high level of organic matter in the brook may act to bind substances making them less bioavailable. Conversely, high organic material depletes much needed oxygen levels from a highly stressed water body.

Dissolved Oxygen

Dissolved oxygen (DO) is an important indicator of a healthy water body. In the marsh area, there is very little available oxygen to support life and the oxygen entering the water is immediately taken up by other microbial activity. The levels for DO are within the guidelines for RHB-01, RHB-02, RHB-03, and RHB-05; however, an extremely low concentration of dissolved oxygen was recorded at RHB-04, even for polluted waters. Low DO levels at this site therefore present a risk to any living organism in this area. With these few measurements, further study is required.

5.2 Metals

Some metals have more adverse impacts than others and their behavior in the environment can result in deleterious impacts on aquatic species. Metals as a constituent of leachate should be analyzed when performing analysis on water and sediment quality, and interpretation of analysis can provide insight in assessing levels of pollution in a given area. With reference to this project, the concentrations of certain metals in both water and sediment samples present a concern to the immediate aquatic environment of Skerries Brook. Of the metals tested, aluminum, iron, zinc, lead, and cadmium are worth highlighting for discussion.

Aluminum

Aluminum was tested in the water samples, but not in the sediment. This metal yielded concentrations which exceed the CEQG limit in sites RHB-02 and RHB-03. The average concentration for aluminum in RHB-04, at the landfill, was lower than the post-marsh sample (RHB-03), and the mouth of the river sample (RHB-02) (See Appendix D; Graph W1). It is possible the chemical makeup of the leachate entering the brook causes further aluminum from the streambed to be leached.

Iron

The iron content in both the water and sediment samples is extremely high. There is no limit provided by CEQG for sediment; however, the values for water samples are two orders of magnitude higher than the CEQG limit. The high values for iron in the water samples accurately reflect St. John's Harbour ACAP's concern of excess iron during the initial visual assessment of the site (See Appendix D; Graph W2).

The values for iron in sediment are so high that the analysis was performed as a percentage instead of recorded in ug/g like the other metals. The highest percentage of iron in Skerries Brook is post marsh (RHB-03), followed by the landfill site (RHB-04) and

then at the mouth of the brook (RHB-02). The results indicate a very disproportionate concentration of iron being emitted from the landfill into Skerries Brook, and consequently into the Atlantic Ocean. The paired sediment and water sample stations do not match with respect to the sites which exhibited the most iron, but this observation may be attributed to the finer particle size collected in site RHB-03 as opposed to site RHB-04, where the sediment was far grittier.

Zinc

The level of zinc found in both water and sediment samples exist in concentrations that exceed the guidelines. In the water samples, zinc was highest at site RHB-03, followed by RHB-04 and RHB-02 (See Appendix D; Graph W3).

In the sediment samples, the values for zinc exceed the ISQG limit and in some cases exceed the PEL limit. RHB-03 is again the highest, followed by RHB-04 and RHB-02 (See Appendix D; Graph S2). As in the case of aluminum, the concentration of zinc in the water samples is greater post-marsh than it is pre-marsh. This is also the case with the sediment samples, indicating that there is not much uptake of this metal from the wetland. Further assessment is necessary for conclusive results.

Lead

No testing for lead was conducted in the water samples, but the levels in sediment are above the ISQG limit. The concentration of lead for RHB-03 is the highest, followed by RHB-02 and RHB-04. The values at RHB-02 and RHB-04 are even lower than the control site (See Appendix D; Graph S1). All values are below the PEL limit, but should still represent a concern to the health of the aquatic environment in this area because they exceed the ISQG limit. The reference site was close to a roadway and may have some influence from lead based gasolines.

Cadmium

Cadmium is considered a highly toxic metal in aquatic environments. Unfortunately, the detection limit for this metal in water was set at 2.0 ug/L, which is too high because the CEQG value is 0.12 ug/L for marine and 0.017 ug/L for freshwater. The results show that concentrations in the samples are lower than the detection limit, but it is not conclusive whether they may pose risks to Skerries Brook.

The detection level for cadmium in sediment was also set too high at less than 1.0 ug/g when the ISQG value is 0.6 ug/g. The concentrations recorded for cadmium in sediment are all less than 1.0 ug/g; however, as is the case with the water samples, it is unknown whether the concentrations are above or below the limit of 0.6 ug/g. Further testing at a lower detection level would yield more conclusive results for cadmium.

Other Significant Observations for Metals

Canadian Environmental Quality Guidelines are not available for all metals and it is difficult to determine their significance. The CEQG might not be available because the metal is not considered significant in the aquatic environment or because there is insufficient data to determine a guideline. For these instances, the reference site is helpful in evaluating whether some concentrations of certain metals are elevated within Skerries Brook.

Manganese, strontium and barium all possess values that exceed the reference site. For manganese, both water and sediment samples demonstrate concentrations exceeding the reference, except for the mean sediment sample value at RHB-04. The average concentrations in the water samples do not completely reflect the average

concentrations in the sediment samples and according to the sediment samples; the marsh does not necessarily have any remediation value for manganese uptake from the landfill.

Sediment analysis did not include strontium and barium; however the results from the water samples indicate elevated levels in RHB-01 to RHB-04 compared with the reference site. These results indicate elevated levels of strontium and barium compared to the reference, but their significance relative to other metals is not clear.

5.3 Polycyclic Aromatic Hydrocarbons (PAHs)

The results for PAHs in both water and sediment samples are elevated. PAHs are usually present in fairly low concentrations in water. The fact that relevant concentrations of PAHs were present in several of the water samples indicates that their presence is significant in the environment and should therefore pose a concern relative to the health of Skerries Brook. Only the PAHs posing the greatest concern in terms of exceeding the CEQG limits will be included in this discussion.

Phenanthrene

The only significant sample indicating elevated concentrations of phenanthrene for the water samples is at sample site RHB-04, by the landfill (See Appendix D; Graph W5).

For sediment samples, phenanthrene displayed values above both the ISQG limit in site RHB-05, and above the PEL limit in sites RHB-03 and RHB-04 (See Appendix D; Graph S7). As outlined in the summary section, on July 17th, the sediment sample yielded an abnormally high result for RHB-05 at 385 ng/g, compared to the limit of 40 ng/g. This caused the overall average for the reference site to increase. The reason for the high value may be due to close proximity to a roadway, unclean equipment, or a sampling mistake.

Overall, phenanthrene poses more acute toxic threats to aquatic organisms in Skerries Brook as opposed to carcinogenic risk because of its low molecular weight. This is especially true at the base of the landfill, which exhibits the highest average for this PAH.

Naphthalene

The only significant levels of naphthalene detected in the water samples were detected at sampling site RHB-04 (See Appendix D; Graph W4).

For the sediment samples, naphthalene exceeds the ISQG limit in sites RHB-03 and RHB-04 (See Appendix D; Graph S3). Naphthalene is considered more acutely toxic than carcinogenic because of its low molecular weight and can therefore impose immediate risks to the aquatic environment. Since both the post-marsh and pre-marsh sites have greater concentrations than the guidelines, this PAH presents a risk to the aquatic environment in this area.

Acenaphthene

Acenaphthene is present in sediment samples and while RHB-02 exceeds the ISQG value, RHB-03 and RHB-04 also exceeds the PEL limit (See Appendix D; Graph S5). Acenaphthene is clearly above the guideline in sediment and should pose a risk to the aquatic environment in all Skerries Brook sediment sampling stations.

Fluorene

Fluorene concentrations in the sediment samples are above both the PEL limit in sites RHB-03 and RHB-04. These values should therefore present a concern to the aquatic environment in this area (See Appendix D; Graph S6).

