A Comprehensive Report on Cyanobacteria:

Paddy's Pond Watershed,

St. John's, Paradise, Conception Bay South, NL

An investigation of land use and water quality parameters that may have led to a cyanobacteria bloom

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Executive Summary

The Paddy's Pond drainage area is located on the outskirts of St. John's and flows though the towns of Paradise and Conception Bay South. In 2007, a first ever cyanobacteria bloom was reported in Paddy's Pond and evidence of the bacteria was discovered as far as several kilometers down the watershed in Three Island Pond. Some forms of cyanobacteria are known to be toxic in elevated concentrations. A preliminary government investigation was conducted in 2007, followed by environmental investigations in 2008 both by Northeast Avalon ACAP (NAACAP) and by the provincial Department of Environment and Conservation, Water Resources Management Division. Evidence of cyanobacteria was noted by both agencies in lesser concentrations than what was reported in 2007; however minor blooms were recorded on several occasions during the summer. Cyanobacteria are known to thrive in certain environmental conditions that include warm temperatures, calm water conditions, and nutrient enrichment. An investigation into land-use showed that the Paddy's Pond watershed was rapidly being developed by diverse sources including residential, commercial, recreational, agricultural, and industrial outfits. Results from the ensuing water quality analysis showed that water temperatures were at times relatively high, and various nutrient constituents such as ammonia nitrogen, total organic carbon and particularly phosphorus were notably high at certain sites. More research is needed to determine whether these conditions were caused by development pressures, by severe weather patterns that occurred in 2007, by natural conditions, or by a combination of reasons. More monitoring is also recommended to document any future evidence of cyanobacteria in this watershed.

Acknowledgements

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1.0 Introduction

Responding to a call made in 2007 to several agencies and organizations, the provincial Department of Environment and Conservation Water Resources Management Division investigated a plume of “blue-green algae”, discovered by a resident living near Paddy’s Pond just outside St. John’s. More correctly known as cyanobacteria, the slimy green mass of “blue-green algae” was the first large bloom ever recorded on the island of Newfoundland, and was a concern not only due to aesthetic reasons, but also because the bacteria can potentially release various toxins that have known health effects into the water, including microcystin-LR, which has a Health Canada guideline for drinking water of 1.5 μg/L associated with it (2008). This initiated an investigation by DFO and the Province of NL into the cause of the bloom, the quality of the water found in Paddy’s Pond and the five other ponds within that watershed, and whether microcystin-LR was present as well.

In 2008, the Province partnered with Northeast Avalon ACAP (NAACAP) and continued the monitoring and testing of the system of ponds in the Cochrane Pond/Paddy’s Pond watershed for the presence of cyanobacteria, microcystin-LR, and other water quality indicators, such as nitrogen, phosphorus, and carbon that would help explain why there would be a bloom. An investigation took place into the types of land use, and also of the recent weather and storm patterns that might account for a bloom. Land development has increased within the watershed, and the cumulative effects of poor land and water management may have built up to a point where the watershed can no longer buffer itself against these effects. This is, in part, a possible explanation of why a cyanobacteria bloom was able to occur in this watershed, since many bodies of water on the Avalon Peninsula are nutrient poor and may not support the rapid growth of these bacteria.

1.1 Scope

The study focused on the monitoring of the Paddy’s Pond watershed for the presence of cyanobacteria and various indicators of water quality potentially relating to favorable conditions for cyanobacteria. The environmental data for this study was collected from June to October 2008 at 14 sites upstream and downstream of Paddy’s Pond, including a reference site at the headwaters in Thomas Pond. Using information from a 2007 report by the Government of Newfoundland and Labrador (NL Ministry of Environment and Conservation, 2007) that investigated the original cyanobacteria bloom in the Paddy’s Pond system, this report aims to continue the investigation in partnership with the Department of Environment and Conservation Water Resources Management Division, and with DFO and Environment Canada to monitor the development of another rise in cyanobacteria and the potential reasons why this would happen. The monitoring was conducted through a series of five field visits over the study period to the various monitoring sites. Water was sampled at each site and tested for cyanobacteria and other water quality parameters, and sediment was also collected during one of the site visits and tested.

2.0 Background on Cyanobacteria

Cyanobacteria, which are sometimes also referred to as "blue-green algae", are an important group of photosynthesizing single-celled bacteria that are a common component of freshwater and marine phytoplankton communities. While they exist in many types of aquatic environment, freshwater cyanobacteria tend to develop optimally in calm, warmer waters (Health Canada, 2008). They have the important ability to fix nitrogen, and are reliant on the macronutrients nitrogen, phosphorus, and carbon for their biological processes. Cyanobacteria play a significant role in cycling these nutrients within the ecosystem, aiding in the life processes of other organisms. Additional parameters, such as temperature and light, and the micronutrients iron and molybdenum, are also very important in the life processes of cyanobacteria (Health Canada, 2008).

Photo 1: *Cyanobacteria bloom on upper end of Paddy's Pond near site CB05.* [**Source:** DFO 2007]

A major factor that limits the growth of cyanobacteria is the availability of phosphorus. Cyanobacteria can store phosphorus in their cells for use in times when it is not available in the water column. Since phosphorus is often stored in sediments, cyanobacteria often take advantage and flourish in times when the sediment is heavily disturbed (Health Canada, 2008). Cyanobacteria also compete heavily with other small organisms for nutrients and light; they have the ability to control their buoyancy so as to move their bodies up and down in the water column depending on where nutrients and the best quality sunlight is located. This function is a process of photosynthesis and can only work during the daytime; thus, at night cyanobacteria often float to the surface because their buoyancy controls are disabled (Health Canada, 2008).

In the event that cyanobacteria flourish due to a significant change in the environmental conditions within the water column, a bloom will occur. A bloom is commonly characterized by a blue to green coloured growth in or on the water, caused by the growth of thousands of cyanobacteria cells per milliliter of water, forming a visible mass. Although cyanobacteria in low concentrations make up a very important component of naturally occurring phytoplankton, a bloom is often indicative of nutrient enriched water and can cause drastic deteriorations in water quality in the location of the bloom, due to a significant decrease in dissolved oxygen and of available light (Health Canada, 2008). If the penetration of light is reduced, then water temperatures will decrease and photosynthesis will decrease, resulting in an increase of carbon dioxide in the water and, thus, an even greater decrease in dissolved oxygen will result.

Another significant danger of a cyanobacteria bloom is that many species of cyanobacteria produce toxins, known as cyanotoxins (Vasconcelos, 2001), which can persist in the environment for months and can cause chronic and acute illnesses in many types of organisms that come into contact, ingest, or inhale these toxic compounds (Health Canada, 2008).

Photo 2: *Smaller occurrence of cyanobacteria bloom at site CB05 in 2008.*

Photo 3: *Close-up of thick cyanobacterial growth at site CB05 in 2008.*

2.0.1 Microcystin

One of the most common types of cyanotoxin is a group of chemicals known as microcystins. There are over 60 variants of microcystins known that fall under three main toxicity classifications: hepatotoxins (liver toxins); neurotoxins; and skin irritants – with the main type being the hepatotoxins (Vasconcelos, 2001). One type of microcystin in particular, known as microcystin-LR, has a toxic maximum allowable concentration (MAC) for drinking water set by Health Canada (2008) at 1.5 µg/L, and can sometimes be detected in higher concentrations in water during and after a major cyanobacterial bloom. Microcystins, such as microcystin-LR, are contained within the cell walls of cyanobacteria and can be slowly released by young growing cells, but are mainly released in higher quantities when the cells die and decompose (Health Canada, 2008).

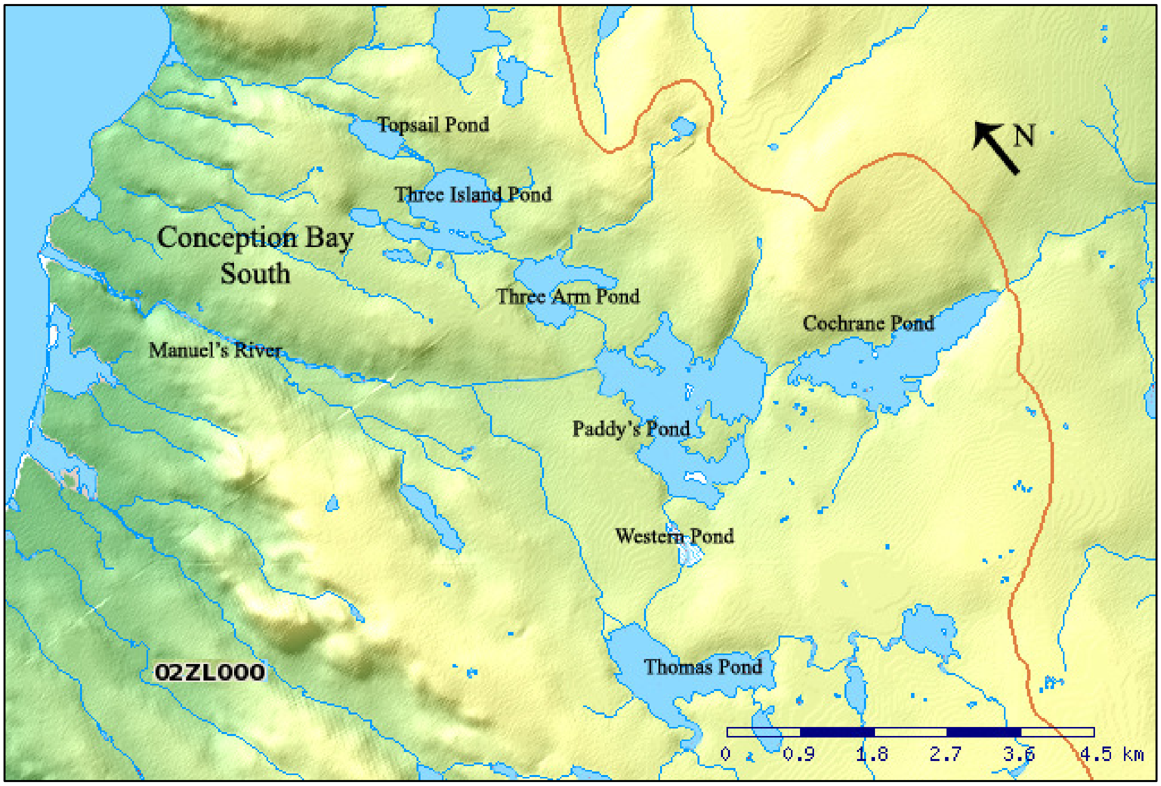
A report from the World Health Organization (WHO) states that Microcystin-LR can be acutely toxic to humans and livestock in high enough doses, and concentrations of this toxin can increase within a cell in conditions of higher phosphorus, temperatures, and light penetration (WHO, 2003). Another very informative report on the toxicity of cyanotoxins, including microcystins, was posted in the journal Limnetica (Vasconcelos, 2001), which states that cyanobacteria can use microcystins as a defense against other aquatic organisms in order to compete with them for nutrients and light. Thus, using microcystins, cyanobacteria can diminish the populations of other organisms within phytoplankton communities, as well as within zooplankton communities, which tend to graze on phytoplankton; thus allowing the cyanobacteria to form large colonies and form visible blooms (Vasconcelos, 2001). Fish can also be negatively affected by microcystins though both absorption of the affected water and through the ingestion of zooplankton, which in turn obtain the toxins by feeding upon cyanobacteria and by absorbing the toxins from the water as well (Vasconcelos, 2001).

Photo 4: *Advisory put forth for swimmers in Three Island Pond during the 2007 bloom.*

2.1 Study Area

The study area encompassed the watershed that is the Paddy's Pond drainage area, which flows through the system of ponds leading towards Conception Bay. This includes Paddy's Pond, Three Arm Pond, Three Island Pond, and Topsail Pond, and also includes Thomas Pond and Cochrane Pond, which both partially flow into Paddy's Pond. The study area did not include the drainage into Manuel's River because there was no evidence of cyanobacteria there in 2007. More than half of the sample sites were chosen in the area on and between Paddy's Pond and Cochrane Pond because this is the region within the watershed that is most developed industrially and agriculturally, and thus potentially could be one reason why there was a large cyanobacteria bloom in Paddy's Pond in 2007. Figure 1 shows the system of linked ponds that make up the Paddy's Pond Watershed and its proximity to Conception Bay.

Figure 1: *Digital Elevation Map (DEM) of Paddy's Pond and surrounding drainage area. The higher elevations are denoted by yellow shades and the lower elevations are denoted by green shades. Shadows indicate sharp changes in elevation. The brown line denotes a major watershed boundary.*



2.1.1 Description of Watershed

As seen from Figure 1, the Paddy's Pond watershed is made up of several linked bodies of water that all flow towards Conception Bay in the north. Cochrane Pond and Thomas Pond are at the top of the system at about 180m in elevation above sea level; both flow into Paddy's Pond, which in turn flows into Three Arm Pond down through to Three Island Pond and Topsail Pond at lower elevations of approximately 100m to 120m above sea level. Water flows from Topsail River out of Topsail Pond to the sea approximately 10km downstream of Cochrane Pond and Thomas Pond.

The watershed itself is located in a post-glaciated, boreal forest ecoregion. The intact boreal forest is made up mainly of coniferous trees and boggy wetlands. The ponds act as larger reservoirs, but release water constantly through series of interconnected streams. Some of the boggy features act as retaining areas for water as well. The higher elevations have more boggy areas, and the low-lying areas are generally characterized by increased forest cover. Due to the effects of glaciation, the overburden layer is often thin and generally only holds water closer to the surface because of the close association to the bedrock beneath, which creates a hydrological barrier. This largely helped to create the bogs and areas of standing water, and as well as the network of overland flow in the form of rivers and streams.

The surficial hydrology of the entire system is partially controlled by human action through dams, spillways and control structures built at the outlet of each pond in this watershed. For example, Thomas Pond and Paddy's Pond both have outlets that should naturally flow into Manuels River, however much of the flow into Manuels River from Thomas Pond is now dependant upon the water level in that pond that may at times cause it to overflow at the spillway and enter the river. Additionally, Cochrane Pond has an outlet at either end that causes it to flow out of two opposite directions; one being into Paddy's Pond to continue to flow through that system, and the other is towards the municipality of Goulds to eventually enter the sea in the eastern side of the Avalon Peninsula. The flow that is directed into the Goulds, an area heavily influenced by agriculture and suburban development, is considered to be a different watershed which falls beyond the scope of this project.

2.1.2 Development in the Watershed

The Paddy's Pond drainage area is not pristine; in fact, there is quite a lot of development occurring in the watershed. There are areas of recreational, residential, agricultural, and industrial land-use in the upper reaches, although areas of residential use are primarily found further downstream. Recreational use ranges from hunting, camping and RV'ing, to sport paintball, and to boating, mostly all in the upper reaches of the area. Float planes are also used extensively on Paddy's Pond.

While significant pressure from development does occur upstream from Cochrane and Thomas Pond to Three Arm Pond, much of the shoreline fringes around these ponds are still somewhat wooded and there are extensive reaches of wilderness still intact in parts as well. The lower reaches of the watershed, starting at Three Island Pond, flows through the town of Conception Bay South and Paradise. This section is more heavily built up, mostly from suburban housing developments and cabins, there are fewer wooded or natural areas around the shoreline fringes, and much of the interior wilderness has been lost to wood clearing and housing developments. Commercially, there is a small eel fishery in Three Island Pond as well.

More specifically pertaining to the upper reaches of the watershed, human activity in that area is quite diverse. It ranges mainly from different types of agriculture to various quarrying industries, to recreational parkland:

Although farming is much more large-scale in the Goulds area, there are still various agricultural activities occurring around Cochrane Pond including a sod farm and a large-scale poultry farm. Although they are generally well contained through the actions of corporate stewardship, good site design, and environmental policy, these types of agricultural industry can otherwise potentially pose a threat to adjacent water bodies and streams due to the possible release of nitrogen and phosphorus found in either fertilizer or manure used or produced on their respective sites. In general, nutrients such as these coming from this type of land use over time in high enough concentrations have been known to enrich water bodies through the process known as eutrophication, which is often visibly characterised by excessive plant growth and cellular blooms. There are also livestock farms located more than a kilometer upstream of Thomas Pond in the headwaters of the watershed. Since they are located farther upstream it is unknown how contained they are or whether they would have any impact on the system at this point.

There are also several quarries in the Paddy's Pond area, some of them quite large and rapidly expanding. In general, unless they are well contained and designed, quarries can be a potential threat to a watershed because they can disrupt the hydrological cycle and can cause sedimentation to occur in adjacent watercourses and ponds. Depending on the natural composition of the material being quarried, nutrients such as phosphorus and nitrogen compounds can be released, of which can also contribute to eutrophication. The access roads to these quarries and their heavy use from aggregate filled trucks can potentially become a pathway for minerals and nutrients to enter the aquatic environment as well.

Additionally, two sections of highway and heavy arterial roads span between Three Island Pond and Cochrane Pond, and in between the short distance between Paddy's Pond and Cochrane Pond are several roads other than the Trans Canada Highway that provide access to various retail businesses, government outlets, RV parkland, and agricultural and industrial sites. One of the access roads is particularly dusty and is heavily used by large industrial vehicles.

In regards to the watershed as a whole, each body of standing water has a control structure installed at the outlet. These structures contain dams, sluices, and sometimes spillways to control the height and amount of water contained in each reservoir or pond. The primary reason for this is for the production of smaller-scale hydroelectricity on the Topsail River located farther downstream. In times of flooding, excess water will flow over the spillways into otherwise dry rivers or smaller wetlands, or the sluice gates will have to be opened to allow a greater volume of water into the rivers that connect the main bodies of water. It is quite possible that the control structures built on the pond outlets could also have since changed and minimized the circulation patterns within the reservoirs behind them. This could potentially result in less movement of water within the water bodies themselves and could also disrupt the natural thermodynamics of the water systems as well, perhaps providing a more ideal environment for the proliferation of cyanobacteria cells.

2.2 Site Selection

Fourteen sites were chosen within the watershed at locations between Thomas Pond and Topsail Pond, two of which were occasional sites that were dependant upon conditions and the availability of a small vessel with which to carry out the work. Most of the sites chosen were located in and around Paddy's Pond and Cochrane Pond; this was due to the fact that the predominant cyanobacteria bloom from 2007 was reported in Paddy's Pond, as well as to the fact that there are so many types of land-use in this area that could potentially assist in providing the conditions that may encourage a bloom of this type. Although the sites were labeled *CB01 – CB15*, there was no site labeled *CB13.* This was due to a site being dropped at the beginning of the sampling period as it was not necessary for this study; hence there are only 14 sites despite the apparent presence of 15 sites.

Photo 5: *Outlet of Thomas Pond at site CB07 leading towards the control structure.*

Photo 6: *Outlet of Paddy's Pond at site CB09.*

Sites were selected in the outlets of all six water bodies, including Thomas Pond (*CB07*), which was also chosen to be a reference site. The reason Thomas Pond was chosen to be a reference was due to its relatively pristine conditions being upstream of the rest of the study area and upstream of and away from most of the other types of development mentioned in *Section 2.1.2*. Many sites were chosen in small streams that flowed both between Cochrane Pond and Paddy's Pond, and in small streams that flowed into Paddy's Pond from boggy areas near Cochrane Pond. The two intermittent sites were selected in Paddy's Pond, one being in the south end at about 4m depth and one being in the mouth of the river that flows out of Western Pond (from Thomas Pond) at the western shore. Both of these sites required access by watercraft, thus could only be sampled on two occasions.

The site selection process was based on sites selected with the 2007 report by the Department of Environment and Conservation, and as well as through correspondence and planning with their Water Resources Management Division and DFO's Eastern

Habitat branch in 2008. This included making site visits and examining air photos in detail, so as to choose the most useful locations for sampling as possible in terms of being able to show the potential pathways that various water quality constituents could be traveling in relation to developmental pressures that could potentially be contributing to the problem.

The following table and maps show the GPS coordinates and locations of the fourteen sites chosen: *Table 1* gives the coordinates and directions to each site; Figure 2 shows the sites chosen in the upper reaches from Thomas Pond to Three Arm Pond; Figure 3 shows a close-up of the Paddy's Pond and Cochrane Pond section where a higher concentration of sites are revealed within the insert; and Figure 4 shows the sites selected in the lower reaches of the watershed from Three Arm Pond to Topsail Pond. These images were derived and edited from digital elevation maps (DEMs) obtained from GeoBase (2009) and thus can show certain characteristics of the watershed, such as the shape, relative elevation, and general flow trends of the watershed using different shades of yellow and green, and as shown by Figure 1, the general flow is northward.

Photo 7: *Sampling at site CB03, just upstream of Paddy's Pond*

Photo 8: *Sampling in Paddy's Pond at site CB05, which receives runoff from culvert shown*

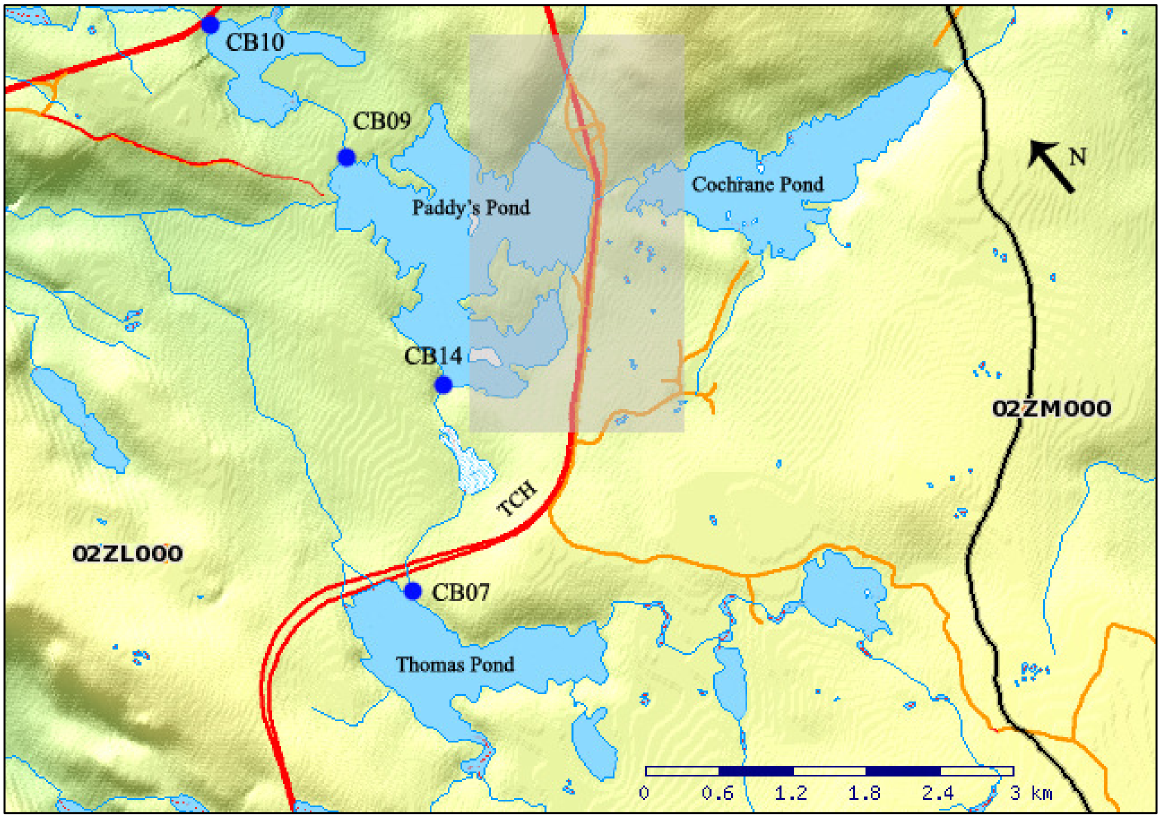
Photo 9: *Site CB06 looking upstream, just upstream of Paddy's Pond*

Photo 10: *Sampling at site CB12, Topsail Pond. It is the furthest site downstream.*

Table 1: *GPS location and short site description of sampling locations*

Site	Location of Sampling Sites	GPS Coordinates (Lat, long, or UTM)
CB01	Culvert located at west TCH merge zone on Paddy's Pond Access Road	N 47 28.057' W 052 53.236'
CB02	Culvert marked by two orange stakes located just east of chicken farm access on Cochrane Pond Access Road	N 47 27.075' W 052 53.281'
CB03	Culvert just east of culvert #2 on Cochrane Pond Access Road, across from culvert #1 on other side of TCH	N 47 28.035' W 052 53.196'
CB04	Culvert adjacent to Cochrane Pond Park access on Cochrane Pond Access Road	N 47 28.462' W 052 52.575'
CB05	Culvert outfall into Paddy's Pond on east end of Paddy's Pond Access Road	N 47 28.558' W 052 52.556'
CB06	Culvert located at east TCH merge zone on Cochrane Pond Access Road	N 47 28.987' W 052 52.232'
CB07	Control Structure at north end of Thomas Pond headed east on TCH	N 47 23.691' W 052 54.976'
CB08	Control Structure at Cochrane Pond, Cochrane Pond Park Access	N 47 28.418' W 052 52.328'
CB09	Control Structure on North end of Paddy's Pond, access from small road just past the ranch at the unpaved end of Fowler's Rd.	N 47 29.313' W 052 53.634'
CB10	Control Structure at North end of Three Arm Pond, headed east on Manuels Arterial Highway	N 47 30.079' W 052 53.794'
CB11	Control Structure at north end of Three Island Pond, access from Three Island Pond Road just south of intersection with Buckingham Drive	N 47 30.856' W 052 53.918'
CB12	Bridge at north end of Topsail Pond at the swimming area just upstream of control structure	N 47 31.465' W 052 54.204'
CB14	Outlet to Paddy's Pond from Western Pond and Thomas Pond, south-western shoreline. Access with boat	Zone 22 E 0356726 N 5259007
CB15	South-east side of Paddy's Pond about 100m from shoreline. Access with boat	Zone 22 E 0358157 N 5259628

Figure 2: *DEM showing sites located in the upper reaches of the watershed, as well as the road network present in the area. The density of sites within one portion of this map area is quite high and is denoted by the shaded area on the map. This shaded area is expanded in the following map to show the rest of the sites more clearly.*



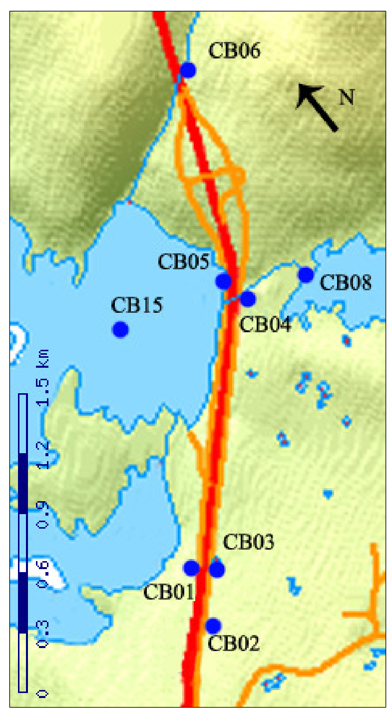
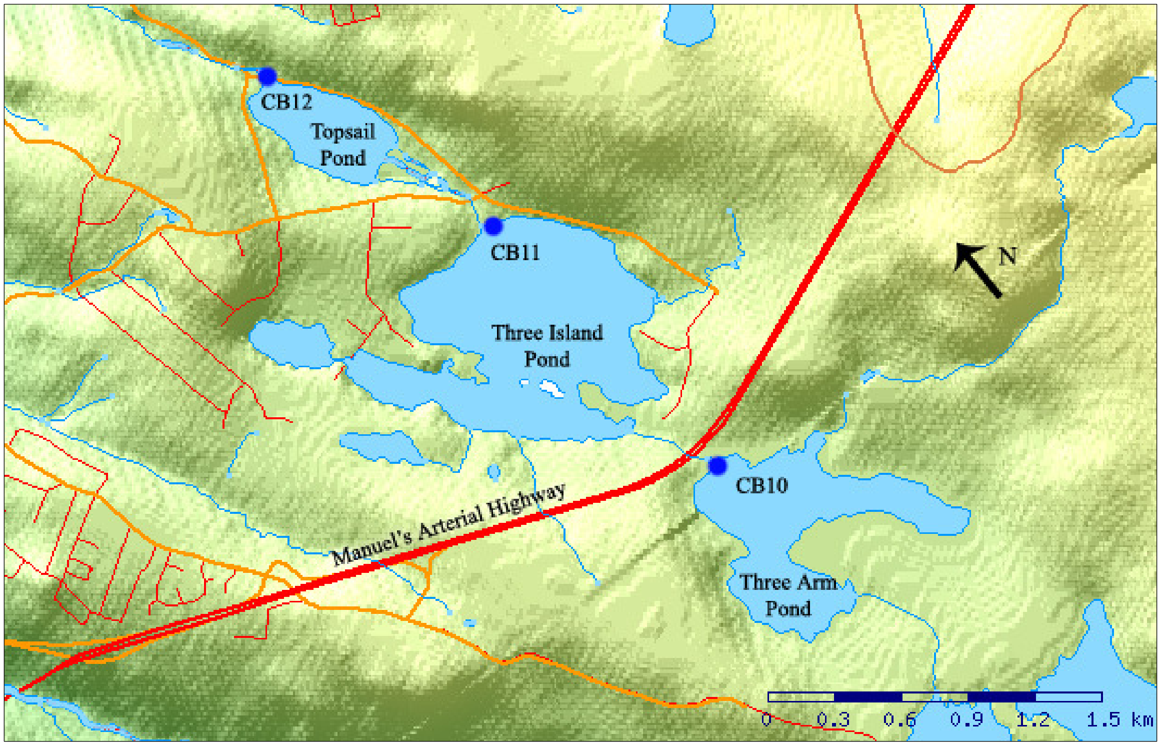


Figure 3: *Enlargement of shaded area from Figure 2. It shows the sites that are located more closely together in and between Cochrane Pond and Paddy's Pond. It also shows the highway and access roads that pass between the two water bodies as well.*

Figure 4: *DEM showing sites located in the lower reaches of the watershed as well as the suburban road network present in the area.*



3.0 Methodology

A comprehensive work plan was devised that included preliminary planning of the project, establishing partnerships with various governmental labs, site monitoring and sampling, collecting field data, and the final interpretation of this data to eventually produce a detailed report to be used for educational purposes and, if necessary, further action. The methods used in the field had been standardized previously by NAACAP staff and were used in this project to ensure the quality of the data collected.

3.1 Sampling

Fieldwork was conducted by NAACAP staff once a month from June to October of 2008. Concurrent fieldwork was also conducted by the Water Resources Management Division, also once a month, as a separate study that would complement the results of the NAACAP study. Both NAACAP and the Province tested for similar chemical and physical parameters in water, however, the Provincial team also gathered data on certain biological parameters that NAACAP was unable to collect. NAACAP collected water samples and *in-situ* water quality readings on June 3rd, July 8th, August 4th, September 3rd, and October 2nd, and also collected sediment samples on September 3rd. Sampling for metals in water were only taken on August 4th. It was noted that heavy rain events occurred on the June and August dates.

In accordance with standardised protocol, sample bottles and their caps were rinsed three times before the actual grab samples were taken. Depending on what the analyte was some samples had to be injected with an appropriate type of strong acid to ensure their proper preservation before being analysed in the lab. Nitric acid, HNO_3, was used to preserve samples to be tested for metals; and sulphuric acid, H_2SO_4, was used to preserve samples to be analysed for various nutrients. Additionally, all samples were kept cool in an icebox or chilled cooler to further ensure their proper preservation. A duplicate was taken at random on each sampling trip for each type of sample taken for quality control. All field equipment such as the *in-situ* monitoring probe was properly calibrated before each sampling date for accuracy and quality assurance purposes. Proper field gear was worn at all times as needed, such as waterproof rain pants and jacket, and rubber boots or waders. GPS coordinates and photographs were also taken at every site for proper documentation of location and conditions.

3.2 Field Analysis

A multi-parameter water quality monitoring sonde or probe manufactured by Hydrolab™ (Quanta-G model) was used to collect instantaneous *in-situ* water quality data while in the field. The instrument, consisting of sophisticated monitoring sensors and specially designed firmware encased in a stainless steel protective tube, could detect six major water quality parameters and displayed its readings on a specialized receiver to be recorded by the user. The six parameters and their units (where applicable) are as follows:

- Temperature (°C)
- pH
- Specific Conductance (µS/cm)
- Dissolved Oxygen (mg/L, and in %)
- Salinity (PSS, similar to ppt)
- Total Dissolved Solids (g/L)

The monitoring probe was also cleaned and calibrated to known standards before each sampling date to ensure proper readings were produced. The data was collected in the field on paper and then transferred immediately to an electronic spreadsheet and backed up for protection.

3.3 Lab Analysis

Water and sediment samples were taken in the field according to the protocol outlined above and sent to Environment Canada's accredited Environmental Science Lab in Moncton, New Brunswick for analysis. The water samples were preserved with an appropriate type and volume of strong acid as needed and analysed for trace elements and heavy metals; nutrients, such as ammonia, nitrates, phosphorus, total inorganic and organic carbon; and various ions, compounds, and various constituents such as chloride, sulphate, colour, alkalinity, and total suspended solids. The sediment was sent in amber glass jars with Teflon-lined lids to be analysed for metals as well. The results from all the samples were then sent back to be interpreted and organised for the purposes of this report.

In the concurrent study by the NL Water Resources Management Division, samples were sent to various labs around Canada to be tested for additional parameters. Their field crew sent water quality samples to Environment Canada's accredited Environmental Science Lab in Burlington, Ontario; sent total and fecal coliform samples to the Public Health Laboratories at the Miller Center in St. John's; sent cyanobacterial and microcystin-LR samples to HydroQual Labs in Calgary; and collected chlorophyll data using a YSI field instrument that included a chlorophyll sensor for their study as well. The collected data was shared with NAACAP and is reported in the official document produced by the Province (Dept. of Environment and Conservation, 2008).

4.0 Results and Discussion

Over the sampling period, 157 water samples were taken in total, including 11 duplicates. Additionally, 13 sediment samples were taken in total, including one duplicate. The analysis of this many samples meant that much care had to be taken in interpreting such an enormous amount of data in the most effective manner. For the purposes of this report, this section summarizes the most relevant results and interpretations as comprehensively as possible; the raw data is posted in the appendices. The data is reviewed in a holistic sense so to offer a more complete understanding of the watershed and possible implications towards the cyanobacteria bloom by providing a general overview of the water quality of all the sites in relation to each other, as well as going further into depth on specific parameters that could have led to the bloom.

The relevant results being reported on consist mainly of the means of the raw data for each site sampled; however, raw data was also drawn upon as needed. The mean values were displayed graphically to aid in the visual comparison between the sites and to show common data trends that arose with respect to water quality in each site. All of the downstream means were compared with the most upstream site, CB07, since it was noted in *Section 2.2* that it was designated as a reference site and generally accepted to be representative of background water quality levels.

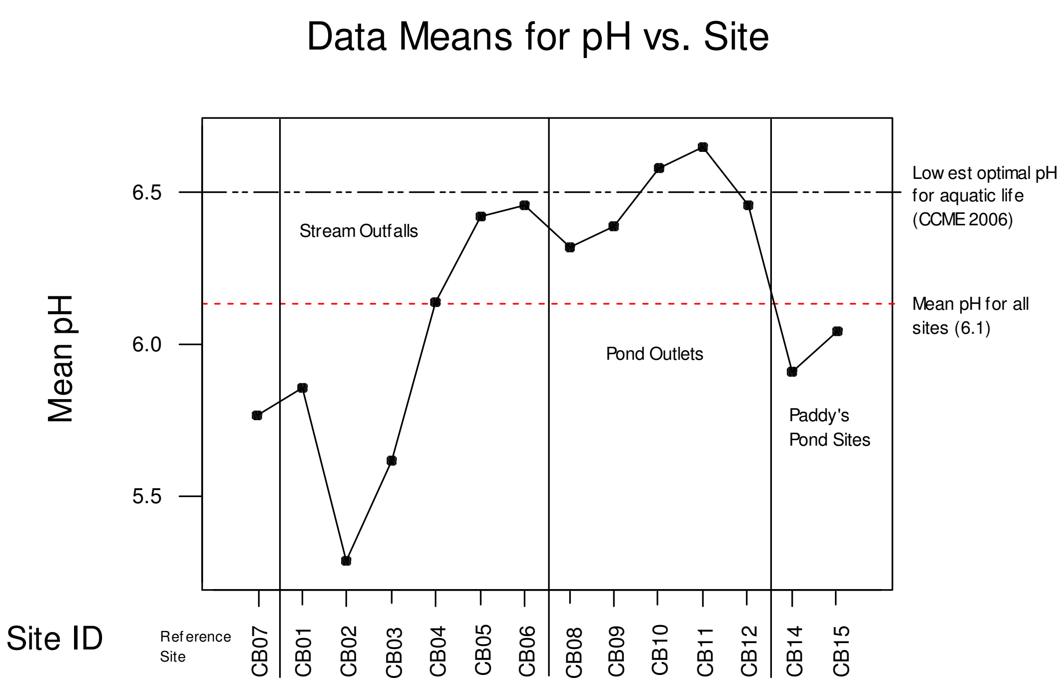
4.1 Overview of Water and Sediment Quality within the Watershed

The following subsections characterise the general water and sediment quality within the Paddy's Pond drainage basin to provide an overview of what the conditions were like at each station in relation to their relevance in the watershed at the time of sampling. This preliminary analysis will try and establish a relationship between sites with frequent adverse conditions and with those more likely to endure ecological impacts from the consequences of a cyanobacteria bloom, using the reference site as a tool for establishing a comparison with implied baseline data as well. Only parameters of interest were included in this section; however all of the raw data is available in the appendices.

4.1.1 pH

The calculated mean values for pH per sample site are located in the following graph. The raw values for pH for each site per sampling sweep are located in Appendix A.

Figure 5: *Mean pH values per sample site showing the lower end of the CCME guideline for pH, and the mean pH of all the sites. Each site is graphed in accordance to what type of sample site it is.*



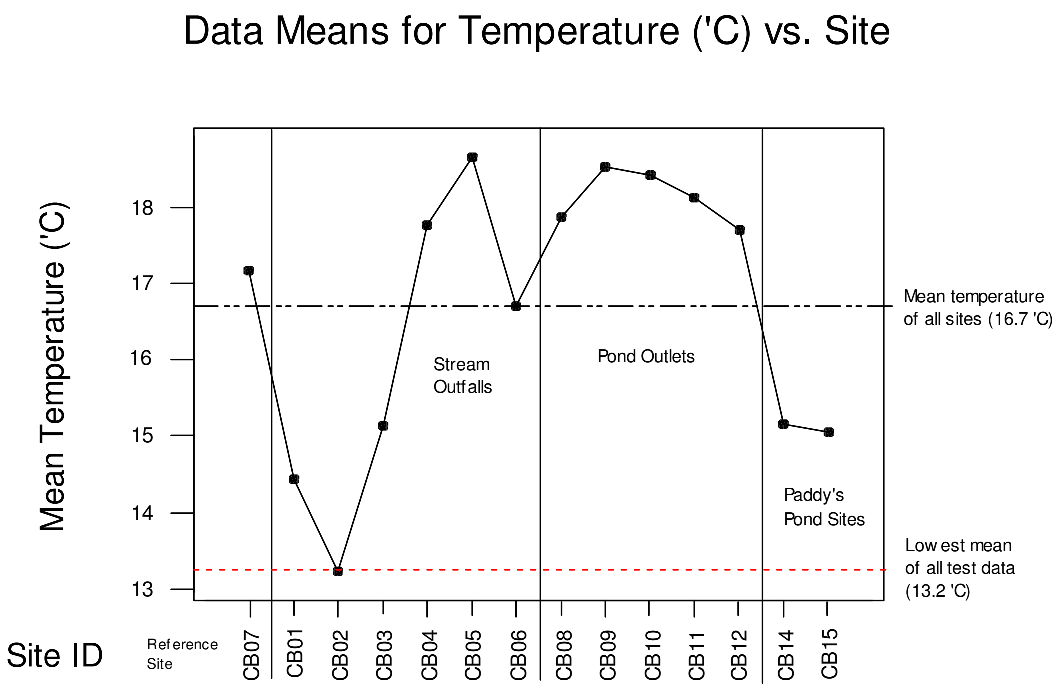
As observed from the above graph (*Figure 5*), the mean pH varied amongst the sites in the watershed. Most of the values fell below the acceptable range of pH as derived by CCME (2006), however due to the naturally acidic nature of streams and water bodies in the boggy Northeast Avalon region, this was not a concern in most cases as the aquatic habitats, flora, and fauna have long since adapted to this type of condition. The presence of aquatic plants, algae, and cyanobacteria could temporarily raise the pH of the surrounding water during the day since these organisms remove carbon dioxide from the water during the diurnal photosynthesis process; however, in this case, aquatic photosynthesizing organisms were not in abundance throughout the watershed, except in sections of Paddy's Pond. The pH was generally higher in the downstream sites and this was likely because of the decreasing influence of bogs in the lower elevations. Site CB02 showed a very low pH with a mean value of 5.29, which was lower than all of the other mean values in the other sites. It was unclear as to whether this site was receiving acidic runoff from any type of industrial or agricultural activity, however it did receive water directly from a bog and was certainly a factor leading to the low pH values measured in site CB02.