Other Significant PAHs

Acenaphthylene, anthracene, fluoranthene, pyrene, benzo(a)pyrene, and chrysene all exceed the ISQG values in various sampling locations, but their overall averages do not exceed the PEL limit for any of these PAHs (See Appendix D; Graphs W6, W7, S4, S8, and S9). In addition to this, other PAHs in water samples showed values near or at the quality guidelines, but the detection limit was set too high for confident determination of significant concentrations. In particular, anthracene, pyrene, and benz(a)anthracene yielded values in the water samples that were possibly greater than the guidelines, but the detection limits for analysis were greater than the guideline value.

In most cases RHB-04 exhibits the highest average concentrations for PAHs, and as previously discussed, some of these values exceed the Probable Effects Level (PEL) in addition to exceeding the ISQG values. Typically, RHB-03 concentrations were generally lower than RHB-04 concentrations. Since RHB-04 is located at the closest discharge point to the landfill, it is expected that the values would be highest in this sampling station and, in general, this was the case. Since RHB-03 is further downstream, the concentration of PAHs in both water and sediment are expected to be relatively lower. An objective of this project was to examine the value of the marsh/wetland in this area to detoxify the leachate leaving the landfill. In general it would appear the marshy area is providing some remediation value, however, for some parameters the levels of PAH compounds are elevated in sediment and water further downstream. A more comprehensive investigation would need to be conducted, including a survey of plant species in the marsh known to help remove chemicals. The sampling station at the mouth of the river, RHB-02, displayed noticeably lower values for the PAHs and so it can therefore be stated that the concentration of PAHs in the sediment is most likely diluted by the flowing water.

The adsorption of PAH compounds in sediment is also dependent on the particle size of the sediment. The finer the particulate size, the greater the overall surface area for the PAH substances to adhere. The analysis on particle size distribution revealed that RHB-02 consisted of 0.0% Gravel, 65.6% Sand, 30.3 % Silt, and 4.2% Clay; RHB-03 consisted of 19.2 Gravel, 44.2% Sand, 29.3% Silt, and 7.3% Clay; RHB-04 was 51.8% Gravel, 35.1% Sand, 9.6% Silt, and 3.4% Clay; and RHB-05 was 51.1% Gravel, 33.7% Sand, 10.8% Silt, and 4.4% Clay. Fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)pyrene, chrysene, dibenz(a,h)Anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeo(1,2,3-c,d)pyrene, and benzo(g,h,i)perylene all exhibited exceptionally high values at the reference site (RHB-05) on the sampling event of July 17th. This caused the averages for these PAHs to increase for all the reference values, exceeding the ISQG levels in all cases. Subsequent sampling demonstrated PAH contamination was not present suggesting the results from the July 17th event may have been a sampling/laboratory anomaly. The reference site is also near a roadway and so there may have been a release of crankcase oil from an automobile prior to sampling.

Overall, the PAHs present a significant concern since many of the values recorded exceed levels known to cause adverse effects to aquatic species. As previously mentioned, when particulate matter is high as is the case in Skerries Brook,

PAH's attach easily to these particles and are deposited into the sediment. The carcinogenic and acutely toxic effects of PAHs make this group of compounds a risk to the aquatic life in Skerries Brook. There were no fish visible through the turbid water; however, the sound of frogs was reported near the marsh and flocks of ducks also inhabit this area.

6.0 Conclusions

The following conclusions result from this survey:

The landfill design appears to contravene the Newfoundland and Labrador *Waste Disposal Regulations*, as follows;

- Residential developments have taken place within the 1.6 km development exclusion zone.
- The disposal site is less than 150 meters from a water body (Skerries Brook).
- The environmental health of Skerries Brook is adversely affected by leachate discharged from the Robin Hood Bay landfill. Several species of polycyclic aromatic compounds (PAHs) and metals are elevated above acceptable environmental quality guidelines. Excessive amounts of toxic ammonia and the severely limited amounts of dissolved oxygen is extremely deleterious to any aquatic species that may inhabit Skerries Brook. While a detailed benthic invertebrate or fish survey was not conducted, observations during the site sampling events suggest the stream may be devoid of aquatic life, likely as a result of the toxic leachate from the landfill.
- The RHBSL is unlined, the cover is permeable, and it has been in use for over 40 years. As currently designed, this landfill is highly inappropriate for the growing population of the Greater Avalon Region and with residential waste increasing, and even more toxic constituents being disposed; the likelihood for the leachate quality to improve without treatment is unlikely.
- The Robin Hood Bay Sanitary Landfill is discharging a liquid waste stream that appears to be harmful to Skerries Brook and surrounding area. The landfill is unlined, poorly capped, and uncontained. While the Gartner Lee Report has conducted an investigation of the re-engineering aspects of the landfill, the results outlined in this report clearly demonstrates the need for proper leachate collection and treatment. Waste handling has improved at the RHBSL in recent years. These include separate disposal of hydrocarbon and sewage sludge, scrap metal recovery, and a cardboard ban. Prior to consideration to expanding the landfill to accept waste from the greater Avalon region, further improvements in waste diversion, recycling and landfill re-design are essential.
- The wetland/marsh may be providing some remedial value for the removal of toxic constituents from the leachate. However, it would appear that the quantities of some substances are overwhelming the remediation capacity of the marsh.
- The discharge of ammonia and PAH contaminated leachate to Skerries Brook and the marine environment may be in direct violation of the Federal Fisheries Act which prohibits the deposit of substances harmful to fish.

The study has achieved its objectives and contributes significantly to the information and research available on the impacts that the current operation of the Robin Hood Bay landfill has on the adjacent environment. The results of this research can provide a useful aid for regulatory authorities when considering environmental and health issues associated with the site, and in determining the level of regulatory compliance of this landfill. Most importantly, this study serves to raise awareness that the RHBSL poses significant risk to the surrounding environment. The extent of these risks was not fully quantifiable in this study but should serve as a springboard for further assessment and responsible care on the part of stakeholders.

7.0 Recommendations

- The City of St. John's should ensure the operation of the RHBSL complies with the Government of Newfoundland and Labrador's *Environmental Protection Act (Waste Disposal Regulations)*. Waste handling practices should be modernized at the landfill and be included in future operating permits. Alternative and creative mitigation measures must be implemented where the site cannot meet guidelines. For example, it is impractical to remove residential development from within the 1.6 km zone; however, greater efforts for waste management, waste reduction, etc., should be explored.
- Ammonia levels in leachate entering Skerries Brook and the marine environment could be toxic to aquatic species. The City of St. John's needs to be proactive and diligent in mitigating the impact of this discharge.
- Current operational practices to reduce dispersion of wind blown debris are inadequate. To minimize this problem, further attention to daily waste cover and periodic clean-ups must be revisited and improved to address the current shortcoming. The windfence should be cleared regularly and refuse sufficiently buried to reduce the impacts of refuse becoming airborne.
- The City of St. John's should consider the leachate management recommendations of the Kavanagh and Associates report (2000) and the Gartner Lee report (2004). The Kavanagh & Associates report states increased slopes to collect the leachate and a low permeability covering could gradually lower the volume of leachate produced by 75%. There are two possible leachate management strategies suggested by the study. The first involves exploring the attenuating capacity of the nearby marsh. The current project suggests the marsh does contribute to reducing the concentration of some contaminants in the leachate. Further engineering design would be required to realize the full mitigation potential of the marsh. The other potential leachate management plan suggested by the Kavanagh study involves collecting the leachate via a cut-off wall. The leachate would then have to be treated prior to discharge or re-injected in to the landfill. Capping the landfill with an impermeable layer and re-directing lateral infiltration of ground and surface water will gradually dry out the landfill. This process reduces the amount required to treat but also concentrates the leachate. A third alternative would be to increase the permeability of the landfill cover, collect and re-inject leachate. This process essentially makes the landfill a 'bioreactor', and speeds the rate of decomposition of waste.
- The City of St. John's needs to take a more proactive role in managing waste at the Robin Hood Bay site, engaging input from stakeholders such as nearby residential and commercial property owners, waste haulers and recyclers, the East Coast Trails Association, St. John's Harbour ACAP, and the Multi Material Stewardship Board. There must be a greater government effort to promote waste reduction in the Avalon Region. The Greater Avalon Regional Waste Management Committee (GARWMC), and other interested stakeholders such as the City of St. John's, City of Mount Pearl and surrounding communities must invest in educational materials to promote the reduction of waste entering RHBSL.