Of importance to constituents dissolved in the water that contribute to the growth of cyanobacteria cells, the pH can play a role in the solubility of such parameters. It should be noted that while in many cases a lower (acidic) pH will lead to an increase in solubility of various metals and salts, the opposite is true for nitrogenous compounds, such as ammonia, which are necessary for the growth of cyanobacteria (CCME, 2006). From this study, the values obtained for pH in all of the sites were quite low in this regard and it would be expected that certain nitrogenous compounds would generally not be able to exist in high quantities.

4.1.2 Temperature

The calculated mean values for temperature (°C) per sample site are located in the following graph. The raw values for temperature for each site per sampling sweep are located in Appendix A.

Figure 6: *Mean temperature values (°C) per sample site showing the mean temperature of all the sites, as well as the lowest mean temperature value of all the test sites. Each site is graphed in accordance to what type of sample site it is.*



Ambient water temperature is considered to be a limiting factor for the growth of cyanobacterial cells, wherein the bacterium prefers to flourish in warmer water. Taking into account the cooler rain events that occurred and the time span of sampling from the warmer month of June to the colder month of October, the mean water temperatures of some of the sites were relatively low, with the mean temperature of all the sites combined being 16.7°C (*Figure 6*). However, due to the fact that water temperature changes at a much slower rate than the ambient air temperature, it is presumed that all of the sites would experience monthly temperature changes proportionately; thus, the trend noted in Figure 6 is considered to be an accurate representation of the mean temperature at each site relative to the other sites.

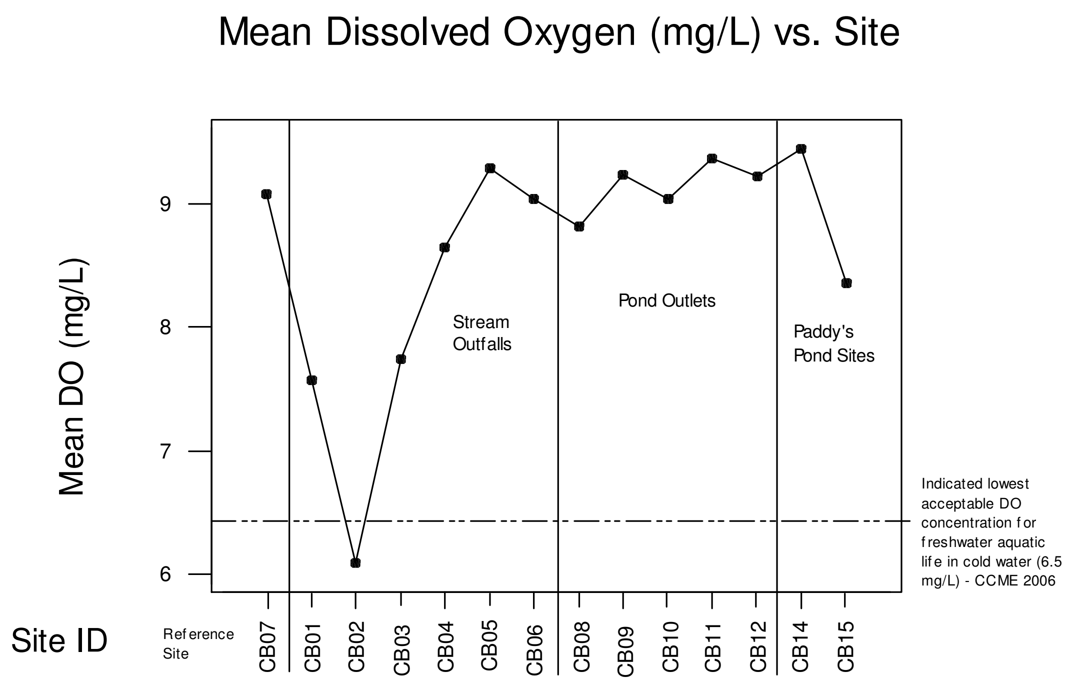
The sites at the pond outlets were relatively warm, especially at Paddy's Pond with the mean water temperature being 18.5°C. Site CB05 in Paddy's Pond was warm as well, with a mean temperature of 18.7°C, and could have been due to its shallowness and proximity to the shoreline, as well as its appropriate position for exposure to sunlight. Sites CB14 and CB15 were cooler than the combined mean temperatures, but could have been due to various reasons: site CB14 was in a shady position and received cold water from the shaded stream that flowed out of Western Pond; while site CB15 was in the middle of the pond where the water was deeper and cooler. The warmer water measured at either end of Paddy's Pond and in the pond outlets where cyanobacteria was recorded to be the most dense most likely contributed in part to the positive growth of the cells.

The coldest water recorded was at site CB02, which had a mean temperature of 13.2°C (*Figure* 6), and was mostly due to the fact that it was a small stream in a shaded area and received cold runoff from a boggy area, which may have also been influenced by a cool groundwater spring present in the area.

4.1.3 Dissolved Oxygen

The calculated mean values for Dissolved Oxygen (DO) per sample site in mg/L are located in the following graph. The raw values for DO for each site per sampling sweep are located in Appendix A.

Figure 7: *Mean DO values (mg/L) per sample site showing the lower end of the CCME guideline for DO. Each site is graphed in accordance to what type of sample site it is.*



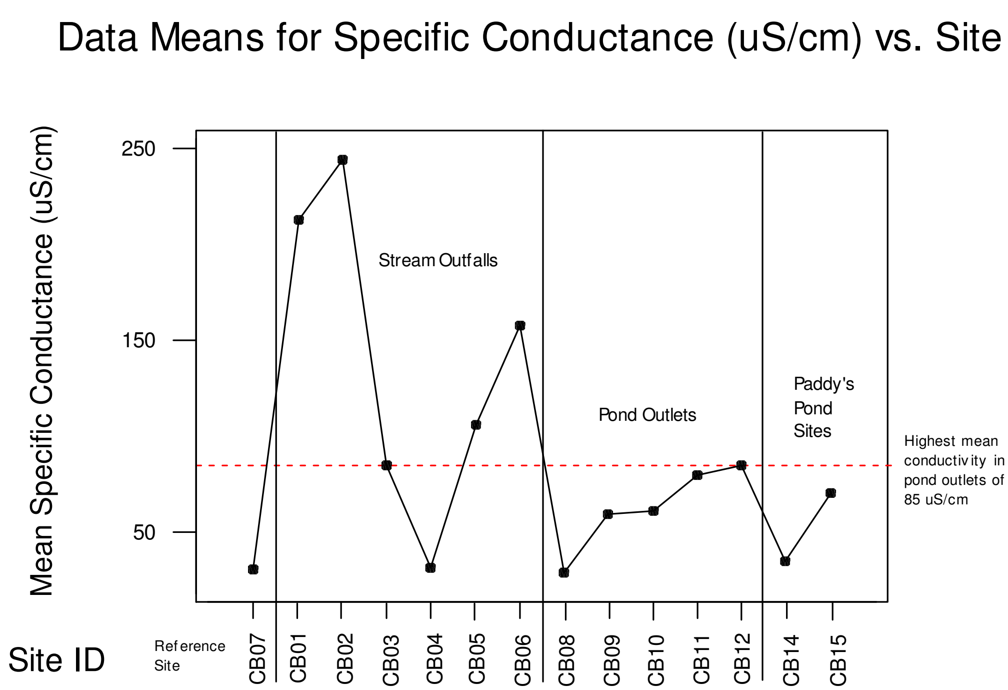
As shown from Figure 7, with the exception of site CB02, mean dissolved oxygen (DO) levels all fall within a healthy range that supports aquatic life (CCME, 2006), including cyanobacteria, which tolerate both the presence and absence of oxygen. It is interesting to note that while site CB02 is the coldest site (*Figure* 6); it is also the site with the lowest mean value of dissolved oxygen at 6.1mg/L (*Figure* 7). Colder water has the tendency to dissolve higher amounts of oxygen; given this, it was possible that there was a spring of poorly oxygenated groundwater contributing to the site. The water quality at site CB02 may have also been relatively poor. This will be examined further in the coming subsections.

Sites CB01 and CB03 exhibited the next lowest mean DO levels; although they both fell within the CCME derived healthy range for DO, they were the only other sites with mean values below 8.0 mg/L (*Figure* 7), and after site CB02, were also the next coldest sites (*Figure* 6). However, since the summer low-flow period may have contributed to intervals of standing water at the sites and in and around the culvert upstream and downstream the sites, the reduced levels of DO measured at these locations may have been attributed to this.

4.1.4 Specific Conductance

The calculated mean values for specific conductance (µS/cm) per sample site are located in the following graph. The raw values for specific conductance for each site per sampling sweep are located in Appendix A.

Figure 8: *Mean specific conductance values (µS/cm) per sample site showing the highest mean value attained in the pond outlets. Each site is graphed in accordance to what type of sample site it is.*



No particular water quality guideline exists for evaluating levels of measured specific conductance (SpC); however it is known that SpC is closely related to salinity because it reflects the amount of electrical conductivity created in the presence of certain metallic salts in the water. A statistical correlation was made in a report by NAACAP (Ficken, 2008) between conductivity and salinity, in that as SpC rises so will salinity. As will be mentioned in section 4.1.5, freshwater will begin to change its threshold of salinity at values above 0.5 PSS (Venice System, 1959); thus, due to the derived correlation between the two parameters, a mean value of SpC greater than 1000 µS/cm may indicate an unnatural alteration of a freshwater body, for example. Other studies have been conducted by NAACAP (Ficken 2006, 2008, 2009) showing that many natural bodies of water in the Northeast Avalon region exhibit values of less than this amount. These reports also show that, in most cases, the levels of conductivity measured in the natural streams and bodies of water is generally less than 500 µS/cm, and often much less in samples analysed at headwater streams. Additionally, it was shown from these reports that in more urban settings, particularly in winter during road salting periods, or in industrial settings involving effluent discharge, the SpC can often rise above 500 µS/cm. Thus, for the purposes of this report regarding the interpretation of specific conductance, mean values of less than 500 µS/cm will not be considered to be of concern to the ecology of the watershed or to be highly influenced by nearby developments on land.

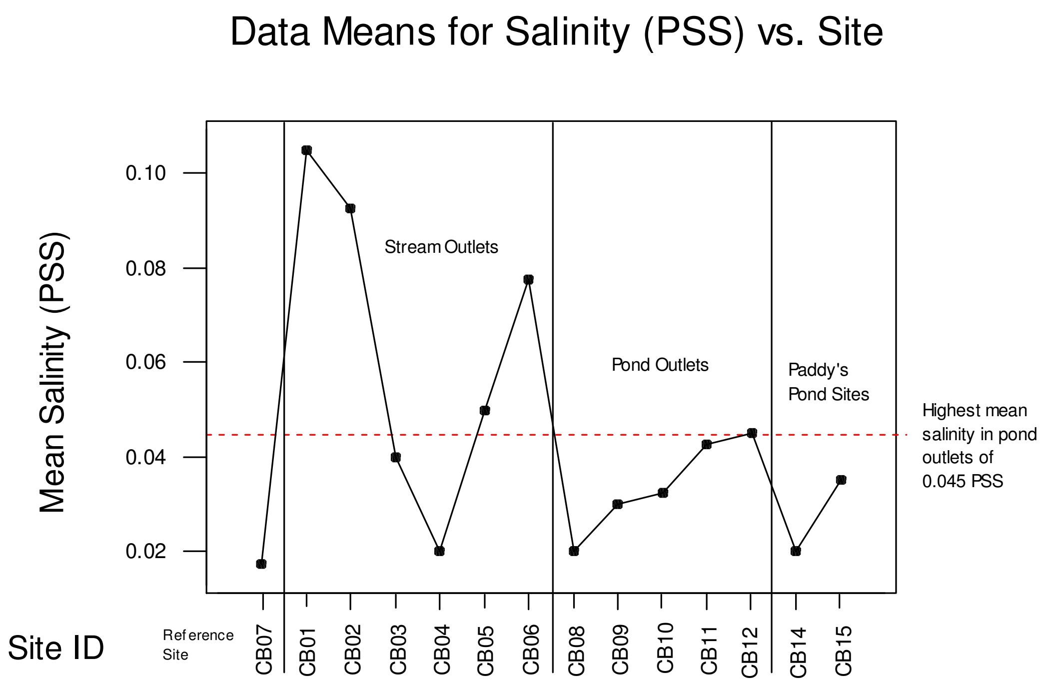
As shown in Figure 8, the overall mean values of specific conductance within the sites were relatively low. The highest mean values of SpC were found in sites CB02, CB01, and CB06 respectively, with the uppermost value being in site CB02 at a mean of 245 µS/cm. Since sites CB01 and CB02 have mean conductivity values of above 210 µS/cm, although of relatively low values, their means are 7 and 8 times more (respectively) than that of the mean value of the reference site (CB07), which has a mean specific conductance of 30 µS/cm. Compared with site CB07, which is a large body of water, sites CB01 and CB02 are small, low-flowing streams or roadside ditches that could quickly become more concentrated in various dissolved substances. However, the type of constituents contributing to the levels of SpC found at these sites could possibly influence the growth of cyanobacteria as they travel downstream into Paddy’s Pond.

All of the other sites, with the exception of sites CB05 and CB06, have mean values of 85 µS/cm or less, and are not considered to be very affected by dissolved constituents that would indicate anthropogenic input. However, from the trend of the graph in Figure 8, the conductivity values do rise slightly within the pond outlets the further downstream you go, indicating that there could be a slight influence on water quality due to the fact that there are more people and roads downstream. Similarly, this could also reflect a natural increase since it would be expected that various dissolved constituents would be picked up and concentrated in the lower reaches of the watershed. Site CB05, which has a mean value of 106 µS/cm, also has a relatively low specific conductance but could potentially be receiving some additional runoff due to its close proximity to the Trans Canada Highway, thus contributing to its slightly higher mean value of conductivity.

4.1.5 Salinity

The calculated mean values for salinity (PSS) per sample site are located in the following graph. The raw values for salinity for each site per sampling sweep are located in Appendix A.

Figure 9: *Mean salinity values (PSS) per sample site showing the highest mean value attained in the pond outlets. Each site is graphed in accordance to what type of sample site it is.*



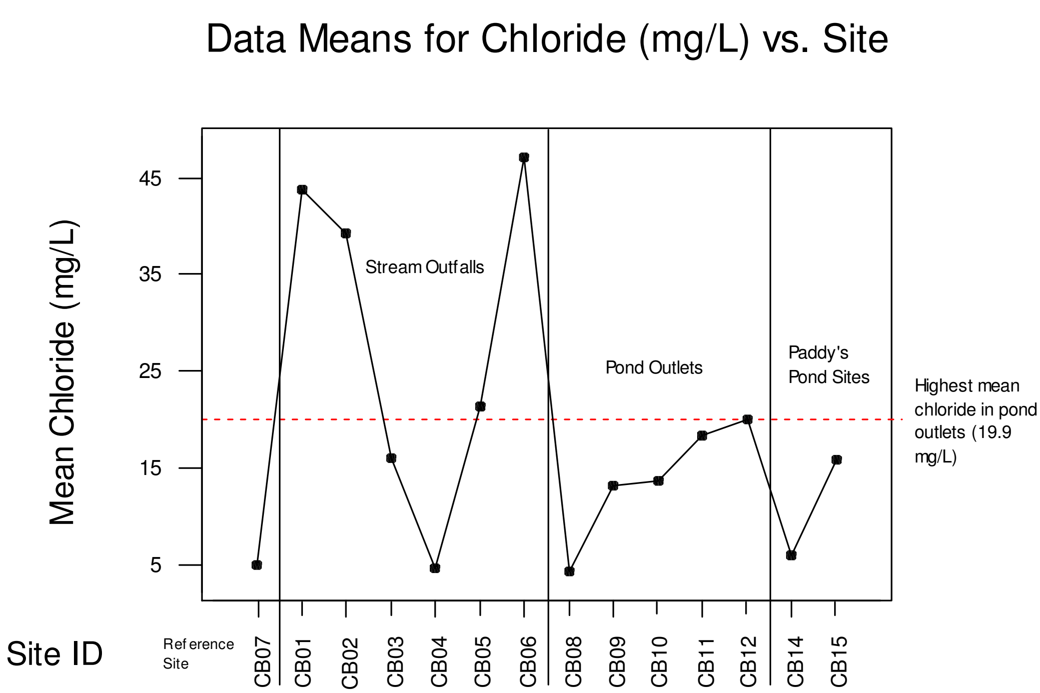
While the ambient salinity concentration is not necessarily a factor that directly influences cyanobacteria growth, many constituents, such as fertilizers, that can contain cyanobacteria-promoting nutrients are made of inorganic and organic salts that would influence the levels of salinity measured. Thus, an increase in the level of salinity recorded could potentially indicate an anthropogenic input of nutrients.

Figure 9 shows that the mean values of salinity are proportional to the mean values observed for conductivity (*Figure 8*), in that the general trends in the two graphs shown are the same. As shown in section *4.1.4*, sites CB01, CB02, and CB06 have the highest mean values of salinity; with the highest being site CB01 at a mean value of 0.11 PSS. While site CB06 has a mean value of 0.08 PSS, site CB05 was the next highest with a mean value of 0.05 PSS. All of the other sites had lower mean values of salinity, which, in the pond outlets, increased slightly downstream. The reference site, CB07, had the lowest mean level of salinity of less than 0.02 PSS. Although site CB01 had a mean salinity measuring nearly 7 times higher than the reference site, indicating relative contamination, the level of salinity found at that site is still low considering fresh water does not begin to turn to a brackish state until it reaches a level of 500 mg/L (Venice System, 1959) which to the current standard unit is approximately 0.5 PSS. Nonetheless, although slight, there were possible anthropogenic loadings in sites CB01, CB02, and perhaps in CB06, which may be evidence that conditions had eventually become more favorable for the cyanobacteria bloom through input via these sites.

4.1.6 Chloride Ion

The calculated mean values for chloride (mg/L) per sample site are located in the following graph. The raw values for chloride for each site per sampling sweep are located in Appendix B.

Figure 10: *Mean chloride values (mg/L) per sample site showing the highest mean value attained in the pond outlets. Each site is graphed in accordance to what type of sample site it is.*



Since cyanobacteria can thrive in both fresh water and salt water, measuring variables such as chloride mainly serve to establish an understanding of whether certain sites may be affected by anthropogenic activity in that chloride containing substances, such as salt, or chloride salt-based fertilizers, may be present if an increase in chloride is shown in the samples. According to a report by Evans and Frick (2002), chronic toxicity in fresh water organisms due to elevated chloride content in the water begins at about 210 mg/L; thus, since the highest mean value of chloride identified in this study was in site

CB06 at 47.1 mg/L (*Figure* 10), and the highest single value recorded was 78.2 mg/L in site CB06 (*Appendix B*), it was concluded that none of the sites contained very much chloride. However, it was noted from Figure 10 that since the reference site had a very low mean value of 4.9 mg/L chloride, and that sites CB01, CB02, and CB06 had comparatively high levels (the lowest being 39.2 mg/L in site CB02), that these three sites may have experienced an input of chloride, although the levels were relatively low, and the sites were small, low-flowing streams that may have become more easily concentrated. All of the other sites had low mean values of less than 22 mg/L.

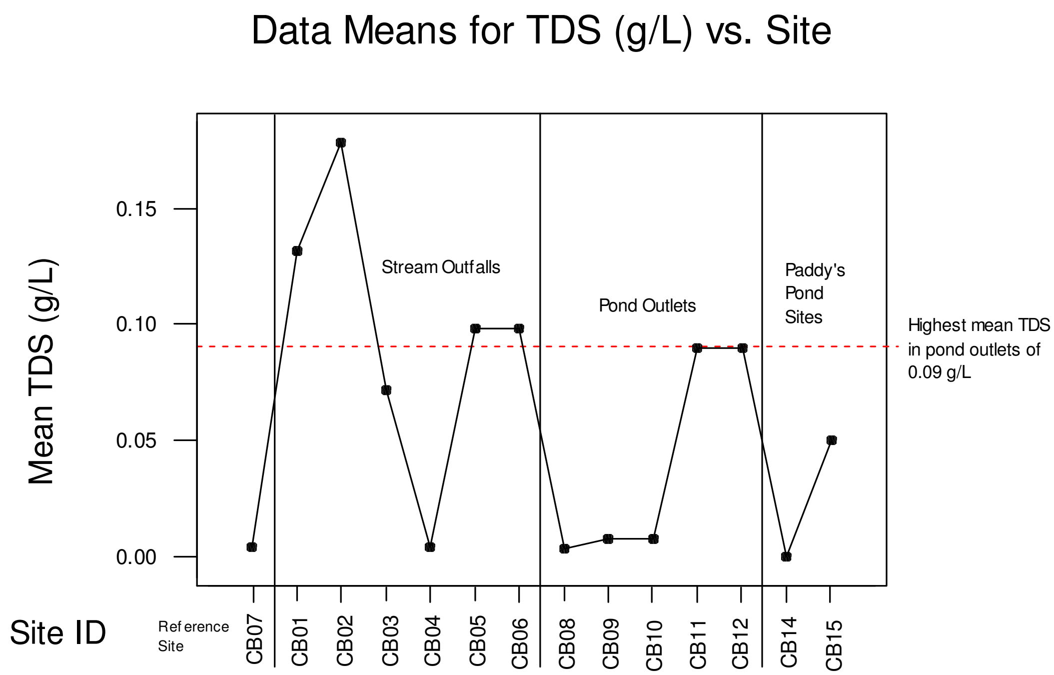
Although the mean chloride concentrations were determined to be low in this case, increased chloride is known to increase the bioavailability of metals in the water column and could potentially disrupt the density gradient, which would change the availability of oxygen and nutrients at different depths (Evans and Frick, 2002). Since certain sites did experience an increase in chloride levels, chloride-enriched water from these sites could produce a slightly more favorable environment for cyanobacteria in the receiving waters.

Also of note, the graph in Figure 10 shows an almost identical trend to the graphs in Figures 8 and 9. This would be expected since chloride is related to salinity and specific conductance; however, while salinity and specific conductance were measured with one instrument, chloride was measured separately in a lab. This is good for quality assurance purposes as the results for chloride from the lab are proportional to the results measured with the probe for the other two parameters, meaning all equipment must have been working properly and the samples had been properly cared for.

4.1.7 Total Dissolved Solids

The calculated mean values for total dissolved solids (TDS) per sample site in g/L are located in the following graph. The raw values for TDS for each site per sampling sweep are located in Appendix A.

Figure 11: *Mean TDS values (g/L) per sample site showing the highest mean value attained in the pond outlets. Each site is graphed in accordance to what type of sample site it is.*

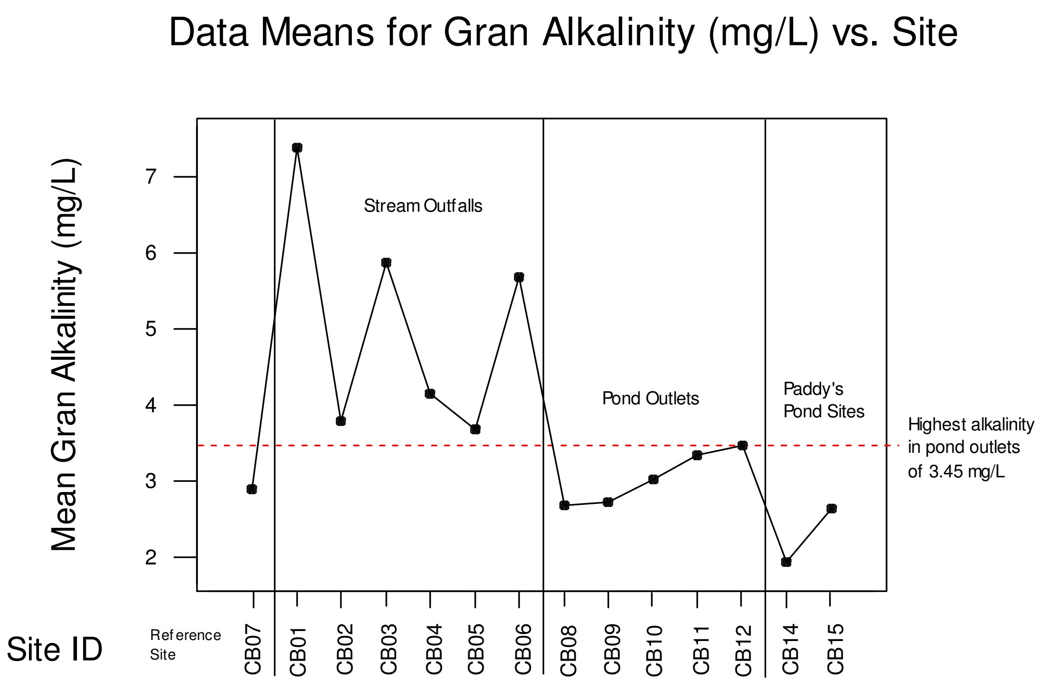


The mean values obtained from the total dissolved solids (TDS) results showed that instance of TDS in all of the sites was generally low, with the highest mean value being 0.18 g/L in site CB02 (*Figure 11*). While there was one instance of TDS being as high as 0.3 g/L in site CB02, showing a potential for anthropogenically derived dissolved constituents in that site, generally any less than 0.5 g/L TDS is relatively little in a freshwater environment. Since the reference site and the rest of the upstream pond outlets showed almost no level of TDS, it was assumed that any measurable levels of TDS was most likely increased somewhat by human activity; these sites include CB01, CB02, CB05, CB06, and the two most downstream sites CB11 and CB12, and their means showed at least 9 times the mean amount of TDS found at the reference site. From these conclusions, although minimal, there could have been some influence on cyanobacteria activity due to the increased TDS, particularly from sites CB01 and CB02, which showed the highest mean values for TDS (*Figure 11*).

4.1.8 Gran Alkalinity

The calculated mean values for alkalinity (mg/L), expressed as Gran Alkalinity per sample site, are located in the following graph. The raw values for alkalinity for each site per sampling sweep are located in Appendix B.

Figure 12: *Mean alkalinity values (mg/L), expressed as Gran Alkalinity per sample site, showing the highest mean value attained in the pond outlets. Each site is graphed in accordance to what type of sample site it is.*



Due to the non-carbonate nature of the underlying bedrock (Hayes, J., 1987) and to the naturally acidic, boggy conditions in this region, the overall alkalinity was very low (< 10 mg/L) at all of the sites (*Figure 12*). This means not only that the ability of the water in this watershed to buffer pH was vastly decreased, but also means there was no natural bicarbonate and carbonate ionic buffer that could potentially serve to precipitate toxic metals and other human caused substances from the water (Murphy, 2007). Thus, the aquatic ecosystem in the Paddy's Pond drainage basin as a whole was quite sensitive to change, and could have been drastically influenced by a sudden or gradual change in water quality in 2007 that may have helped lead to favorable conditions for the reported cyanobacterial growth.

4.1.9 Arsenic (As)

The values for arsenic (As) per sample site in µg/L as attained from the water samples collected on August 4th 2008 are located in the following graph. The raw values for As for each site are also located in Appendix B.

Figure 13: *Values of arsenic (µg/L) per sample site, highlighting the value attained in the reference site. Each site is graphed in accordance to what type of sample site it is.*

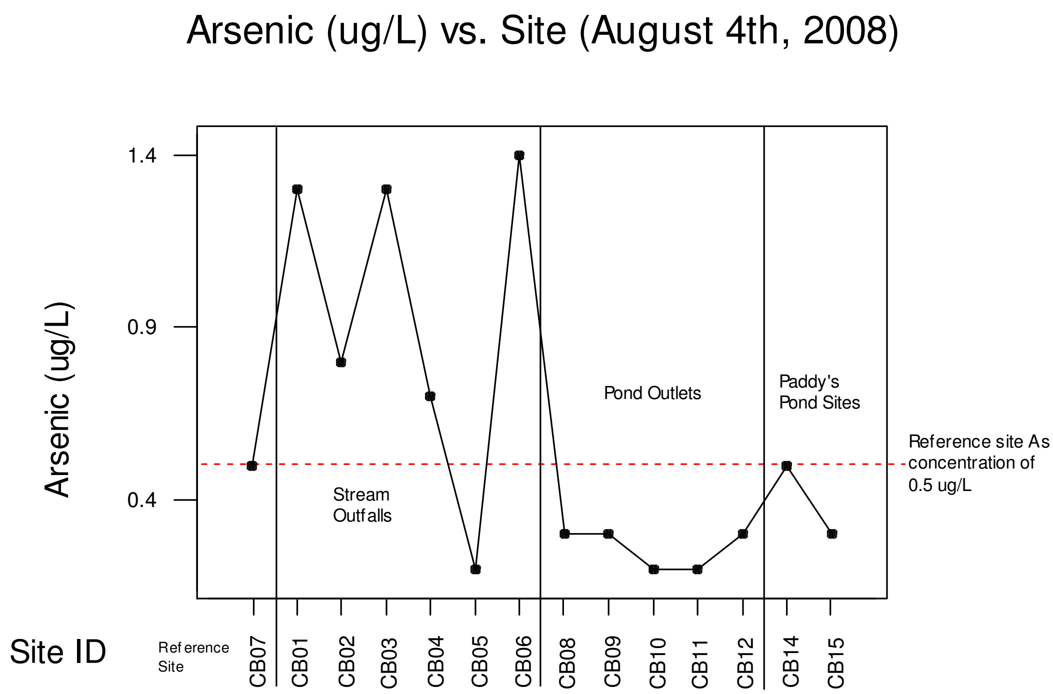
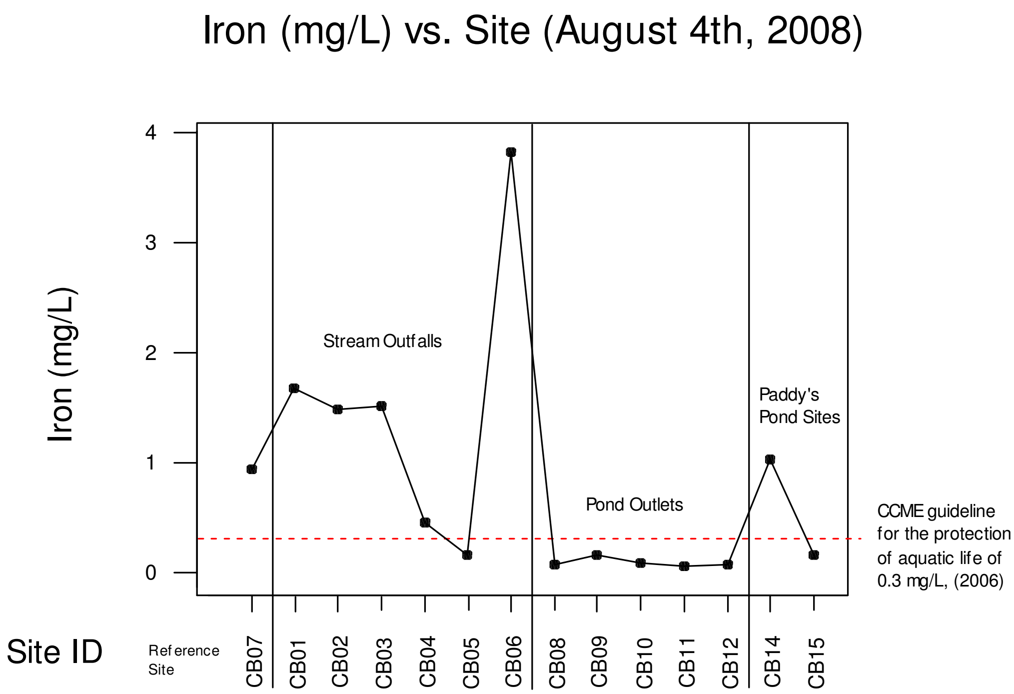


Figure 13 shows that there was a low occurrence of the toxic metal arsenic (As) in the water samples since the reference site had a mean value of 0.5 µg/L, and the highest mean value of As recorded was only 1.4 µg/L in site CB06. While sites CB01 and CB03 (at 1.3 µg/L each) and CB06 had the highest mean values of As, they were still less than 3 times higher than the reference; and the CCME derived guideline for the protection of aquatic life for As (2006) is 5.0 µg/L. The CCME Canadian Environmental Quality Guidelines (CEQG) factsheet for arsenic also states that levels of As in uncontaminated surface waters are generally less than 2.0 µg/L (2006). Thus, while the mentioned sites had relatively poorer water quality in terms of arsenic, these sites could be just concentrating natural levels of As due to their low-flowing nature; anthropogenic loadings of arsenic were unlikely in this case. It was relevant to this study, however, in that it reinforced the possibility that these sites could be providing potential pathways for water concentrated in various substances to flow into Paddy's Pond, creating an advantageous environment for cyanobacteria at these points.

4.1.10 Iron (Fe)

The values for iron (Fe) per sample site in mg/L as attained from the water samples collected on August 4th 2008 are located in the following graph. The raw values for Fe for each site are also located in Appendix B.

Figure 14: *Values of iron (mg/L) per sample site showing the related CCME guideline for the protection of aquatic life. Each site is graphed in accordance to what type of sample site it is.*



A report by Health Canada (2008) states that iron is an important micronutrient for plant life as well as that of cyanobacteria. Iron (Fe) aids in photosynthesis and the fixation of nitrogen. Too much iron, however, can also cause the fixation of other nutrients and elements that are required by plants to survive (BC Ministry of Environment, 1998). Figure 14 shows that, in many cases, mean values of iron fell above the CCME derived guidelines for the protection of aquatic life of 0.3 mg/L (CCME, 2006), and in some cases these values were well above this guideline. Alternatively, some recorded values also fell below this guideline. Due to the naturally occurring Fe-rich water that flows from boggy areas in the Northeast Avalon region, somewhat elevated concentrations of iron were expected in the samples, as was shown in the reference site (CB07), which had a value for iron of 0.94 mg/L. However, these naturally high levels of Fe could have also potentially contributed to the conditions that led to the cyanobacteria bloom. It should be noted that sites CB01 – CB06 were in the vicinity of old iron culverts, some of which had begun to decay over time. Given this, sites CB01 – CB03 had iron levels of 1.67, 1.48, and 1.51 mg/L respectively, and may have provided ideal levels of iron that would promote a cyanobacterial bloom as well.

Additionally, the highest value of iron recorded was in site CB06 at a concentration of 3.82 mg/L; at more than 12 times the CCME guideline, this site was so concentrated in iron that much of the Fe detected at that site was probably not naturally occurring, hence, site CB06 may have been a potential pathway for contaminated water to enter Paddy's Pond, creating a favorable environment for cyanobacteria. Alternatively, it could also be possible that iron was so high in this site that cyanobacteria growth may have been somewhat inhibited as well; however, this upper limit of iron is not well understood either.

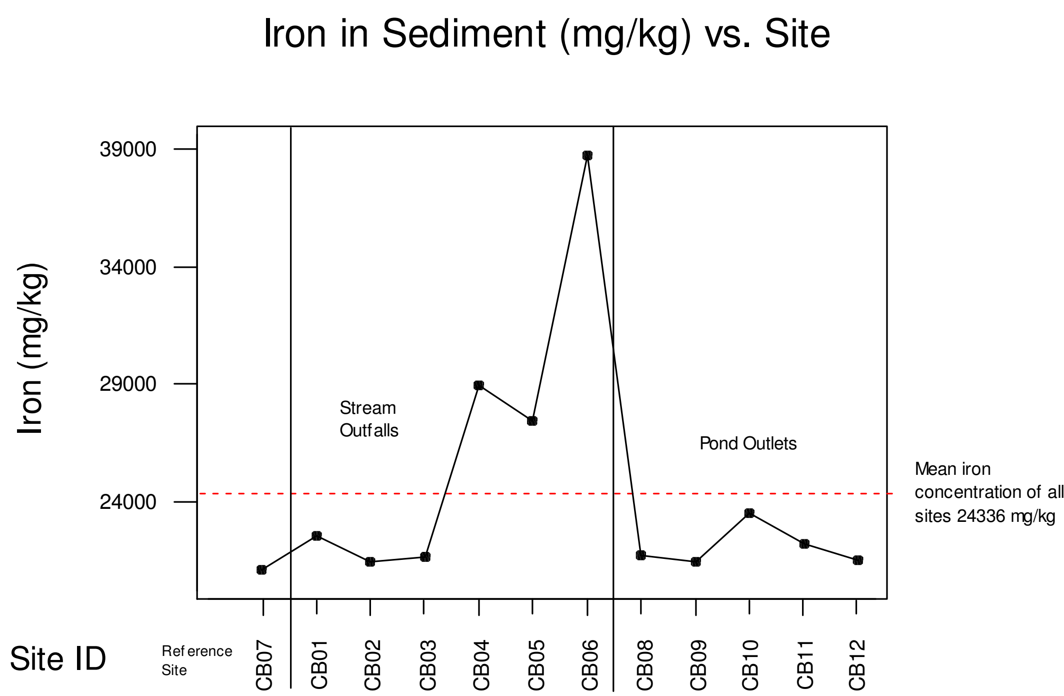
4.1.11 Molybdenum (Mo)

Due to the fact that the concentrations of molybdenum (Mo) in most of the sites were below the detection limits (0.1 ug/L), no graph was produced; however site CB07 did have a concentration of 0.3 µg/L and sites CB08 and CB09 had concentrations of 0.1 µg/L each (*Appendix B*). In certain concentrations, molybdenum is essential to aquatic plant life and cyanobacteria in that it aids in nitrogen uptake and carbon fixation (Health Canada, 2008). According to a factsheet on molybdenum produced by CCME (1999), phytoplankton and periphyton communities (both which include cyanobacteria) are limited by a concentration of less than 0.06 µg/L Mo, and promoted optimally at 25 µg/L, and then inhibited again at levels above 25 µg/L. Site CB07 had a level of 0.3 µg/L, which is 5 times the limiting amount. The rest of the sites may also have been close to 0.1µg/L however it was unclear because the equipment sensitivity was not high enough. Thus, the concentrations of molybdenum in this case may have been too low to have much influence on the presence of cyanobacteria.

4.1.12 Iron (Fe) in Sediment

The values for iron (Fe) per sample site in mg/kg as attained from the sediment samples collected on September 3rd 2008 are located in the following graph. The raw values for Fe for each site are also located in Appendix C.