8.0 References

- Alabaster, J.S., and R. Lloyd. 1982. Water quality criteria for fresh water fish. 2nd ed. Food and Agriculture Organization, United Nations. Butterworths in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Dissolved Oxygen (Freshwater) Fact Sheet; 1999.
- Alker, S.C. (1995). The compositions of leachate from waste disposal sites. In R.W. Sarsby (Ed.), Waste disposal by landfill (pp.215-223). United Kingdom.
- ASTDR (Agency for Toxic Substances and Disease Registry). 1990. Toxicological profile for ethylbenzene. U.S. Department of Health and Human Services, Washington DC in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Ethyl Benzene Fact Sheet; 1999.
- Buikema, A.L., Jr., and A.C. Hendricks. 1980. Benzene, xylene, and toluene in aquatic systems: A review. Published by the American Petroleum Institute in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Benzene Fact Sheet; 1999.
- Campbell, P.G.C., and A. Tessier. 1996. Ecotoxicology of metals in aquatic environments: Geochemical aspects. In: Ecotoxicology: A hierarchical treatment, M.C. Newman and C.H. Jagoe, eds. Lewis Publishers, Boca Raton, FL in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, Zinc Fact Sheet; 1999.
- CCME (Canadian Council of Ministers of the Environment). 1996. Appendix XXI – Canadian water quality guidelines: Updates (May 1996), cadmium. In: Canadian water quality guidelines, Canadian Council of Resource and Environment Ministers. 1987. Prepared by the Task Force on Water Quality Guidelines. Ottawa in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Cadmium Fact Sheet; 1999.
- CCME. 2000. Canadian Water Quality Guidelines for the Protection of Aquatic Life AMMONIA. Canadian Council of Ministers of the Environment, Winnipeg, MB. R3C 1T5.
- CCREM (Canadian Council of Resource and Environment Ministers). 1987. Canadian Water Quality Guidelines in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Ammonia Fact Sheet; 1999.
- CEPA (Canadian Environmental Protection Act), R.S., 1985. c. 16 (4th Supp.) in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Community Support Friends of the Earth Program to Assist Grassroots Activists. (1999). Landfill Manual: Leachate [Online]. Available: <http://www.foe.org/ptp/chapter3.html> [2001, February 3]
- Daniel, D.E. (1995). Pollution prevention in landfills using engineered final covers. In R. W. Sarsby (Ed.) Waste disposal by landfill (pp. 73-92). United Kingdom.
- Doudoroff, O., and D.L. Shumway. 1970. Dissolved oxygen requirements of freshwater fishes. FAO Technical Paper No. 86. Food Agriculture Organization, United Nations, Rome in

- Canadian Water Quality Guidelines for the Protection of Aquatic Life, Dissolved Oxygen (Freshwater) Fact Sheet; 1999.
- Eisler, R. 1988. Lead hazards to fish, wildlife, and invertebrates: A synoptic review. Biol. Rep. 85(1.14). U.S. Department of the Interior, Fish and Wildlife Service, Laurel, MD in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, Lead Fact Sheet; 1999.
- Eisler, R. 1987. Polycyclic aromatic hydrocarbon hazards to fish, wildlife, and invertebrates: A synoptic review. Biological Report, Publication No. 85(1.11). Contaminant Hazard Reviews Report No. 11. U.S. Department of the Interior, Fish and Wildlife Service, Patuxent Wildlife Research Center, Laurel, MD in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Environment Canada. 2001. Ammonia in the aquatic environment. Ottawa.
- Environment Canada (Environment Canada). 1999. Canadian Environmental Protection Act Priority Substances List II – Supporting document for Ammonia in the Aquatic Environment. DRAFT – August 31, 1999 in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Ammonia Fact sheet; 1999.
- Environment Canada (Environment Canada). 1997. Problem formulation for Ammonia in the aquatic environment. Canadian Environmental Protection Act Priority Substances List 2. Version 5.0, November 4, 1997.
- Environment Canada. 1997. Canadian water quality guidelines for chromium. Supporting document. Environment Canada, Science Policy and Environmental Quality Branch, Ottawa. Unpub. draft doc in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Cadmium Fact Sheet; 1999.
- Fishbein, L. 1984. An overview of environmental and toxicological aspects of aromatic hydrocarbons. I. Benzene. Sci. Total Environ. 40:189–218 in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Benzene Fact Sheet; 1999.
- Gartner Lee Limited. 2003. Reduction of Greenhouse Gas Emissions: Methan Gas Study for Robin Hood Bay Landfill. Prepared for City of St. John's. November, 2003.
- Gartner Lee Limited. 2004. Robin Hood Bay Landfill Engineering Feasibility Assessment. Prepared for City of St. John's. October, 2004.
- Government of Canada. 1993. Arsenic and its compounds. Canadian Environmental Protection Act Priority Substances List Supporting Document. Health and Welfare Canada and Environment Canada, Ottawa in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Arsenic Fact Sheet; 1999.
- Government of Canada. 1993. Toluene. Canadian Environmental Protection Act Priority Substance List Supporting Document. Environment Canada and Health and Welfare Canada, Ottawa in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Toluene Fact Sheet; 1999.

- Government of Newfoundland and Labrador, Department of Environment. 2001. Protecting Our Environment For Tomorrow. A public consultation paper for a strategy for waste management.
- Goyette, D., and J. Boyd. 1989. The relationship between polycyclic aromatic hydrocarbon (PAH) concentrations in sediment and the prevalence of liver lesions in English sole (*Parophrys vetulus*) from Vancouver Harbour 1985/86 and 1987. Environment Canada, Conservation and Protection, Environmental Protection, Pacific and Yukon Region, Marine Programs. Draft in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Greater Avalon Regional Waste Management Committee. 2002.
- Griffin, H., & Minty, D. (1993). Finding the balance for earth's sake: Municipal waste management. St. John's: Breakwater.
- Haywood, G.P. 1983. Ammonia toxicity in teleost fishers: a review by Geoffrey P. Haywood. Dept of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, Nanaimo, B.C in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Ammonia Fact Sheet; 1999.
- Herbes, S.E., and L.R. Schwall. 1978. Microbial transformation of polycyclic aromatic hydrocarbons in pristine and petroleum-contaminated sediments. Appl. Environ. microbiol. 35:306–316 in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Hughes, G.M. 1981. Effects of low oxygen and pollution on the respiratory system of fish. In: Stress and fish, A.D. Pickering, ed. Academic Press Inc., London in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Dissolved Oxygen (Freshwater) Fact Sheet; 1999.
- International Joint Commission. 1986. 2.2 Ammonia. In: 1985 Annual Report. Report of the Aquatic Ecosystems Objectives Committee. Windsor, Ontario
- Kavanagh & Associates Limited. 2000. City of St. John's Robin Hood Bay Sanitary Landfill Operational Study. Kavanagh & Associates Limited.
- Kavanagh & Associates Limited. 2002. City of St. John's Robin Hood Bay Sanitary Landfill Operational Study. Kavanagh & Associates Limited.
- Kavanagh & Associates Limited. 2003. City of St. John's Robin Hood Bay Sanitary Landfill Operational Study. Kavanagh & Associates Limited.
- Lee, G.F., & Jones-Lee, A. (1993). Sardinia '93IV International Landfill Symposiums: Groundwater Pollution by Municipal Landfills: Leachate composition, detection and water quality significance [Online]. Available: <http://members.aol.com/annejlee/pap/if-conta.htm> [2001, January 15]
- Manahan, Stanley E., 1994. Environmental chemistry; 6ed. Boca Raton: Lewis.

- McNeely et al. 1979. Water Quality Sourcebook: A guide to water quality parameters. Environment Canada publication, Ottawa, Ontario. Cited in WQB 1989.
- Moore, J.W., and S. Ramamoorthy. 1984. Aromatic hydrocarbons: Polycyclics. In: Organic chemicals in natural waters: Applied monitoring and impact assessment, R.S. DeSanto, ed. Springer-Verlag, New York in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Neff, J.M. 1984. Bioaccumulation of organic micropollutants from sediments and suspended particulates by aquatic animals. *Fresenius J. Anal. Chem.* 319:132–136 in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999 in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Neff, J.M. 1979. Polycyclic aromatic hydrocarbons in the aquatic environment, sources, fates and biological effects. Applied Science Publishers Ltd., Essex, England in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Nielsen, I.R., and P. Howe. 1991. Environmental hazard assessment: Toluene. Department of the Environment, London in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Toluene Fact Sheet; 1999.
- NRCC (National Research Council of Canada). 1983. Polycyclic aromatic hydrocarbons in the aquatic environment: Formation, sources, fate and effects on aquatic biota. NRC Associate Committee on Scientific Criteria for Environmental Quality. Publication No. NRCC 18981. Ottawa in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Nriagu, J.O. 1989. Effects of atmospheric trace metal deposition on aquatic ecosystems. Background paper prepared for a workshop on The Effects of Atmospheric Contaminants on Aquatic and Terrestrial Ecosystems. Centre for Clean Air Policy, Washington, DC in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Arsenic Fact Sheet; 1999.
- OMOEE (Ontario Ministry of Environment and Energy). 1994. Scientific criteria document for the development of a provincial water quality guideline for toluene.
- OMOEE, Standards Development Branch, Toronto in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Toluene Fact Sheet; 1999.
- Pawlisz, A.V., R.A. Kent, U.A. Canadian water quality guidelines *Water Qual.* 12:185–193 in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Cadmium Fact Sheet; 1999.
- Pellerano, M., 1995. The basics of landfills [Online]. Available: <http://www.enviroweb.org/issues/landfills.htm> [2001, January 19]
- Prosi, F. 1989. Factors controlling biological availability and toxic effects of lead in aquatic organisms. *Sci. Total Environ.* 79:157–169 in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, Lead Fact Sheet; 1999.

- Qasim S. & W. Chiang, 1994. Sanitary landfill leachate : generation, control, and treatment. Lancaster, Pa. : Technomic Pub. Co.
- Raven, P.H. & G.B. Johnson. 1989. Biology. Times Mirror/Mosby College Publishing. New York ISBN 0-8016-4041-5.
- Reuther, R. 1986. The occurrence and speciation of arsenic in the aquatic environment. A literature review. 86-11-20. SERG, Kil, Sweden in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Arsenic Fact Sheet; 1999.
- Rodgers, J.H., K.L. Dickson, F.Y. Saleh, and C.A. Staples. 1987. Bioavailability of sediment-bound chemicals to aquatic organisms: Some theory, evidence and research needs. In: Fate and effects of sediment-bound chemicals in aquatic systems, SETAC Special Publication Series, K.L. Dickson, A.W. Maki, and W.A. Brungs, eds. Pergamon Press. New York in Canadian Sediment Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Russo, R.C., and R.V. Thomann. 1978. In: Proceedings of the First and Second USA-USSR Symposia on the effects of Pollutants on Aquatic Ecosystems. EPA-600/3-78-076.
- Slooff, W., J.A. Janus, A.J.C.M. Matthijsen, G.K. Montizaan, and J.P.M. Ros (eds.). 1989. Integrated criteria document. PAHs. Report No. 758474011. National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Southworth, G.R. 1979. Transport and transformations of anthracene in natural waters. In: Aquatic toxicology: Proceedings of the Second Annual Symposium on Aquatic Toxicology, L.L. Marking, and R.A. Kimerle, eds. ASTM STP 667. Philadelphia in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Suzuki, J., H. Okazaki, Y. Nishi, and S. Suzuki. 1982. Formation of mutagens by photolysis of aromatic compounds in aqueous nitrate solution. Bull. Environ. Contam. Toxicol. 29:511–516 in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- Thanabalasingam, P., and W.F. Pickering. 1986. Arsenic sorption by humic acid. Aquat. Toxicol. 12: 233–246 in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Arsenic Fact Sheet; 1999.
- Trussell, R. P. 1972. The percent un-ionized ammonia in aqueous ammonia solutions at different pH levels and temperatures. J. Fish. Res. Bd. Canada. 29: 1505-1507
- USEPA (U.S. Environmental Protection Agency). 1982b. An exposure and risk assessment for benzo(a)pyrene and other polycyclic aromatic hydrocarbons: Vol. III. Anthracene, acenaphthene, fluoranthene, fluorene, phenanthrene, and pyrene. USEPA, Office of Water Regulations and Standards, Washington, DC in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.

- USEPA (U.S. Environmental Protection Agency). 1982c. An exposure and risk assessment for benzo(*a*)pyrene and other polycyclic aromatic hydrocarbons: Vol. IV. Benzo(*a*)pyrene, acenaphthylene, benz(*a*)anthracene, benzo(*b*)fluoranthene, benzo(*k*)fluoranthene, benzo(*g,h,i*)perylene, chrysene, dibenz(*a,h*)anthracene, and indeno(1,2,3-*c,d*)pyrene. USEPA, Office of Water Regulations and Standards, Washington, DC in Canadian Water Quality Guidelines for the Protection of Aquatic Life, PAH Fact Sheet; 1999.
- USEPA. 1985. Ambient Water Quality Criteria for Ammonia – 1984. United States Environmental Protection Agency, Office of Water Regulations and Standards, Washington, DC, 20460, USA. Report EPA 440/5-85-001. 217 pp.
- USEPA. 1989. Ambient Water Quality Criteria for Ammonia (Saltwater) – 1989. United States Environmental Protection Agency, Office of Water Regulations and Standards, Washington, DC, 20460, USA. Report EPA 440/5-89-004. 59 pp.
- Wetzel, R.G. 1983. Limnology. 2d ed. Saunders College Publishing, Philadelphia in Canadian Water Quality Guidelines for the Protection of Aquatic Life, Dissolved Oxygen (Freshwater) Fact Sheet; 1999.
- WHO (World Health Organization). 1986. Environmental Health Criteria 54. Ammonia. IPCS International Programme on Chemical Safety. Geneva, Switzerland. ISBN 92-4-154194-6.

Appendix A: Visual Figures of RHBSL and Sampling Sites



Figure A1: View of RHBSL from the East Coast Trail.