Figure 15: *Values of iron in sediment (mg/kg) per sample site showing the mean iron in all the sites. Each site is graphed in accordance to what type of sample site it is.*

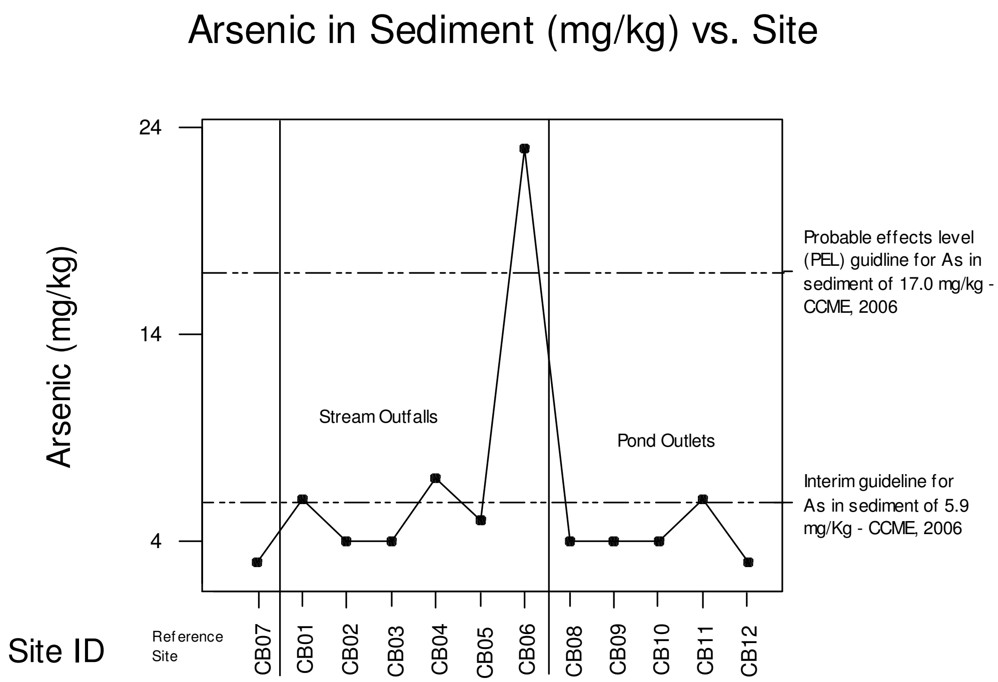


Similarly to the results of the water analysis for iron (*Section 4.1.10*), site CB06 had by far the highest iron concentration detected in the sediment samples as well at 38,743 mg/kg (*Figure 15*), possibly owing somewhat to the decaying iron culvert a few meters downstream of the sampling site. When compared with site CB04, which had the next highest concentration at 28,920 mg/kg, it was probable that site CB06 had been receiving unnaturally sourced loadings of iron, thus it could have been contributing toward the conditions in Paddy's Pond that led to the cyanobacteria bloom, particularly since iron had been identified as a limiting factor for cyanobacterial growth in the report by Health Canada (2008). Iron levels recorded in the sediment at all of the other sites were relatively low and the mean concentration from all the sites combined was 24,336 mg/kg (*Figure 15*).

4.1.13 Arsenic (As) in Sediment

The values for arsenic (As) per sample site in mg/kg as attained from the sediment samples collected on September 3rd 2008 are located in the following graph. The raw values for As for each site are also located in Appendix C.

Figure 16: *Values of arsenic in sediment (mg/kg) per sample site showing the CCME Probable Effects Level (PEL) and Interim guidelines for As in sediment. Each site is graphed in accordance to what type of sample site it is.*

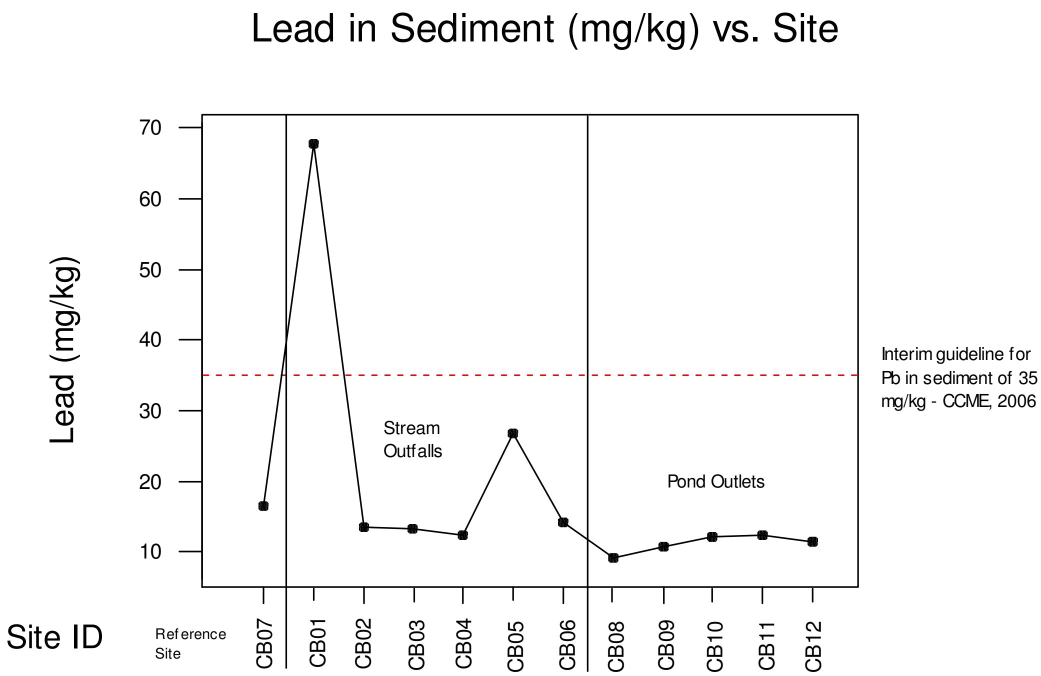


According to the CEQG sediment quality fact sheet on arsenic (CCME, 2003), mean background arsenic (As) concentrations in lake and stream sediments across Canada vary between 2.5 mg/kg and 10.7 mg/kg; hence, some natural levels of As would be expected to be found in the sediment samples taken. However, given this understanding, site CB06, which had the highest amount of As detected in the sediment samples at a concentration of 23.0 mg/kg, was more than 7 times the concentration found in the sediment analysed from the reference site (CB07), which was recorded at 3.0 mg/kg; and the next highest concentration of As recorded in the sediment samples was only 7.0 mg/kg at site CB04 (*Figure 16*). Additionally, as shown in Figure 16, site CB06 greatly exceeded the CCME derived Probable Effects Level (PEL) of 17.0 mg/kg for arsenic in sediment for the protection of aquatic life (2003). Due to the notably high level of arsenic in site CB06, it was possible that human activity had contributed to the high level of arsenic in the sediment at site CB06. This provides additional evidence that site CB06 could have been a potential pathway for undesirable constituents to enter Paddy's Pond, in turn possibly contributing to a favorable environment for cyanobacterial growth.

4.1.14 Lead (Pb) in Sediment

The values for lead (Pb) per sample site in mg/kg as attained from the sediment samples collected on September 3rd 2008 are located in the following graph. The raw values for Pb for each site are also located in Appendix C.

Figure 17: *Values of lead in sediment (mg/kg) per sample site showing the CCME interim guidelines for Pb in sediment. Each site is graphed in accordance to what type of sample site it is.*

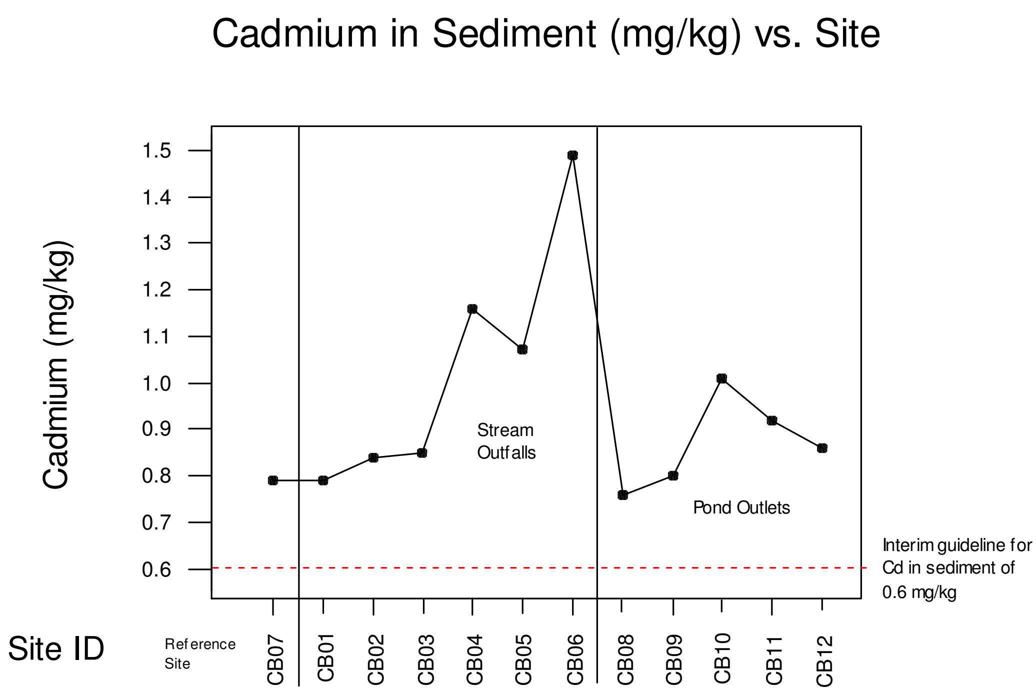


The Canadian Environmental Quality Guidelines (CEQG) sediment quality fact sheet on lead (Pb) states that from extensive research conducted, mean background lead concentrations in lake and stream sediments across Canada vary between 6 mg/kg and 12.7 mg/kg, and that most of the background concentrations of Pb are less than the interim freshwater guideline for sediment of 35.0 mg/kg (CCME, 2003). Given this information, a significant amount of Pb was detected in the sediment sampled from site CB01, at a value of 67.8 mg/kg (*Figure 17*). The next highest concentration of Pb found in the sediment samples was at the outfall into Paddy's Pond (CB05) measured at 26.8 mg/kg; and the values detected in the sediment at the rest of the sites were all lower than 17.0 mg/kg. When compared with the lower concentrations of lead at the rest of the sites, the high concentration of Pb in site CB01 suggests the consistently poor environmental quality of the samples taken from site CB01, implying again that this could be a potential conduit of contaminated water into Paddy's Pond, which could lead to conditions favoring a cyanobacteria bloom.

4.1.15 Cadmium in Sediment

The values for cadmium (Cd) per sample site in mg/kg as attained from the sediment samples collected on September 3rd 2008 are located in the following graph. The raw values for Cd for each site are also located in Appendix C.

Figure 18: *Values of cadmium in sediment (mg/kg) per sample site showing the CCME interim guidelines for Cd in sediment. Each site is graphed in accordance to what type of sample site it is.*



The Canadian Environmental Quality Guidelines (CEQG) sediment quality fact sheet on cadmium (Cd) states that mean background cadmium concentrations in lake and stream sediments across Canada vary between 0.32 mg/kg and 0.63 mg/kg, and that most of the background concentrations of Cd are less than the interim freshwater guideline for sediment of 0.6 mg/kg (CCME, 2003). In this case, all of the sites exhibited high levels of cadmium (Cd) in the sediment samples since all of the levels recorded exceeded the Canadian background levels and the interim guideline for Cd in sediment (CCME, 2003), (*Figure 18*). However, since even the sediment at the reference site (CB07) had a level of Cd measured at 0.79 mg/kg, much of the cadmium was probably naturally inherent.

However, of note, site CB06 had the highest concentration of cadmium in sediment at a level of 1.49 mg/kg, and compared with the concentrations measured in the other sites, site CB06 stood out as being particularly high (*Figure 18*). Since only one sediment sample was taken per site throughout the entire sampling period, not enough information was collected to determine whether this value had any statistical significance; however, for the purposes of this report, assuming the generally stable nature of sediment, similar values of Cd concentrations in sediment were interpolated for each site in order to perform a hypothetical statistical analysis of variance (ANOVA) on the data. Upon calculating the ANOVA, it was determined that there was statistically significant variance between concentrations of Cd in sites CB06 and the reference site. Thus, the Cd concentration in site CB06 was determined to be unusually high; although more samples would have to be taken to determine if this site were actually anthropogenically contaminated with cadmium, the possibility of human impact was not necessarily ruled out since it has been shown in some of the previous subsections that the water and sediment samples in site CB06 were, in some cases, more concentrated in various metallic parameters and salty ions than some of the other sites. In contrast, due to the shallow, low-flowing nature of this site, it could also have been that these various parameters, including cadmium, could have become more easily concentrated there regardless, whether naturally derived or not. However, this still helps to back the previously noted evidence that site CB06 could potentially be a passageway for contaminants of different types to enter Paddy's Pond, possibly contributing to favorable conditions for cyanobacteria to thrive.

4.2 Overview of Nutrient Loadings in the Watershed

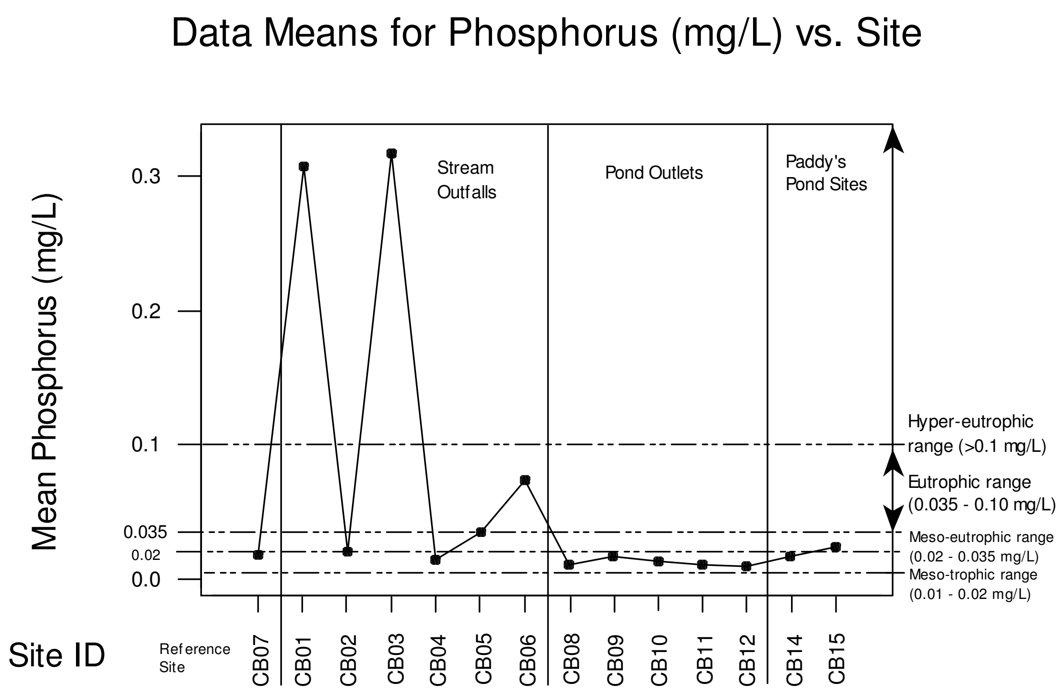
The most significant factor that would lead to a substantial increase of cyanobacteria cells, outside of general environmental factors, is the increase of nutrients into the aquatic ecosystem. Although any type of parameter that would be considered a nutrient to an aquatic environment can affect cyanobacteria populations, the most critical nutrient, often considered the primary limiting factor, would be phosphorus. Phosphorus is essential to all plant life and photosynthesizing algae and bacteria, however in high amounts it can cause eutrophication, which leads to heavy biological competition that can often lead to a cyanobacteria bloom. Various other less critical limiting factors include different forms of nitrogen and carbon.

The following subsections summarize the findings of the nutrients analyses. An attempt will be made to establish a relationship between the concentrations of specific nutrients and the presence of cyanobacteria. As well, an understanding of the pathways and origins of nutrients into and through the watershed will be established through the examination of this data.

4.2.1 Phosphorus (P)

The calculated mean values for phosphorus (P) per sample site in mg/L are located in the following graph. The raw values for P for each site per sampling sweep are located in Appendix B.

Figure 19: *Mean phosphorus values (mg/L) per sample site showing the CCME derived trigger ranges and general trophic categories for phosphorus. Each site is graphed in accordance to what type of sample site it is.*



The biological productivity in an aquatic system is highly influenced by the presence of phosphorus. The CCME (2006) have derived a "trigger range" of aquatic productivity based on the amount of phosphorus present compared with the background levels, which categorizes the different ranges of phosphorus as they relate to the ecological state of the water body sampled. Although there were no background levels of phosphorus available, the CCME recommends that a site with 50% higher phosphorus than in the reference or to background levels could potentially trigger observable effects above the upper limit of a particular trigger range. In this case, the chosen reference site (CB07) at Thomas Pond could serve as a useful way of inferring expected background levels of phosphorus, and although true trophic classifications can not be made, the mean phosphorus data from the sample sites can be placed into the CCME's trigger ranges to estimate their possible status of biological productivity as they compare to the condition of the reference site.

The CCME trigger range classifies a relatively unproductive system as "*oligotrophic*"; a productive system as "*mesotrophic*"; and a highly productive range as "*eutrophic*". There are also sub ranges, such as "*meso-eutrophic*", and extreme ranges, such as "*ultra-oligotrophic",* and "*hyper-eutrophic*". As compared with background levels, an ecosystem with a phosphorus range of more than 0.035 mg/L is generally considered to be eutrophic, and a system with a range of greater than 0.100 mg/L is generally considered to be hyper-eutrophic; thus biological productivity and, consequently, cyanobacterial growth would be expected to increase greatly in these ranges. The British Columbia Ministry of Environment (1998) set their local eutrophic range as low as 0.025 mg/L; hence, some variability in production status could be expected depending on the balance between natural and anthropogenic environmental conditions that occur from watershed to watershed in varying regions. Since in this case, if the mean concentration of phosphorus at the reference site is 0.0178 mg/L (*Figure 19*), then at more than 50% above this level a mean concentration of 0.036 mg/L and higher could be considered to have observable changes in biological productivity and could potentially be considered to be in a eutrophic state.

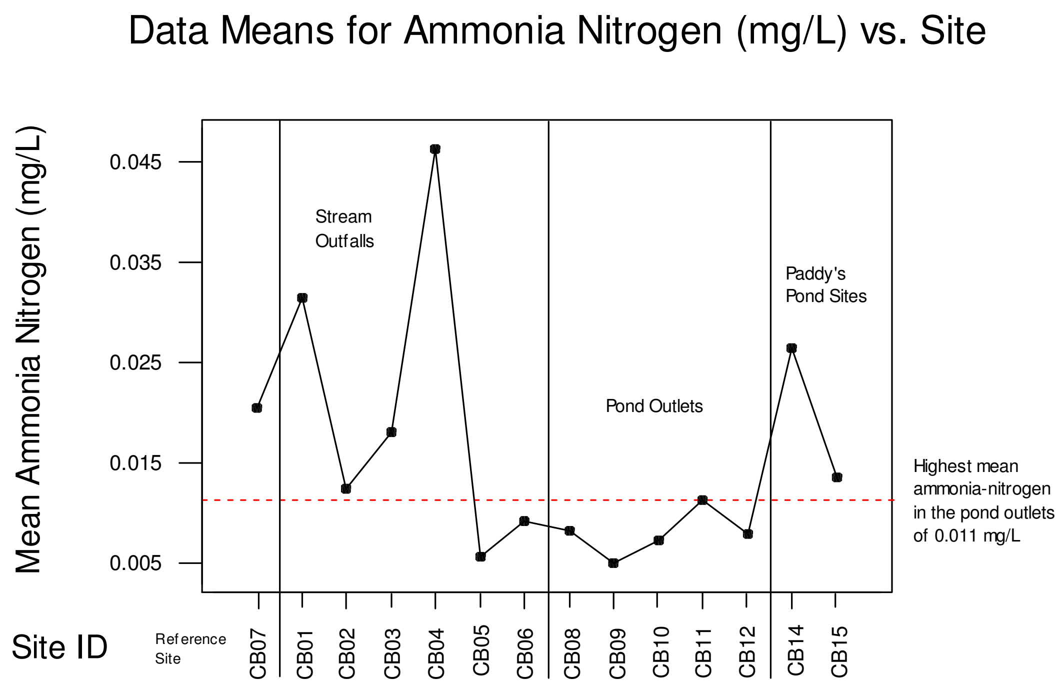
Figure 19 showed that the mean phosphorus levels were very high (greater than 0.100 mg/L) in sites CB01 and CB03; (ranging from 0.185 mg/L to 0.434 mg/L in site CB01, and from 0.181 mg/L to 0.477 mg/L in site CB03). The flow of potentially hyper-eutrophic water from these two shallow sites to Paddy's Pond likely had an impact on the watershed, which may have resulted in the excessive growth of cyanobacteria. Additionally, the shallow site CB06 fell into the eutrophic trigger range, with a mean phosphorus concentration of 0.074 mg/L; site CB05, which is on the edge of Paddy's Pond, fell just short of this range with a mean concentration of 0.035 mg/L. Since sites CB06 and CB05 both flow into Paddy's Pond, it was possible they may have had a positive impact on the increase of cyanobacteria growth in Paddy's Pond, particularly with regards to site CB06. Both sites CB15, in Paddy's Pond, and CB02, which led into Paddy's Pond, fell in the low meso-eutrophic range.