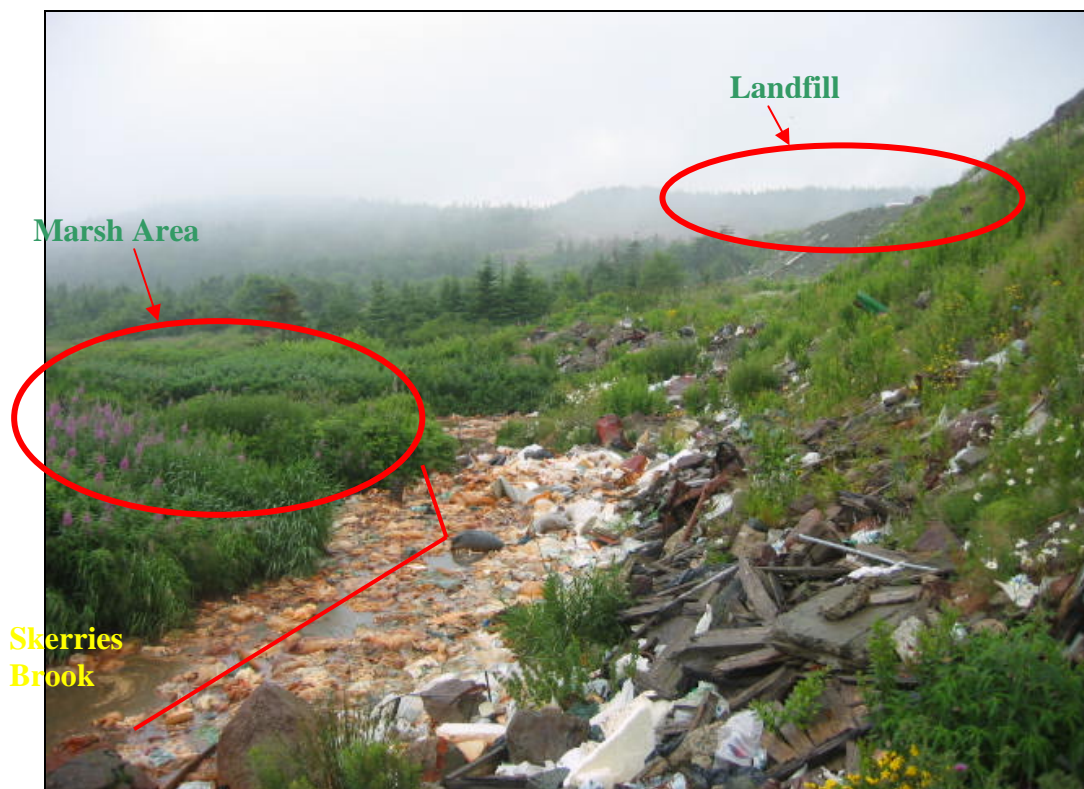


Figure A2: Skerries Brook adjacent to the immediate landfill



Figure A3: Mouth of Skerries Brook flowing into the Atlantic Ocean



Figure A4: Skerries Brook flowing from the landfill and into the Atlantic Ocean



Figure A5: Leachate mixing with surface water and waste.



Figure A6: RHB-01; Marine sample location where Skerries Brook enters into the ocean.



Figure A7: RHB-02; Collecting sediment samples at the mouth of the Skerries Brook.

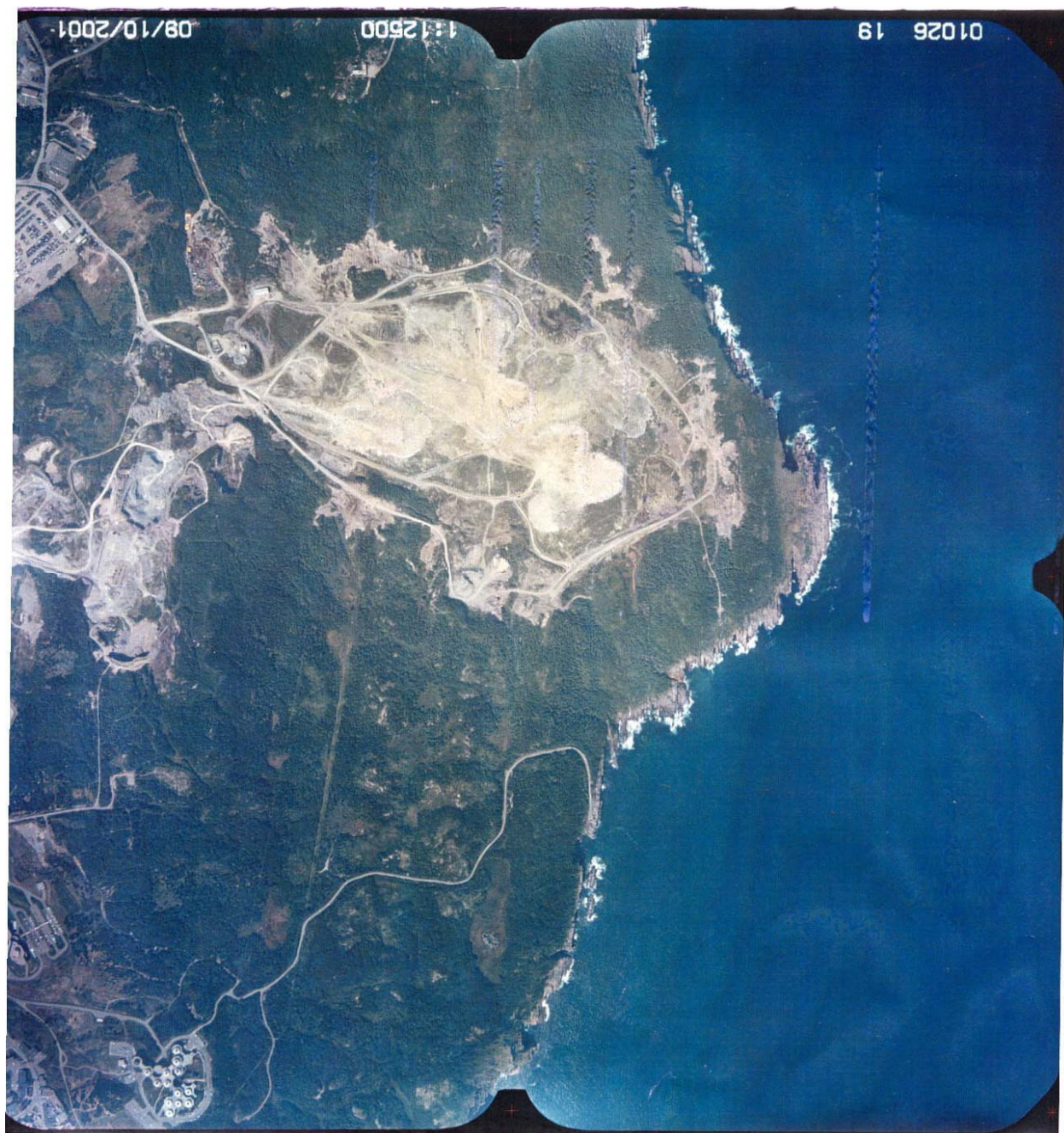


Figure A8: RHB-03; Post-marsh sample in Skerries Brook.



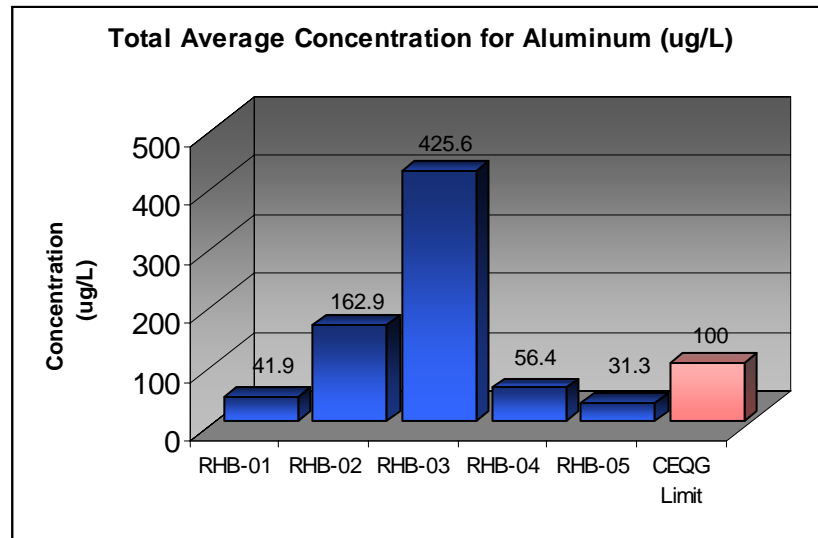
Figure A9: RHB-04: Sampling location pre-marsh where water exited culvert below the landfill

Appendix B: Aerial Photograph of RHBSL

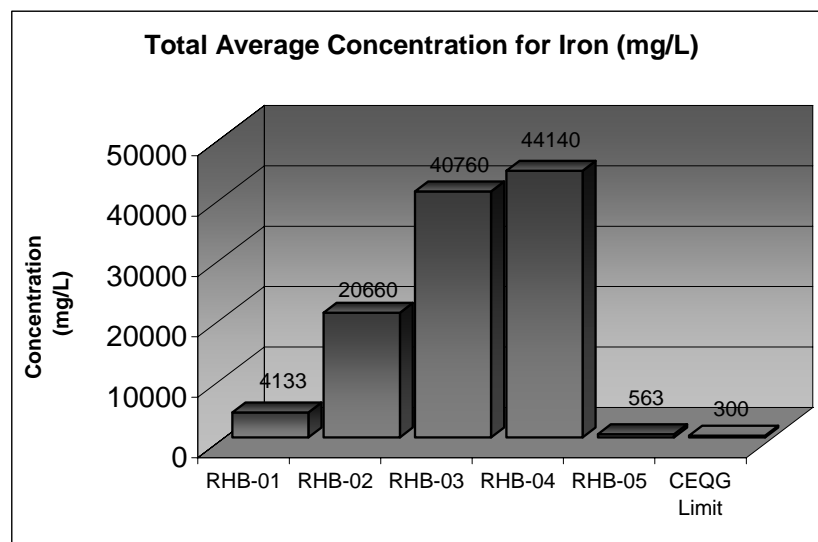


Appendix C: Graphical Depiction for Relevant Concentrations of Substances in Water (1) and Sediments (2)

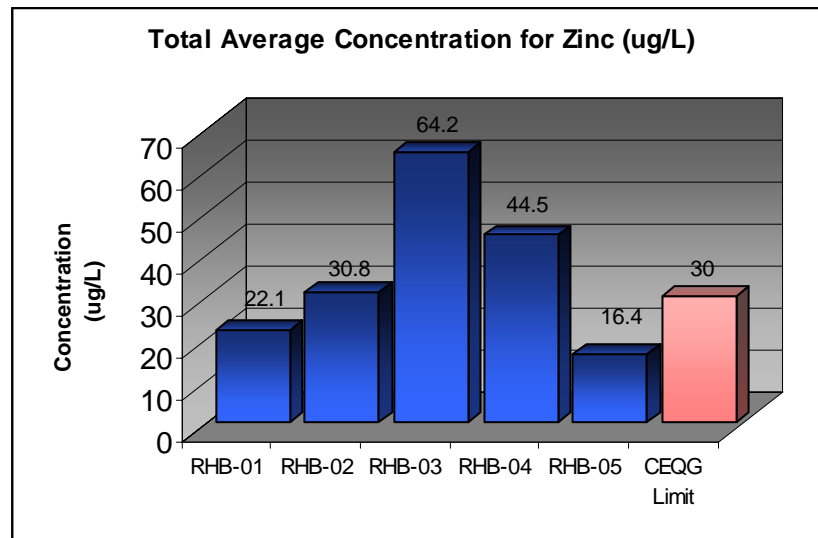
1. Graphical Depiction for Relevant Concentrations of Substances in Water



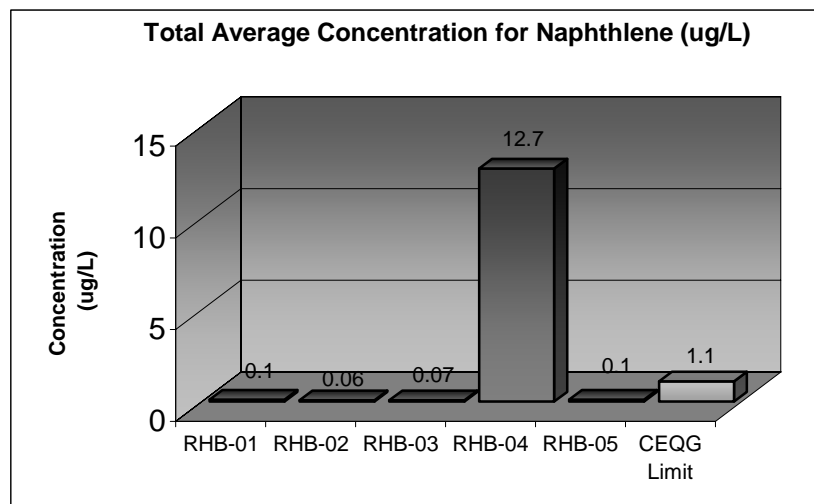
Graph W1: Total Average Concentration for Aluminum (ug/L)



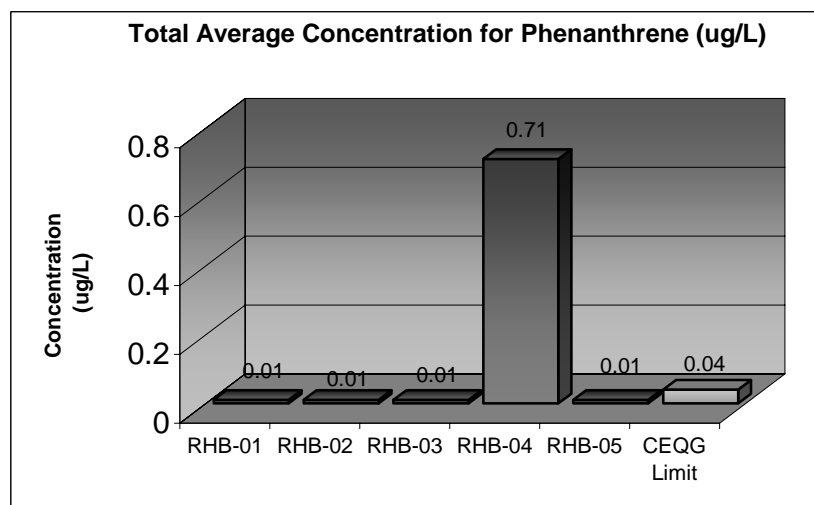
Graph W2: Total Average Concentration for Iron (mg/L)



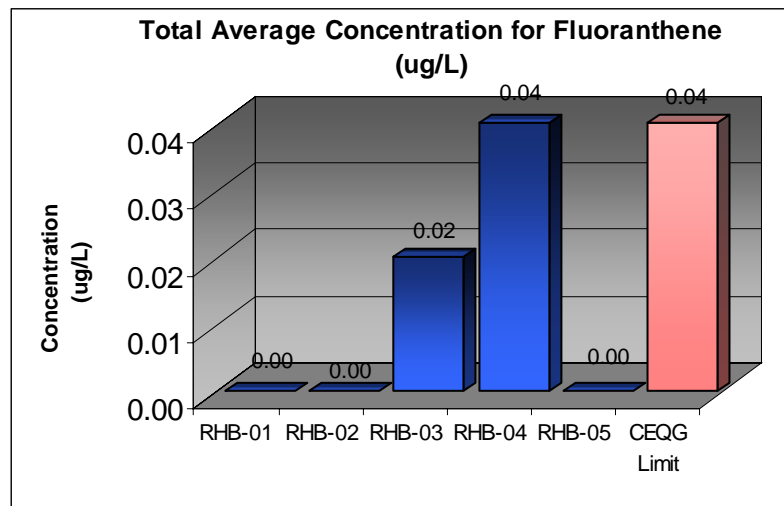
Graph W3: Total Average Concentration for Zinc (ug/L)



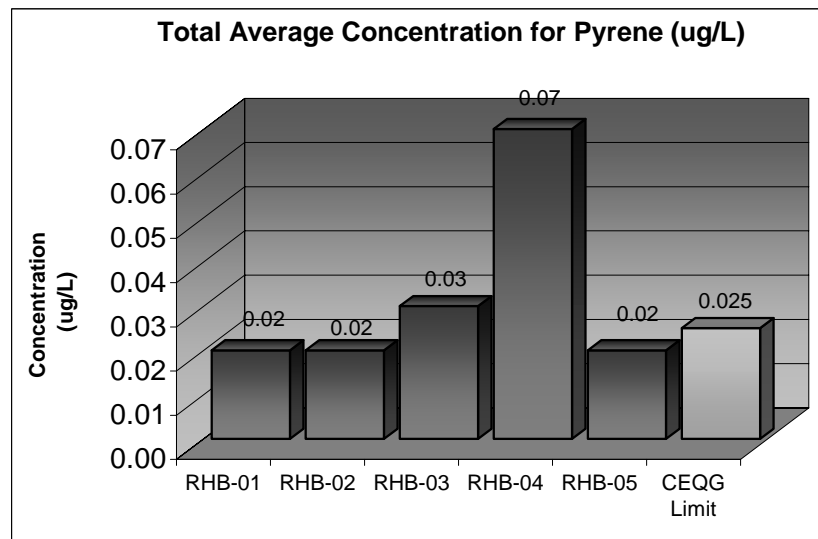
Graph W4: Total Average Concentration for Naphthalene (ug/L)