All of the other sites maintained a mesotrophic status (*Figure 19*), and were less affected by the cyanobacterial bloom, if at all. Some of the downstream sites may have experienced smaller cyanobacterial blooms because enriched water containing high counts of active cyanobacter cells from Paddy's Pond was probably transferred to these sites for short periods through the natural hydrological flow process.

4.2.2 Ammonia-Nitrogen

The calculated mean values for ammonia-nitrogen per sample site in mg/L are located in the following graph. The raw values for ammonia for each site per sampling sweep are located in Appendix B. Ammonia-nitrogen includes all forms of ionized and unionized forms of ammonia.

Figure 20: *Mean ammonia-nitrogen values (mg/L) per sample site showing the Highest mean concentration of ammonia in the pond outlets. Each site is graphed in accordance to what type of sample site it is.*



Cyanobacteria are known nitrogen fixers, in that they must use organic and gaseous nitrogen for their own photosynthetic and growth processes. They convert the otherwise un-usable forms of nitrogen to the highly toxic ammonia (NH_3) and to the much less toxic ionized ammonia (ammonium, NH_4^+), or various essential amino acids. These new compounds are then used by other organisms and further oxidized to create other forms, such as nitrite (NO_2) and eventually nitrate (NO_3) (Murphy, 2007). Ammonia very easily converts to nitrate in water, and since the concentration of NH_3 greatly diminishes with decreasing pH and decreasing temperature (CCME, 2006), it is relatively uncommon to find un-ionized ammonia in high concentrations in the cooler, more acidic waters of the Northeast Avalon region.

Figure 20 shows varying mean concentrations of ammonia-nitrogen recorded throughout the Paddy's Pond watershed. These numbers relate to the concentration of what is known as total ammonia, which includes the combined concentrations of NH_3 and NH_4^+. A report on nutrient loadings by the US Geological Survey states that the chronic exposure limit for aquatic life regarding total ammonia occurs at a concentration of 2 mg/L in cooler, less alkaline water. This number is greatly reduced to 0.1 mg/L as the pH and temperature rises (Mueller and Helsel, 2009). The mean temperatures and levels of pH were relatively low in the Paddy's Pond watershed; thus from Figure 20, it was determined that the mean ammonia-nitrogen concentrations were quite low since the highest mean concentration was recorded in site CB04 at less than 0.05 mg/L. Thus, the anthropogenic input of total ammonia to this system was most likely negligible.

Additionally, since the CCME guideline for the protection of aquatic life is 0.019 mg/L NH_3, two related mathematical equations that took into account pH and temperature had to be performed to determine the fraction of NH_3 to NH_4^+ from the total-ammonia concentrations (found in CCME, 2006), to determine whether there was a lot of toxic ammonia present, which would have indicated a potential anthropogenic source of the nutrient.

In this case, the level of toxic ammonia present in the samples proved to be very low. Although site CB04 consistently had the highest levels of ammonia-nitrogen ranging from 0.021 mg/L to 0.088 mg/L, and with the highest single concentration recorded of all the sites at 0.088 mg/L (*Appendix B*), upon performing the necessary calculations, at its highest concentration and optimal pH/temperature, site CB04 had a concentration of only 0.0001 mg/L NH_3 (toxic, un-ionized ammonia). As this was the highest amount of unionized ammonia calculated, any human induced input of ammonia into the system, if any, most likely did not play a role in influencing the growth of cyanobacteria in the Paddy's Pond watershed.

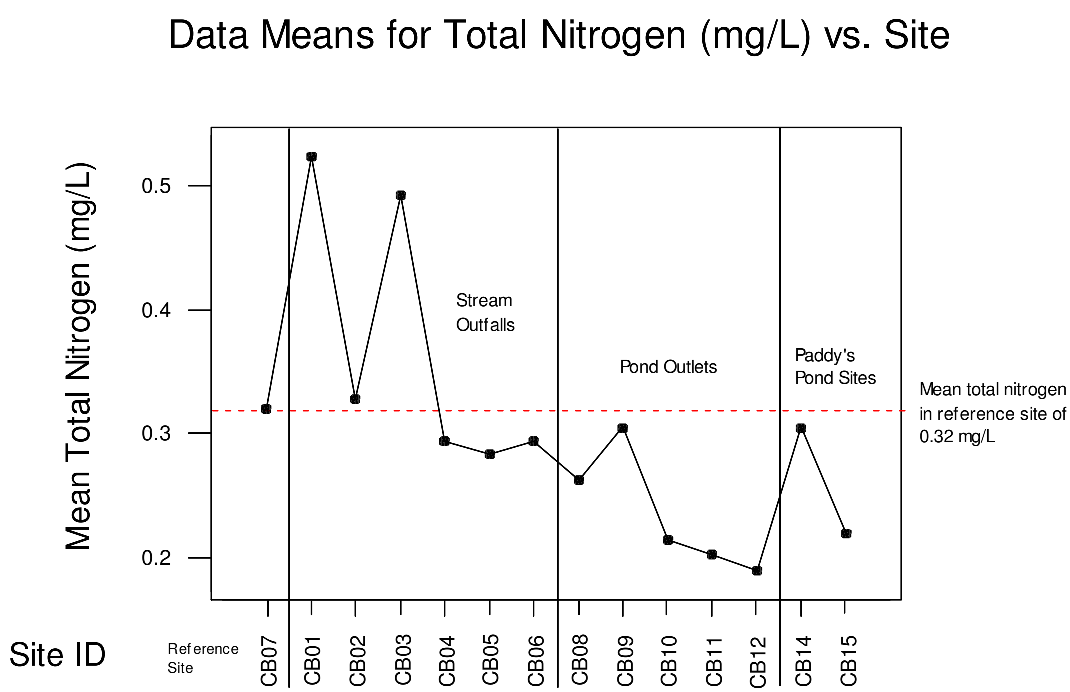
4.2.3 Nitrate (NO_3)

Similarly to the ammonia concentrations mentioned in section 4.2.2, the levels of nitrate (NO_3) measured were also very low. The raw values for nitrates for each site per sampling sweep are located in Appendix B. Although trace quantities of NO_3 were recorded in sites CB01, CB03, CB04 and sometimes CB06, they were too low to determine whether they were anthropogenically derived, and most likely did not contribute to the conditions that led to the cyanobacteria bloom.

4.2.4 Total Nitrogen

The calculated mean values for total nitrogen per sample site in mg/L are located in the following graph. The raw values for total nitrogen for each site per sampling sweep are located in Appendix B. Total nitrogen includes all forms of organic and inorganic nitrogen including nitrates, nitrites, and ammonia.

Figure 21: *Mean total nitrogen values (mg/L) per sample site showing the mean concentration of total nitrogen in the reference site. Each site is graphed in accordance to what type of sample site it is.*



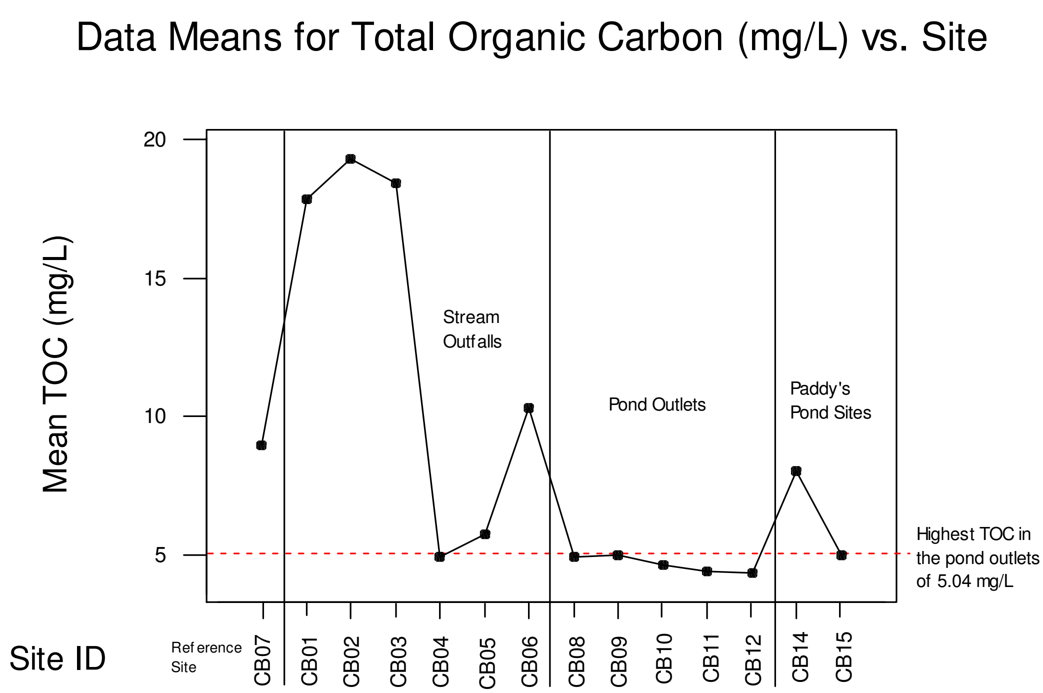
Although there is no CCME related guideline for total nitrogen, which includes all forms of nitrogen, the Alberta Ministry of Environment set their chronic Total-N guideline for the protection of freshwater aquatic life to 1.0 mg/L (1999). Thus, from Figure 21, the mean values of total nitrogen were not considered to be high (less than 1.0 mg/L); however taking into account some spikes in the data means, there may have been some nitrogenous compounds concentrating in parts of the system.

The raw data showed that the highest consistent concentrations of total nitrogen occurred in sites CB01 and CB03, with the highest single amount detected being both in sites CB01 and also CB09 at 0.61 mg/L. On one occasion, site CB05 also had a comparatively high amount recorded in at 0.56 mg/L (*Appendix B*). Sites CB09 and CB14, which were also both located in Paddy's Pond, had identical mean concentrations of 0.305 mg/L. Sites CB04 and CB06, both of which flow into Paddy's Pond, had identical mean concentrations of 0.294 mg/L; all of the other sites with the exception of site CB07 (reference site) had mean concentrations of less than this (*Figure 21*). Site CB07 had a mean concentration of 0.32 mg/L and was higher than the mean concentrations in all the other sites, except in sites CB01 – CB03, which were more susceptible to the concentrating of various nutrients due to their low-flowing, shallow nature. Since Paddy's Pond and some of the influent streams to Paddy's Pond had relatively elevated concentrations of total nitrogen when compared to sites downstream and the upstream site at Cochrane Pond, there may have been the possibility of a slight concentration of nitrogenic compounds into Paddy's Pond, potentially influencing cyanobacterial growth; although when compared to the Alberta guideline of 1.0 mg/L, there was very little nitrogen in this system, and so it may have played a much smaller role than did the presence of phosphorus (*Section 4.2.1*).

4.2.5 Total Organic Carbon (TOC)

The calculated mean values for total organic carbon (TOC) per sample site in mg/L are located in the following graph. The raw values for TOC for each site per sampling sweep are located in Appendix B.

Figure 22: *Mean total organic carbon values (mg/L) per sample site showing the highest mean concentration of TOC in pond outlets. Each site is graphed in accordance to what type of sample site it is.*



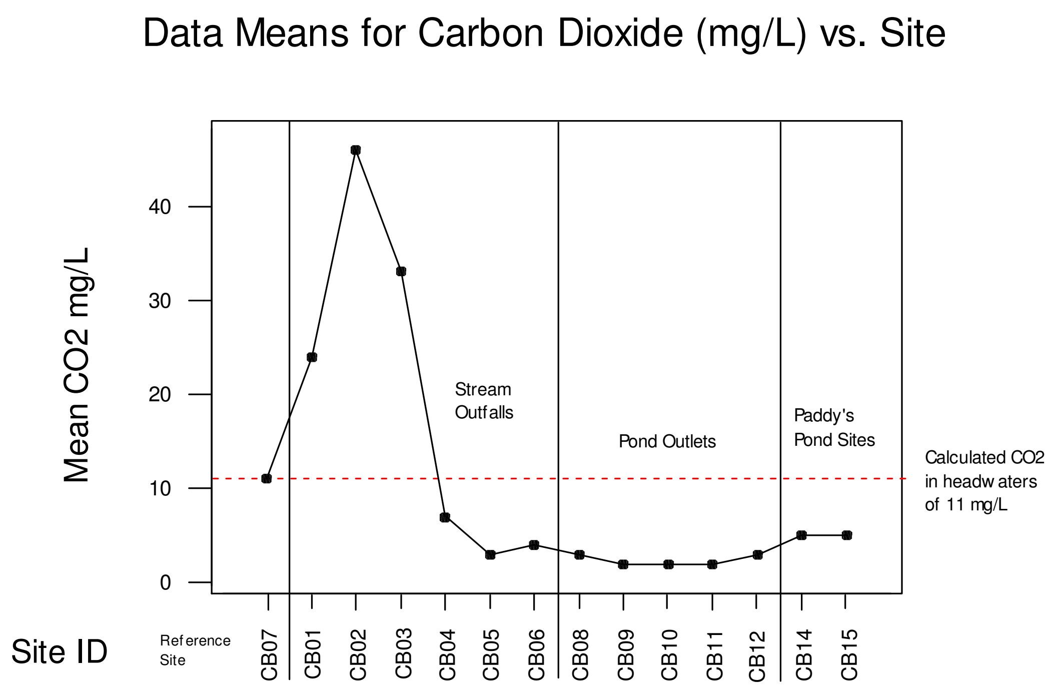
Organic matter, which is made primarily of carbon compounds, plays an important biologic role in aquatic ecosystems in terms of nutrient cycling and the availability of nutrients. According to the BC Ministry of Environment, the total organic carbon (TOC) content of most natural waters generally range between 1 and 30 mg/L TOC (1998). Additionally, according to a coinciding report, a small deviation from measured background levels of TOC can initiate significant changes in an aquatic ecosystem (BC Ministry of Environment, 2001). This same publication links elevated concentrations of TOC to increases in bacterial metabolism due to the fact that it is an important biological nutrient.

Since none of the sites exhibited a mean or raw value of higher than 30 mg/L (*Figure 22, Appendix B*), TOC was likely not a major parameter that led to the rapid growth of cyanobacteria cells. It was noted, however, that sites CB01 – CB03 and CB06 did have the highest mean TOC concentrations, with the highest being from site CB02 at 19.3 mg/L; although, the highest single value detected was 25.2 mg/L at site CB03. Much of the volume of water in these shallow sites was in close contact with the substrate and could be a possible reason why TOC was recorded to be higher at those sites; regardless of this, the overall impact on cyanobacterial growth was likely to have been minimal.

4.2.6 Carbon Dioxide (CO_2)

The calculated mean values for carbon dioxide (CO_2) per sample site in mg/L are located in the following graph.

Figure 23: *Mean carbon dioxide values (mg/L) per sample site showing the mean concentration of* CO_2 *in the reference site. Each site is graphed in accordance to what type of sample site it is.*



Carbon dioxide (CO_2) is an important gaseous carbon compound that is essential to aquatic plant and cyanobacteria growth due to its crucial role in photosynthesis. The solubility of CO_2 in water increases with decreasing temperature and decreasing pH; thus CO_2 would be expected to be present within the samples. Additionally, the presence of total inorganic carbon in the water would provide the bicarbonate ion that, while influencing the alkalinity, is necessary for producing CO_2 (BC Ministry of Environment, 1998). Thus, while CO_2 would be expected to be present, due to the low alkalinity in the samples (*Section 4.1.*8) CO_2 could have been limited as well.

In this case, carbon dioxide was not measured directly; it was instead calculated with a formula that was a function of temperature, pH, and alkalinity (Aquaculture Solutions, and Aquatic Eco-Systems Inc., 2010). Figure 23 shows the mean results of these calculations. It was unclear as to how much carbon dioxide would be considered harmful to aquatic life, or as to the concentration needed to heavily influence cyanobacteria growth; however Figure 23 showed that while most of the sites had a relatively consistent level of CO_2, sites CB01 – CB03 had elevated means. This could have potentially have been due to the higher levels of total inorganic carbon and TOC detected at these sites (*Appendix B*), as well as various factors such as the lower pH, temperature, and dissolved oxygen recorded at these sites, which were in part attributed to the boggy conditions upstream, and the fact that these sites were shallow, low-flowing streams that may have been more susceptible to concentrating higher amounts of CO_2. It was, however, possible that increased levels of CO_2 at these sites could have had a minor influence on the growth of cyanobacteria in Paddy's Pond as it received water from these sites.

4.3 Sunlight as a Limiting Factor of Cyanobacterial Growth

The penetration of sunlight through the water column plays an important role in promoting the growth of photosynthesizing organisms, such as cyanobacteria. The more sunlight available, the more favorable the conditions are for cyanobacteria to flourish. According to the National Climate Data and Information Archive (Environment Canada, 2009), there were more clear days in the period of the 2007 cyanobacteria bloom when compared with the data obtained from the 2008 sampling period. This may have had some additional influence on the positive growth of cyanobacteria in 2007 and on their less significant abundance in 2008.

4.4 Brief Discussion of Biological Findings from Province of NL

The Water Resources Management Division of the Newfoundland and Labrador Department of Environment and Conservation reported on the occurrence of the cyanobacteria blooms in 2007 and 2008, and had done some field sampling and monitoring of various parameters in 2008 that included biological findings and microcystin-LR analysis (NL Ministry of Environment and Conservation, 2008). This section illustrates the key findings of the 2008 report by the Water Resources Management Division as they correspond to the findings of this study. The sites used in the NL study are identical to the sites labeled CB01 – CB15 in this study, and have been re-labeled as such for consistency and clarity in comparing them. In point form, the relevant features of the NL study (NL Ministry of Environment and Conservation, 2008) are as follows:

- Cyanobacteria species identification: *Anabaena sp.* – There are some nuisance and toxic strains of *Anabaena sp.* known that do produce the microcystin-LR toxin (Health Canada, 2008).
- Microcystin-LR was found in all of the pond outlet sites, but only during the month of May, 2008. Most of the toxin was found in site CB07 at a concentration of 0.61 µg/L, and the next highest was detected at the Paddy's Pond outlet with a concentration of 0.48 µg/L. The lowest concentration detected was in the Cochrane Pond outlet at 0.21

µg/L. All of the other outlets exhibited values between 0.28 and 0.30 µg/L. Since Health Canada's official drinking water guideline for microcystin-LR in water is set at 1.5 µg/L (Health Canada, 2008), none of the sites sampled exhibited high levels of the toxin.

- Most of the cyanobacterial cells were located in site CB05 at a concentration of 6,200 cells/ml in May 2008, with many cells also detected in June and July at concentrations of 3,400 and 3,500 cell/ml respectively. The next highest counts occurred in sites CB01 – CB03, and then in sites CB09 and CB06. However, these were not very high counts of cyanobacteria since a maximum recreational use guideline of 20,000 cells/ml was set by the World Health Organization (WHO, 2003).

- Most of the phosphorus detected occurred in sites CB01 and CB03 with the highest concentrations being in June and July, 2008. All of the concentrations from these sites were above 0.20 mg/L, which greatly exceeded the hyper-eutrophic trigger range criteria for phosphorus set by CCME (2006) at concentrations greater than 0.10 mg/L. As no background data for phosphorus was available the Department was unable to classify these sites; however they did place their measured concentrations of phosphorus in the appropriate trigger categories for the purposes of comparing phosphorus data between the sampling sites with the following provision:

"The framework uses trigger ranges, which are ranges of phosphorus levels for a specific freshwater system. The appropriate trigger range is determined according to baseline data and management objectives or goals for the system. If phosphorus levels in the system exceed 50 percent of the baseline level or the upper limit of the trigger range, there maybe an environmental problem and further investigation is triggered. The Department of Environment and Conservation had not conducted water quality analysis on Thomas Pond, Cochrane Pond, Paddy's Pond, Three Arm Pond, Three Island Pond and Topsail Pond prior to the blue-green algae bloom in 2007; therefore, baseline data for phosphorus concentrations has not been established." – NL Ministry of Environment and Conservation, 2008.

In addition, the highest recorded concentration of phosphorus collected by the Department was 0.68 mg/L in site CB03 in July, 2008. The next highest concentrations were found in sites CB05 and CB06 respectively, and both occasionally met or exceeded the CCME hyper-eutrophic trigger range at least once; however, as mentioned in their report, all of those sites were located in shallow, low-flowing streams at or from culverts and were more likely to be more concentrated in phosphorus and other constituents than in a larger body of water:

"The results indicate much higher levels of total phosphorus were detected at Sites #1 and #3, and to a lesser extent Sites #5 and #6 during each monthly sampling period. These sites are all located at the inlets or outlets of culverts that discharge surface drainage into Paddy's Pond. These results may be influenced by the very small volumes of water that served as the source for these samples." – NL Ministry of Environment and Conservation, 2008.

- Nitrogen parameters were generally very low; however the highest concentrations occurred in sites CB01 – CB06, and especially in CB01 and CB03. Although these values were very low.

From the results of the 2008 NL study on cyanobacteria in the Paddy's Pond watershed, it was concluded that while counts of cyanobacteria and levels of total nitrogen and microcystin-LR were generally fairly low, these parameters showed the highest values in and around Paddy's Pond. These same sites sometimes showed higher concentrations of phosphorus in comparison with the other sites, and in particular, sites CB01 and CB03, which always had high concentrations of phosphorus detected. Recognition of most of these sites as being low-volume drainage into culverts and small streams with the potential to concentrate certain elements like phosphorus is important; however, for the purposes of this report, the data obtained from the Province's report helps to reinforce the possibility that some of these sites, particularly sites CB01 and CB03, may have been potential pathways for these constituents to enter Paddy's Pond, which could possibly have encouraged cyanobacterial growth within Paddy's Pond.

5.0 Comparison with Findings at Lake Utopia, NB

In 2003, a similar study had been completed by Eastern Charlotte Seaways (ECS) Inc., which focused on the anthropogenic effects on water quality and the growth of cyanobacteria in Lake Utopia, which is in the Bay of Fundy near Blacks Harbour, New Brunswick (Hansen, 2003). The watershed comprising of Lake Utopia and its associated canals and tributaries had similar ecological and anthropogenic land-use qualities to that of the Paddy's Pond watershed, which made it appropriate to compare with the findings of this report; although industrial activity, which included aquaculture, was more advanced in the vicinity of Lake Utopia.

According to the report, Lake Utopia had experienced consistent problems with cyanobacteria blooms, which were associated with poor management of point source and non-point source nutrient-enriched effluents from the related industrial activity occurring in and around the lake. The cyanobacteria identified in Lake Utopia consisted of a few different biological strains, however much like in the Paddy's Pond bloom, the main strain detected was the toxic *Anabaena sp.*

Although there was either not enough data collected or not enough data available from the ECS report to be able to determine whether there was a true statistical difference between the data collected from this study and from theirs, a key connection observed between the two studies was that most of the sites in the Paddy's Pond watershed generally had a higher mean level of phosphorus in 2008 than in Lake Utopia, which had an all time recorded mean value of less than 0.01 mg/L of phosphorus in 1989 (Hanson, 2003). It was also discovered that the mean levels of total nitrogen in the Paddy's Pond watershed in 2008 were similar to the yearly averages of total nitrogen in the Utopia Lake study (Hanson, 2003). Thus, it was quite possible that since Lake Utopia experienced nutrient loadings similar to that of Paddy's Pond, the environmental conditions in Paddy's Pond relating to nutrient content could have been enough for that period of time to trigger the major cyanobacteria bloom in that area.

Of note, cyanobacteria studies are still ongoing in Lake Utopia and the New Brunswick Department of Environment has developed an interest in the continued monitoring of the situation (NB Ministry of Environment, 2009).

6.0 Conclusions

After careful examination of the water and sediment quality data, it was possible that human activity in the upper reaches of the watershed could have been having an influence on some of the streams in the vicinity of Paddy's Pond, given the higher values of some parameters noted from the corresponding sample sites, although it was unclear as to whether any specific type of land development near Paddy's Pond was distinctly causing any problems. Some sites in particular were more likely to concentrate various constituents as well due to their shallow, low-flowing nature, which in turn was due to their proximity and relation to culverts, and so it was not easy to distinguish between what may have been an anthropogenic loading, and a natural accumulation resulting from the low volumes and poor drainage at those sites. However, it was very clear from the overall data analysis in *Section 4* that, of these sites, sites CB01 – CB03 and CB06 did consistently have water quality, and occasionally, sediment quality issues; thus, they could be regarded as direct pathways for the release of nutrients into Paddy's Pond. Sites CB01 – CB03 would particularly be considered pathways due to their close proximity to the water body. The water in site CB06 eventually runs into Paddy's Pond as a river so it too could be considered a more direct conduit for nutrients and contaminants into Paddy's Pond, although constituents flowing through the water at this site would be subjected to better aeration along their course than the water flowing from sites CB01 to CB03, thus potentially reducing their negative effects before reaching Paddy's Pond. No point source contamination was noted in Paddy's Pond itself.

There may have been another means of passage for nutrients into Paddy's Pond via the remote stream that flows out of Thomas Pond. This stream flows into the small reservoir called Western Pond and then enters Paddy's Pond a short distance downstream at site CB14. Thomas Pond (*CB07*), which was designated as a reference site and flows downstream to Paddy's Pond, tended to have a slightly higher, although not excessive nutrient and microcystin LR content (NL, 2008) than many of the sites sampled at the pond outlets, indicating there could be a possible impact from the farms located farther upstream.

Sites CB05 and CB14 in Paddy's Pond itself were occasionally flagged as well and it was noted that in general Paddy's Pond did have poorer water quality than any of the other large standing bodies of water in the watershed. This could have implications because it means that the less pristine water quality in Paddy's Pond could lend to more favorable conditions for cyanobacteria, especially since there were several other inflows of contaminated or enriched water into the pond as well.

The water and sediment at the pond outlets themselves were generally in a very acceptable state, ecologically, however site CB12 at Topsail Pond was often flagged as showing the most, although relatively low impact from development in its vicinity and upstream. Cochrane Pond and the stream that flowed out of it generally showed very good water quality considering the level and types of development near its northwest shoreline. This suggests that Cochrane Pond itself may not have been a nutrient-releasing reservoir to Paddy's Pond in 2008 and that the other streams flowing into Paddy's Pond were more important in terms of transferring nutrients to support a cyanobacteria bloom. It should, however, be noted that there were, although low, detectable amounts of microcystin LR in Cochrane Pond in 2007 (NL Department of Environment, 2007).

Overall, nutrient loadings from enriched water, particularly from phosphorus, entering Paddy's Pond combined with ideal environmental conditions certainly contributed to the large bloom reported in 2007. A smaller bloom occurred in Paddy's Pond in 2008 as well and may have occurred because of continued loadings from the surface drainage ditches, promoting the re-growth of some cyanobacteria cells that may have survived from 2007. The actual sources of the loadings were inconclusive, however, although it could be said that the bloom may have occurred because the watershed was at a theoretical "tipping point" of enrichment due to the increasing and cumulative effects of development in the area.

Additionally, according to a statement issued by the Canadian Hurricane Centre, a post-tropical storm, Chantal, passed though the area on August 1^{st} 2007 and delivered 96.6 mm of rain to the area. The storm was so severe that 43 mm of rain were reported to have fallen in St. John's and the surrounding area in one hour (Canadian Hurricane Centre, 2007). This may have had critical hydrological implications in that an extreme volume of water passed through the Paddy's Pond system in a very short period of time and may have caused an unusual flushing of nutrient enriched water and sediment from the side streams and from enriched land-based runoff into the primary areas of standing water in the watershed. The storm event combined with the types of land-use and the build-up of nutrients and minerals in the system could have been the primary trigger for the large bloom in 2007, and may have been responsible for its continued presence in 2008.

7.0 Recommendations

Due to the fact that this report consisted mainly of primary research and baseline data, extensive monitoring of all the sites sampled should continue in 2009. Moreover, in 2009 there should be a deeper look into the types of land-use within the watershed and a more in-depth examination of the sizes of individual operations and developments that are present. The proximity of individual developments and operations to water and the relative and potential effects of each on the aquatic environment in how they relate to cyanobacterial growth and eutrophication should be considered in order to better develop a high quality sampling scheme that will further narrow down possible major contributors to the conditions that led to the blooms. From this, it would be recommended that additional sites be added to the monitoring plan to better capture results that would indicate why there might be increased nutrient loadings in certain sections of the watershed. These new sites should be particularly focused in the general vicinity of Paddy's Pond, mainly upstream, since this is where the major inputs of nutrients identified in this report were located.

In addition to the above recommendations on the continued investigation of water quality within the Paddy's Pond drainage basin, it is further recommended that a public awareness campaign be developed. This campaign would ideally be directed towards related industry and to the public, and could be based on the establishment of proper buffer zones, controlling the release of nutrient-laden effluent into the environment, and on effective education relating to the occurrence of cyanobacteria and to the environmental effects of a severe bloom. Essentially, the more people are educated on the matter, the more likely people will take personal action and industry will likely further become corporate stewards of the environment, resulting in a much cleaner watershed and a minimal chance of a future cyanobacteria bloom.

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Appendix A

Data collected in the field for all sites on all sampling dates including the mean results.

Sweep	Site ID	Rain Event	GPS Latitude	GPS Longitude	Time	Date
1	CB01	Y (after 31.2 mm)	N 47' 28.057	W 052' 53.236	3:15 PM	6/3/2008
2	CB01	N	N 47' 28.057	W 052' 53.236	1:25 PM	7/8/2008
3	CB01	Y	N 47' 28.057	W 052' 53.236	1:30 PM	8/4/2008
4	CB01	N	N 47' 28.057	W 052' 53.236	1:50 PM	9/3/2008
5	CB01	N	N 47' 28.057	W 052' 53.236	12:30PM	10/2/2008
mean						
1	CB02	Y (after 31.2 mm)	N 47' 27.975	W 052' 53.281	12:20 PM	6/3/2008
2	CB02	N	N 47' 27.975	W 052' 53.281	12:20 PM	7/8/2008
3	CB02	Y	N 47' 27.975	W 052' 53.281	12:34 PM	8/4/2008
4	CB02	N	N 47' 27.975	W 052' 53.281	12:10 PM	9/3/2008
5	CB02	N	N 47' 27.975	W 052' 53.281	11:30 AM	10/2/2008
mean						
1	CB03	Y (after 31.2 mm)	N 47' 28.035	W 052' 53.196	4:25 PM	6/3/2008
2	CB03	N	N 47' 28.035	W 052' 53.196	12:35 PM	7/8/2008
3	CB03	Y	N 47' 28.035	W 052' 53.196	12:43 PM	8/4/2008
4	CB03	N	N 47' 28.035	W 052' 53.196	12:25 PM	9/3/2008
5	CB03	N	N 47' 28.035	W 052' 53.196	11:45 AM	10/2/2008
mean						
1	CB04	Y (after 31.2 mm)	N 47' 28.462	W 052' 52.575	4:38 PM	6/3/2008
2	CB04	N	N 47' 28.462	W 052' 52.575	12:45 PM	7/8/2008
3	CB04	Y	N 47' 28.462	W 052' 52.575	1:15 PM	8/4/2008
4	CB04	N	N 47' 28.462	W 052' 52.575	1:05 PM	9/3/2008
5	CB04	N	N 47' 28.462	W 052' 52.575	12:05 PM	10/2/2008
mean						
1	CB05	Y (after 31.2 mm)	N 47' 28.558	W 052' 52.556	4:05 PM	6/3/2008
2	CB05	N	N 47' 28.558	W 052' 52.556	1:00 PM	7/8/2008
3	CB05	Y	N 47' 28.558	W 052' 52.556	1:45 PM	8/4/2008
4	CB05	N	N 47' 28.558	W 052' 52.556	1:30 PM	9/3/2008
5	CB05	N	N 47' 28.558	W 052' 52.556	12:20 PM	10/2/2008
mean						

Sweep	Site ID	Rain Event	GPS Latitude	GPS Longitude	Time	Date
1	CB06	Y (after 31.2 mm)	N 47' 28.987	W 052' 52.232	5:30 PM	6/3/2008
2	CB06	N	N 47' 28.987	W 052' 52.232	1:40 PM	7/8/2008
3	CB06	Y	N 47' 28.987	W 052' 52.232	2:05 PM	8/4/2008
4	CB06	N	N 47' 28.987	W 052' 52.232	2:25 PM	9/3/2008
5	CB06	N	N 47' 28.987	W 052' 52.232	12:40 PM	10/2/2008
mean						
1	CB07	Y (after 31.2 mm)	N 47' 23.691	W 052' 54.976	11:55 AM	6/3/2008
2	CB07	N	N 47' 23.691	W 052' 54.976	10:57 AM	7/8/2008
3	CB07	Y	N 47' 23.691	W 052' 54.976	11:40 AM	8/4/2008
4	CB07	N	N 47' 23.691	W 052' 54.976	11:45 AM	9/3/2008
5	CB07	N	N 47' 23.691	W 052' 54.976	11:15 AM	10/2/2008
mean						
1	CB08	Y (after 31.2 mm)	N 47' 28.418	W 052' 52.328	4:52 PM	6/3/2008
2	CB08	N	N 47' 28.418	W 052' 52.328	12:05 PM	7/8/2008
3	CB08	Y	N 47' 28.418	W 052' 52.328	12:55 PM	8/4/2008
4	CB08	N	N 47' 28.418	W 052' 52.328	12:40 PM	9/3/2008
5	CB08	N	N 47' 28.418	W 052' 52.328	11:55 AM	10/2/2008
mean						
1	CB09	N	N 47' 29.313	W 052' 53.634	12:30 PM	**6/4/2008**
2	CB09	N	N 47' 29.313	W 052' 53.634	2:52 PM	7/8/2008
3	CB09	Y	N 47' 29.313	W 052' 53.634	12:10 PM	**8/5/2008**
4	CB09	N	N 47' 29.313	W 052' 53.634	3:50 PM	9/3/2008
5	CB09	N	N 47' 29.313	W 052' 53.634	2:30 PM	10/2/2008
mean						
1	CB10	N	N 47' 30.079	W 052' 53.794	1:00 PM	**6/4/2008**
2	CB10	N	N 47' 30.079	W 052' 53.794	3:15 PM	7/8/2008
3	CB10	Y	N 47' 30.079	W 052' 53.794	12:40 PM	**8/5/2008**
4	CB10	N	N 47' 30.079	W 052' 53.794	4:20 PM	9/3/2008
5	CB10	N	N 47' 30.079	W 052' 53.794	3:00 PM	10/2/2008
mean						
1	CB11	N	N 47' 30.856	W 052' 53.918	11:58 AM	**6/4/2008**
2	CB11	N	N 47' 30.856	W 052' 53.918	2:10 PM	7/8/2008
3	CB11	Y	N 47' 30.856	W 052' 53.918	2:30 PM	8/4/2008
4	CB11	N	N 47' 30.856	W 052' 53.918	3:00 PM	9/3/2008
5	CB11	N	N 47' 30.856	W 052' 53.918	1:50 PM	10/2/2008
mean						

Sweep	Site ID	Rain Event	GPS Latitude	GPS Longitude	Time	Date
1	CB12	N	N 47' 31.465	W 052' 54.204	11:40 AM	**6/4/2008**
2	CB12	N	N 47' 31.465	W 052' 54.204	2:25 PM	7/8/2008
3	CB12	Y	N 47' 31.465	W 052' 54.204	2:50 PM	8/4/2008
4	CB12	N	N 47' 31.465	W 052' 54.204	3:25 PM	9/3/2008
5	CB12	N	N 47' 31.465	W 052' 54.204	2:05 PM	10/2/2008
mean						
			UTM	**UTM**		
1	CB14	Y (after 31.2 mm)	E 0356726	N 5259007	1:00 PM	6/3/2008
3	CB14	Y	E 0356726	N 5259007	3:30 PM	**8/6/2008**
1	CB15	Y (after 31.2 mm)	E 0358157	N 5259628	1:15 PM	6/3/2008
3	CB15	Y	E 0358157	N 5259628	4:00 PM	**8/6/2008**

Sweep	Site ID	pH	Conductivity (mS/cm)	DO (mg/L)	% DO	Temperature ('C)
1	CB01	5.80	0.100	8.15	77.6	14.19
2	CB01	5.74	**0.359**	7.70	77.2	15.65
3	CB01	5.76	0.215	**6.18**	**58.8**	13.42
4	CB01	6.02	0.203	7.18	73.8	16.62
5	CB01	5.97	0.189	8.62	79.9	12.28
mean		5.858	0.2132	7.566	73.46	14.432
1	CB02	**5.17**	0.097	9.43	92.3	14.99
2	CB02	**5.44**	**0.386**	**2.78**	**23.0**	**11.33**
3	CB02	**5.07**	0.119	**6.53**	**62.7**	14.36
4	CB02	**5.53**	**0.457**	**4.89**	**50.2**	12.30
5	CB02	**5.23**	0.164	6.87	**64.9**	13.21
mean		5.288	0.2446	6.1	58.62	13.238
1	CB03	5.65	0.046	9.82	96.7	14.63
2	CB03	5.63	0.105	8.05	84.9	17.98
3	CB03	**5.49**	0.073	**6.03**	/	13.58
4	CB03	**5.51**	0.093	6.63	68.5	16.82
5	CB03	5.79	0.106	8.18	76.1	12.67
mean		5.614	0.0845	7.742	81.55	15.136
1	CB04	5.99	0.028	9.16	92.0	15.64
2	CB04	6.06	0.032	7.85	89.4	21.80
3	CB04	6.43	0.033	8.41	85.3	16.42
4	CB04	6.07	0.028	8.42	92.2	19.70
5	CB04	6.13	0.033	9.38	93.6	15.21
mean		6.136	0.0308	8.644	90.5	17.754

Sweep	Site ID	pH	Conductivity (mS/cm)	DO (mg/L)
1	CB05	6.15	0.082	10.01
2	CB05	6.63	0.120	9.72
3	CB05	6.70	0.096	7.68
4	CB05	6.17	0.139	9.07
5	CB05	6.46	0.094	9.96
mean		6.422	0.1062	9.288
1	CB06	5.97	0.128	9.51
2	CB06	6.46	0.158	8.81
3	CB06	6.75	0.189	8.48
4	CB06	6.52	0.143	8.48
5	CB06	6.58	0.172	9.91
mean		6.456	0.158	9.038
1	CB07	**5.49**	0.024	10.27
2	CB07	5.95	0.029	8.93
3	CB07	5.84	0.032	7.94
4	CB07	5.73	0.031	8.56
5	CB07	5.81	0.034	9.71
mean		5.764	0.03006	9.082
1	CB08	5.91	0.029	9.85
2	CB08	6.57	0.028	8.89
3	CB08	6.76	0.029	**6.69**
4	CB08	6.02	0.027	9.06
5	CB08	6.34	0.031	9.60
mean		6.32	0.0288	8.818
1	CB09	6.07	0.056	10.29
2	CB09	6.64	0.058	9.43
3	CB09	6.47	0.066	7.40
4	CB09	6.36	0.058	9.03
5	CB09	6.40	0.058	10.00
mean		6.388	0.0592	9.23
1	CB10	6.31	0.060	10.20
2	CB10	6.74	0.059	8.88
3	CB10	6.63	0.067	7.82
4	CB10	6.59	0.059	8.36
5	CB10	6.63	0.059	9.95
mean		6.58	0.0608	9.042