Graph W5: Total Average Concentration for Phenanthrene (ug/L)

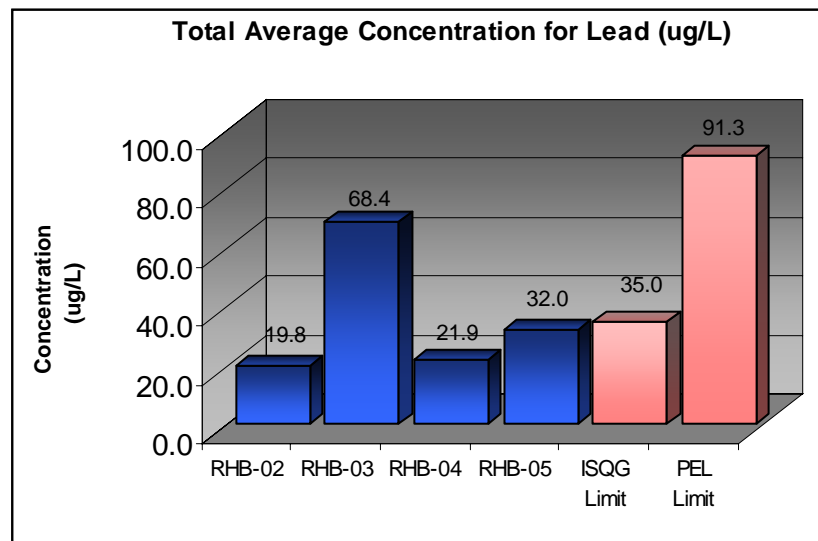


Graph W6: Total Average Concentration for Fluoranthene (ug/L)

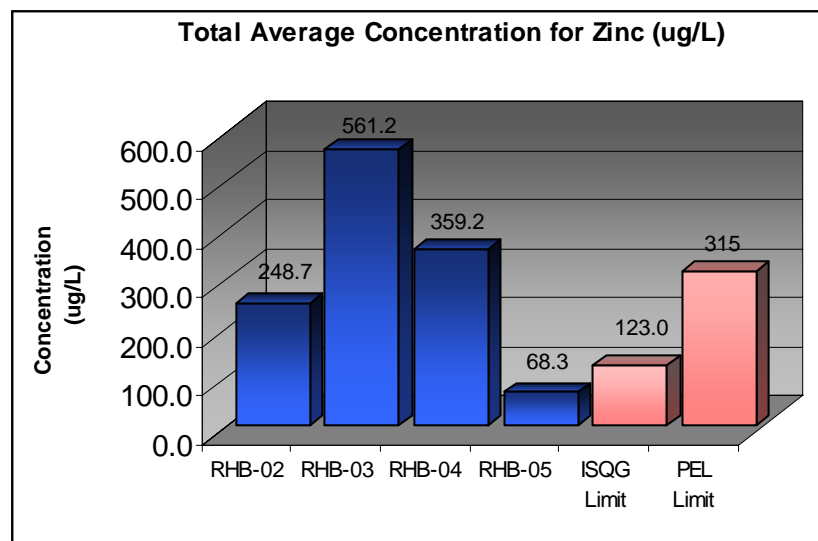


Graph W7: Total Average Concentration for Pyrene (ug/L)

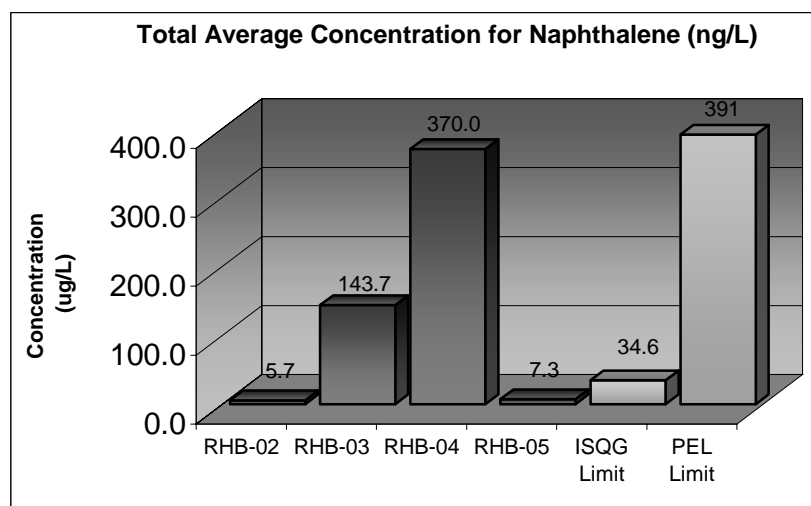
2. Graphical Depiction for Relevant Concentrations in Sediment



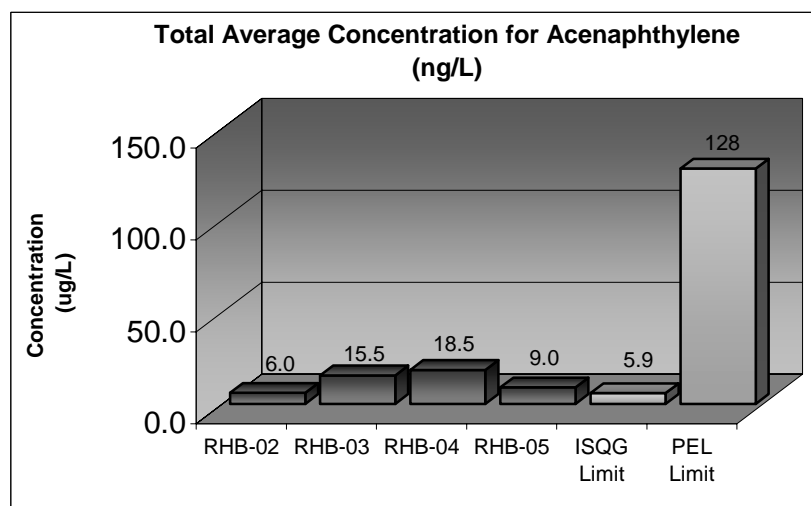
Graph S1: Total Average Concentration for Lead (ug/L)



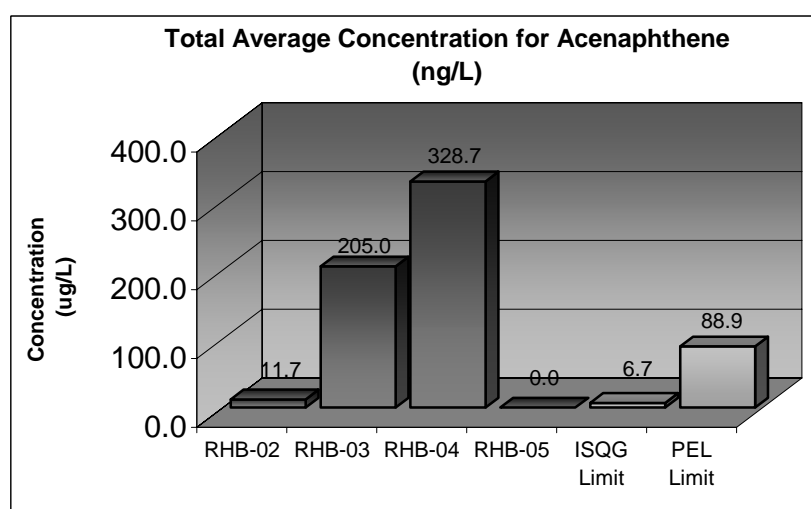
Graph S2: Total Average Concentration for Zinc (ug/L)



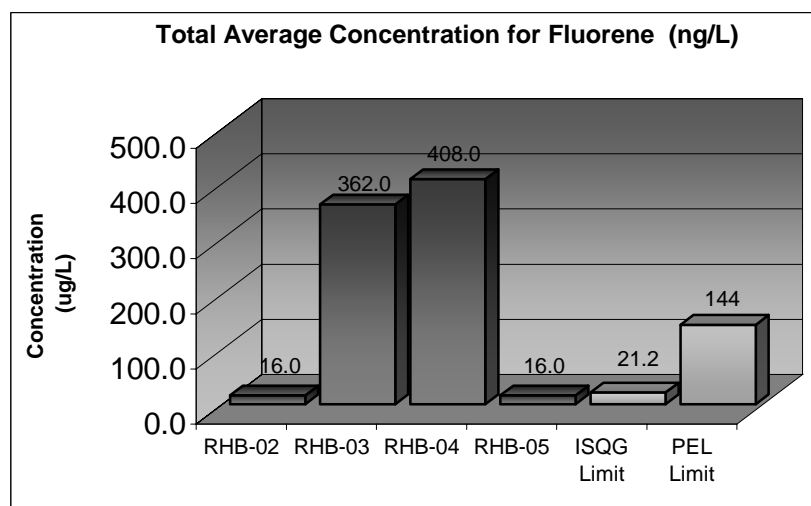
Graph S3: Total Average Concentration for Naphthalene (ng/L)



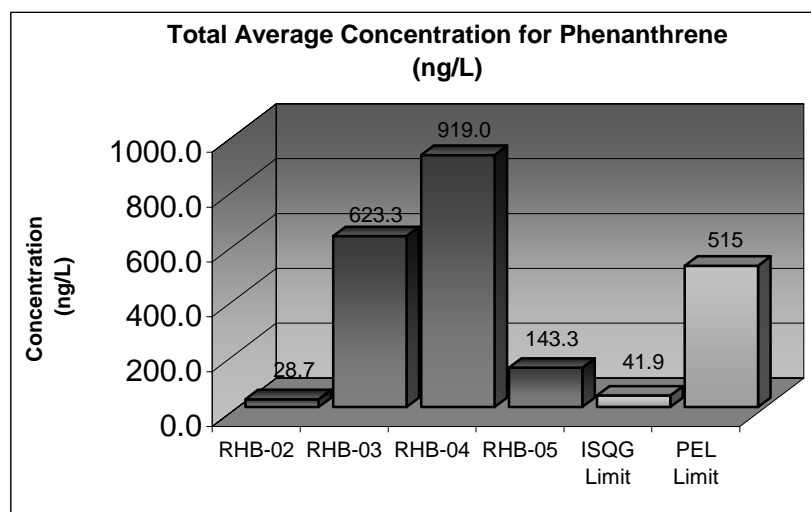
Graph S4: Total Average Concentration for Acenaphthylene (ng/L)



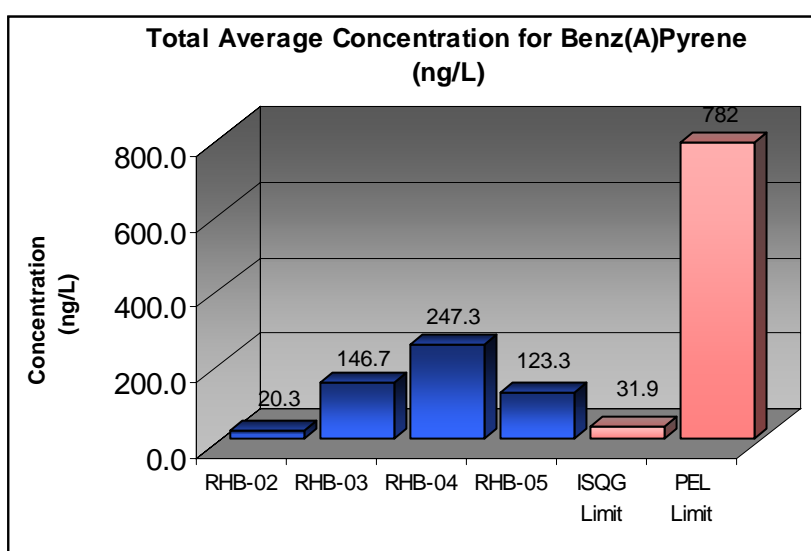
Graph S5: Total Average Concentration for Acenaphthene (ng/L)



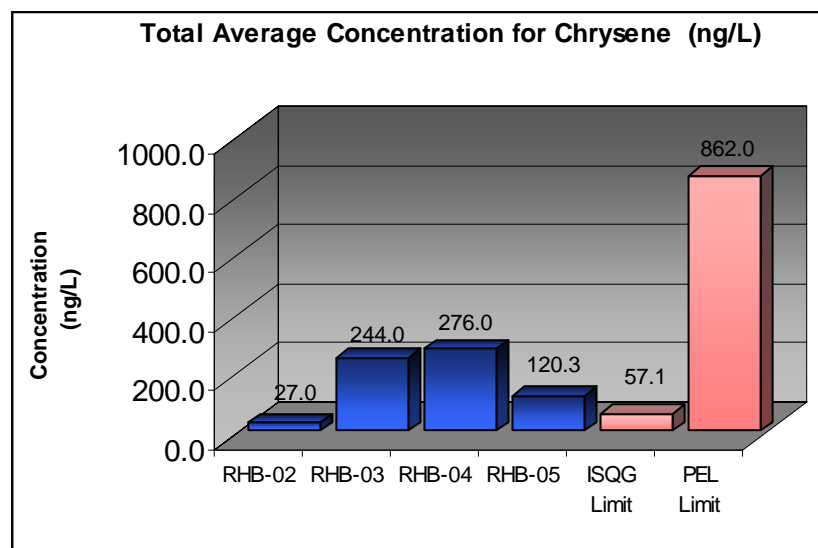
Graph S6: Total Average Concentration for Fluorene (ng/L)



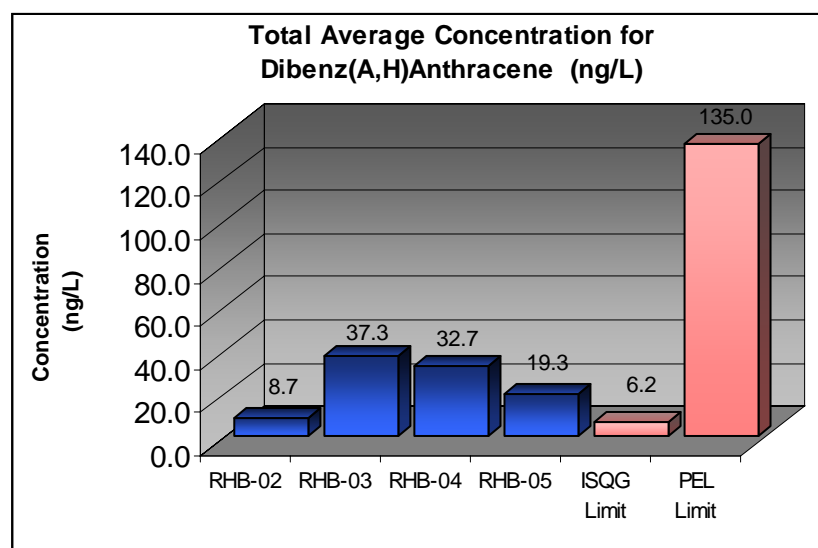
Graph S7: Total Average Concentration for Phenanthrene (ng/L)



Graph S8: Total Average Concentration for Benz(A)Pyrene (ng/L)



Graph S9: Total Average Concentration for Chrysene (ng/L)



Graph S10: Total Average Concentration for Dibenz(A,H)Anthracene (ng/L)