Sweep	Site ID	pH	Conductivity (mS/cm)	DO (mg/L)
1	CB11	6.39	0.078	10.22
2	CB11	6.62	0.080	8.90
3	CB11	7.21	0.091	8.16
4	CB11	6.39	0.075	8.92
5	CB11	6.64	0.074	10.61
mean		6.65	0.0796	9.362
1	CB12	6.18	0.083	10.53
2	CB12	6.50	0.088	9.02
3	CB12	6.73	0.094	7.55
4	CB12	6.30	0.079	9.04
5	CB12	6.57	0.079	9.98
mean		6.456	0.0846	9.224
1	CB14	5.57	0.026	10.45
3	CB14	6.25	0.044	8.44
mean		5.91	0.035	9.445
1	CB15	5.92	0.068	9.85
3	CB15	6.16	0.072	**6.87**
mean		6.04	0.07	8.36

Sweep	Site ID	Salinity (PSU)	TDS (g/L)
1	CB01	0.05	0.1
2	CB01	0.18	0.2
3	CB01	0.10	0.1
4	CB01	\	0.1578
5	CB01	0.09	0.1
mean		0.105	0.13156
1	CB02	0.05	0.1
2	CB02	0.18	0.3
3	CB02	0.06	0.1
4	CB02	\	0.2931
5	CB02	0.08	0.1
mean		0.0925	0.17862

Sweep	Site ID	Salinity (PSU)	TDS (g/L)
1	CB03	0.02	0.0
2	CB03	0.05	0.1
3	CB03	0.04	0.1
4	CB03	\	0.0589
5	CB03	0.05	0.1
mean		0.04	0.07178
1	CB04	0.02	0.0
2	CB04	0.02	0.0
3	CB04	0.02	0.0
4	CB04	\	0.0184
5	CB04	0.02	0.0
mean		0.02	0.00368
1	CB05	0.04	0.1
2	CB05	0.06	0.1
3	CB05	0.05	0.1
4	CB05	\	0.0900
5	CB05	0.05	0.1
mean		0.05	0.098
1	CB06	0.06	0.1
2	CB06	0.08	0.1
3	CB06	0.09	0.1
4	CB06	\	0.0910
5	CB06	0.08	0.1
mean		0.0775	0.0982
1	CB07	0.01	0.0
2	CB07	0.02	0.0
3	CB07	0.02	0.0
4	CB07	\	0.0199
5	CB07	0.02	0.0
mean		0.0175	0.00398
1	CB08	0.02	0.0
2	CB08	0.02	0.0
3	CB08	0.02	0.0
4	CB08	\	0.0176
5	CB08	0.02	0.0
mean		0.02	0.00352

Sweep	Site ID	Salinity (PSU)	TDS (g/L)
1	CB09	0.03	0.0
2	CB09	0.03	0.0
3	CB09	0.03	0.0
4	CB09	\	0.0370
5	CB09	0.03	0.0
mean		0.03	0.0074
1	CB10	0.03	0.0
2	CB10	0.03	0.0
3	CB10	0.04	0.0
4	CB10	\	0.0380
5	CB10	0.03	0.0
mean		0.0325	0.0076
1	CB11	0.04	0.1
2	CB11	0.04	0.1
3	CB11	0.05	0.1
4	CB11	\	0.0480
5	CB11	0.04	0.1
mean		0.0425	0.0896
1	CB12	0.04	0.1
2	CB12	0.05	0.1
3	CB12	0.05	0.1
4	CB12	\	0.0500
5	CB12	0.04	0.1
mean		0.045	0.09
1	CB14	0.02	0.0
3	CB14	0.02	0.0
mean		0.02	0
1	CB15	0.03	0.0
3	CB15	0.04	0.1
mean		0.035	0.05

Appendix B

Data collected from water samples sent to the lab for all sites on all sampling dates including the mean results.

Sweep	Site ID	Date	Colour Apparent	Chloride (mg/L)	Sulphate (mg/L)
1	CB01	6/3/2008	**142**	26.50	2.05
2	CB01	7/8/2008	**175**	68.05	3.79
3	CB01	8/4/2008	**201**	38.41	2.36
4	CB01	9/3/2008	**167**	36.54	2.23
5	CB01	10/2/2008	**107**	49.10	2.75
	mean		158.4	43.72	2.636
1	CB02	6/3/2008	**114**	27.69	1.75
2	CB02	7/8/2008	**175**	50.09	1.78
3	CB02	8/4/2008	**181**	31.00	1.05
4	CB02	9/3/2008	**159**	42.74	1.38
5	CB02	10/2/2008	**119**	44.40	1.65
	mean		149.6	39.184	1.522
1	***CB03***	***6/3/2008***	***138***	*9.11*	*0.98*
1	**CB03**	6/3/2008	**136**	9.72	1.08
2	CB03	7/8/2008	**199**	23.82	1.22
3	***CB03***	***8/4/2008***	***212***	*13.53*	*0.96*
3	**CB03**	8/4/2008	**211**	13.80	0.96
4	CB03	9/3/2008	**165**	19.01	1.09
5	CB03	10/2/2008	**113**	22.61	1.32
	mean		167.7142857	15.94285714	1.087142857
1	CB04	6/3/2008	21	4.34	1.49
2	CB04	7/8/2008	16	4.44	1.56
3	CB04	8/4/2008	16	4.76	1.54
4	CB04	9/3/2008	14	4.61	1.56
5	**CB04**	10/2/2008	15	4.82	1.55
5	***CB04***	***10/2/2008***	*14*	*4.81*	*1.60*
	mean		16	4.63	1.55
1	CB05	6/3/2008	\	23.05	2.37
2	CB05	7/8/2008	21	21.58	2.25
3	CB05	8/4/2008	17	15.33	1.91
4	CB05	9/3/2008	28	30.78	2.82
5	CB05	10/2/2008	21	15.54	1.94
	mean		21.75	21.256	2.258

Sweep	Site ID	Date	Colour Apparent	Chloride (mg/L)	Sulphate (mg/L)
1	CB06	6/3/2008	43	46.95	3.02
2	CB06	7/8/2008	76	41.37	1.28
3	CB06	8/4/2008	51	78.23	2.72
4	**CB06**	9/3/2008	59	33.45	1.04
4	***CB06***	***9/3/2008***	*64*	*34.04*	*1.07*
5	CB06	10/2/2008	41	48.85	1.91
	mean		55.66666667	47.14833333	1.84
1	CB07	6/3/2008	42	4.12	1.05
2	**CB07**	7/8/2008	52	4.69	1.06
2	***CB07***	***7/8/2008***	52	4.7	1.04
3	CB07	8/4/2008	61	5.00	1.05
4	CB07	9/3/2008	79	5.40	1.02
5	CB07	10/2/2008	87	5.68	1.02
	mean		62.16666667	4.931666667	1.04
1	CB08	6/3/2008	25	3.94	1.44
2	CB08	7/8/2008	18	4.23	1.56
3	CB08	8/4/2008	20	4.13	1.51
4	CB08	9/3/2008	18	4.57	1.59
5	CB08	10/2/2008	15	4.78	1.63
	mean		19.2	4.33	1.546
1	CB09	**6/4/2008**	26	14.22	1.88
2	**CB09**	7/8/2008	25	12.79	1.79
2	***CB09***	***7/8/2008***			
3	CB09	**8/5/2008**	21	12.53	1.78
4	CB09	9/3/2008	24	13.10	1.81
5	CB09	10/2/2008	25	12.71	1.80
	mean		24.2	13.07	1.812
1	CB10	**6/4/2008**	22	15.52	2.12
2	CB10	7/8/2008	24	13.41	2.11
3	CB10	**8/5/2008**	14	12.74	2.21
4	CB10	9/3/2008	17	13.29	2.00
5	CB10	10/2/2008	17	12.91	1.96
	mean		18.8	13.574	2.08

Sweep	Site ID	Date	Colour Apparent	Chloride (mg/L)	Sulphate (mg/L)
1	CB11	**6/4/2008**	22	20.89	2.72
2	CB11	7/8/2008	21	18.74	2.57
3	CB11	8/4/2008	15	18.56	2.55
4	CB11	9/3/2008	14	17.01	2.46
5	CB11	10/2/2008	13	16.57	2.36
	mean		17	18.354	2.532
1	CB12	**6/4/2008**	23	23.21	2.89
2	CB12	7/8/2008	17	21.12	2.76
3	CB12	8/4/2008	13	19.20	2.60
4	CB12	9/3/2008	13	18.28	2.59
5	CB12	10/2/2008	12	17.84	2.48
	mean		15.6	19.93	2.664
1	CB14	6/3/2008	45	4.73	1.10
3	CB14	**8/6/2008**	66	7.08	1.20
	mean		55.5	5.905	1.15
1	CB15	6/3/2008	24	17.59	2.09
3	CB15	**8/6/2008**	17	14.13	1.87
	mean		20.5	15.86	1.98

Sweep	Site ID	Nitrate-Nitrogen (mg/L)	Tot Inorg Carbon (mg/L)	Tot Org Carbon (mg/L)	Ammonia Nitrogen (mg/L)
1	CB01	**0.02**	**1.0**	**15.5**	**0.015**
2	CB01	**0.03**	\	**19.1**	**0.025**
3	CB01	**0.05**	1.8	**23.7**	**0.067**
4	CB01	**0.03**	Depleted	**18.5**	**0.019**
5	CB01	<0.02	1.5	**12.4**	**0.031**
mean		0.028	1.433333333	17.84	0.0314
1	CB02	<0.02	<0.5	**13.7**	0.005
2	CB02	<0.02	\	**21.9**	0.005
3	CB02	<0.02	0.5	**24.0**	**0.022**
4	CB02	<0.02	<0.5	**21.1**	**0.019**
5	CB02	<0.02	<0.5	**15.8**	0.011
mean		<0.02	0.3125	19.3	0.0124

Sweep	Site ID	Nitrate-Nitrogen (mg/L)	Tot Inorg Carbon (mg/L)	Tot Org Carbon (mg/L)	Ammonia Nitrogen (mg/L)
1	***CB03***	***0.01***	*<0.5*	***15.5***	*0.008*
1	**CB03**	**0.01**	**1.4**	**15.6**	**0.014**
2	CB03	**0.03**	\	**21.9**	**0.017**
3	***CB03***	***0.05***	*1.3*	***24.9***	\
3	**CB03**	**0.05**	1.4	**25.2**	**0.057**
4	CB03	**0.02**	Depleted	**19.1**	**0.017**
5	CB03	<0.02	1.3	6.7	0.006
mean		0.025714286	1.13	18.41428571	0.0216
1	CB04	**0.03**	0.8	5.4	**0.021**
2	CB04	**0.04**	\	4.8	**0.065**
3	CB04	**0.03**	1.1	5.9	**0.088**
4	CB04	<0.02	0.5	4.8	**0.036**
5	**CB04**	<0.02	0.7	4.5	\
5	***CB04***	*<0.02*	*0.7*	*4.4*	***0.022***
mean		0.021666667	0.76	4.966666667	0.0464
1	CB05	<0.02	<0.5	7.7	<0.002
2	CB05	<0.02	\	4.9	<0.002
3	CB05	<0.02	0.8	5.3	**0.013**
4	CB05	<0.02	1.0	6.3	0.008
5	CB05	<0.02	<0.5	4.6	0.005
mean		<0.02	0.575	5.76	0.0056
1	CB06	<0.02	0.5	8.1	<0.002
2	CB06	**0.01**	\	**12.4**	0.002
3	CB06	<0.02	1.5	12.2	**0.023**
4	**CB06**	<0.02	1.5	11.3	**0.014**
4	***CB06***	*<0.02*	*1.5*	*11.3*	\
5	CB06	<0.02	1.3	6.7	0.006
mean		0.01	1.26	10.33333333	0.0092
1	CB07	<0.02	<0.5	6.5	0.007
2	**CB07**	<0.02	\	7.8	<0.002
2	***CB07***	<0.02	\		
3	CB07	<0.02	<0.5	9.3	**0.035**
4	CB07	<0.02	<0.5	10.5	**0.014**
5	CB07	<0.02	<0.5	10.7	**0.045**
mean		<0.02	<0.5	8.96	0.0204

Sweep	Site ID	Nitrate-Nitrogen (mg/L)	Tot Inorg Carbon (mg/L)	Tot Org Carbon (mg/L)	Ammonia Nitrogen (mg/L)
1	CB08	<0.02	<0.5	5.1	0.005
2	CB08	<0.02	\	4.7	<0.002
3	CB08	<0.02	0.7	5.5	**0.021**
4	CB08	<0.02	0.5	4.9	0.006
5	CB08	<0.02	<0.5	4.5	0.008
mean		<0.02	0.425	4.94	0.0082
1	CB09	<0.02	<0.5	5.0	<0.002
2	**CB09**	<0.02	\	5.2	<0.002
2	***CB09***		\	**TC*	*<0.002*
3	CB09	<0.02	1.1	5.2	**0.018**
4	CB09	<0.02	<0.5R	5.0	0.006
5	CB09	<0.02	<0.5	4.8	0.003
mean		<0.02	0.4625	5.04	0.005
1	CB10	<0.02	0.6	4.7	<0.002
2	CB10	<0.02	\	4.8	<0.002
3	CB10	<0.02	1.1	5.2	**0.018**
4	CB10	<0.02	0.7R	4.4	0.004
5	CB10	<0.02	0.6	4.3	**0.012**
mean		<0.02	0.75	4.68	0.0072
1	CB11	<0.02	0.5	4.5	**0.015**
2	CB11	<0.02	\	4.6	<0.002
3	CB11	<0.02	0.9	4.7	**0.019**
4	CB11	<0.02	1.0R	4.3	0.009
5	CB11	<0.02	0.7	4.2	0.012
mean		<0.02	0.775	4.46	0.0112
1	CB12	<0.02	0.5	4.5	0.004
2	CB12	<0.02	\	4.4	<0.002
3	CB12	<0.02	0.9	4.6	**0.025**
4	CB12	<0.02	1.0	4.0	<0.002
5	CB12	<0.02	0.9	4.5	0.008
mean		<0.02	0.825	4.4	0.0078

Sweep	Site ID	Nitrate-Nitrogen (mg/L)	Tot Inorg Carbon (mg/L)	Tot Org Carbon (mg/L)	Ammonia Nitrogen (mg/L)
1	CB14	<0.02	<0.5	6.3	**0.012**
3	CB14	<0.02	<0.05	9.8	**0.041**
mean		0.01	0.1375	8.05	0.0265
1	CB15	<0.02	<0.5	4.8	0.009
3	CB15	<0.02	0.9	5.2	**0.018**
mean		<0.02	0.575	5	0.0135

Sweep	Site ID	Tot Nitrogen (mg/L)	Gran Alkalinity (mg/L)	TSS (mg/L)	Turbidity (NTU)
1	CB01	**0.61R**	5.45	3.1	\
2	CB01	0.43	8.51	\	\
3	CB01	**0.47**	7.09	5.6	2.9
4	CB01	**0.54**	7.80	4.1	4.9
5	CB01	**0.57**	8.08	4.1	2.5
mean		0.524	7.386	4.225	3.433333333
1	CB02	0.34R	2.00	5.1	\
2	CB02	0.28	3.14	\	\
3	CB02	0.27	2.75	5.0	0.9
4	CB02	0.38	2.77	7.5	1.5
5	CB02	0.37	8.25	2.1	1.0
mean		0.328	3.782	4.925	1.133333333
1	***CB03***	***0.51R***	*5.05*	*3.1*	\
1	**CB03**	**0.59**	5.63	2.1	\
2	CB03	0.40	7.44	\	\
3	***CB03***	\	*6.48*	*2.9*	2.1
3	**CB03**	**0.48**	6.61	8.3	2.0
4	CB03	**0.55**	7.29	<2.0	1.4
5	CB03	**0.48**	2.70	3.1	1.4
mean		0.492	5.863	3.416666667	1.725
1	CB04	0.31R	2.81	1.0	\
2	CB04	0.28	3.56	\	\
3	CB04	0.30	4.22	2.9	1.3
4	CB04	0.29	2.97	<2.0	0.6
5	**CB04**	\	4.17	2.1	0.6
5	***CB04***	*0.29*	*7.20*	*2.1*	*0.5*
mean		0.294	4.155	1.82	0.75

Sweep	Site ID	Tot Nitrogen (mg/L)	Gran Alkalinity (mg/L)	TSS (mg/L)	Turbidity (NTU)
1	CB05	0.20	Depleted	3.1	\
2	CB05	0.22	3.25	\	\
3	CB05	0.20	3.35	2.7	0.5
4	CB05	**0.56**	4.86	5.3	2.1
5	CB05	0.24	3.24	<2.0	0.6
mean		0.284	3.675	3.025	1.066666667
1	CB06	0.24R	2.30	2.1	\
2	CB06	0.31	7.64	\	\
3	CB06	0.32	5.87	14.3	11.0
4	**CB06**	0.33	7.62	5.2	3.6
4	***CB06***	\	*7.8*	*5.4*	*4.1*
5	CB06	0.27	2.88	2.2	1.6
mean		0.294	5.685	5.84	5.075
1	CB07	0.23R	1.23	1.0	\
2	**CB07**	0.42	2.08	\	\
2	***CB07***		2.2	\	\
3	CB07	0.16	2.69	2.8	1.6
4	CB07	0.36	**3.00**	2.1	1.1
5	CB07	0.43	6.14	4.3	1.4
mean		0.32	2.89	2.55	1.366666667
1	CB08	0.28	2.19	3.0	\
2	CB08	0.24	2.61	\	\
3	CB08	0.24	2.52	<2.0	0.6
4	CB08	0.28	2.83	2.2	0.6
5	CB08	0.27	3.23	<2.0	0.4
mean		0.262	2.676	1.8	0.533333333
1	CB09	0.20	1.96	2.1	\
2	**CB09**	0.27	2.78	\	\
2	***CB09***	*0.29*		\	\
3	CB09	**0.61**	3.23	<2.0	1.1
4	CB09	0.24	2.89	<2.0	0.6
5	CB09	0.22	2.78	2.2	0.8
mean		0.305	2.728	1.575	0.833333333

Sweep	Site ID	Tot Nitrogen (mg/L)	Gran Alkalinity (mg/L)	TSS (mg/L)	Turbidity (NTU)
1	CB10	0.21R	2.22	1.0	\
2	CB10	0.17	2.99	\	\
3	CB10	0.19	3.66	3.1	1.0
4	CB10	0.24	3.44	2.1	0.6
5	CB10	0.26	2.82	<2.0	0.4
mean		0.214	3.026	1.8	0.666666667
1	CB11	0.20R	2.52	5.2	\
2	CB11	0.17	3.28	\	\
3	CB11	0.16	3.55	2.1	0.6
4	CB11	0.23	3.86	<2.0	0.4
5	CB11	0.25	3.49	2.1	0.5
mean		0.202	3.34	2.6	0.5
1	CB12	0.20R	2.60	<2.0	\
2	CB12	0.12	3.16	\	\
3	CB12	0.15	3.45	<2.0	0.5
4	CB12	0.25R	4.16	3.3	0.8
5	CB12	0.23	3.92	<2.0	0.7
mean		0.19	3.458	1.575	0.666666667
1	CB14	0.23	1.26	2.1	\
3	CB14	0.38	2.62	<2.0	1.8
mean		0.305	1.94	1.55	1.8
1	CB15	0.21	2.29	2.0	\
3	CB15	0.23	2.96	4.5	0.5
mean		0.22	2.625	3.25	0.5

Sweep	Site ID	Al (ug/L)	Ba (ug/L)	Be (ug/L)	Cd (ug/L)	Cr (ug/L)	Co (ug/L)
1	CB01	\	\	\	\	\	\
2	CB01	\	\	\	\	\	\
3	CB01	**387**	**5**	<1	<3	<2	<5
4	CB01	\	\	\	\	\	\
5	CB01	\	\	\	\	\	\
mean		387	5	<1	<3	<2	<5
1	CB02	\	\	\	\	\	\
2	CB02	\	\	\	\	\	\
3	CB02	**426**	**4**	<1	<3	<2	<5
4	CB02						
5	CB02	\	\	\	\	\	\
mean		426	4	<1	<3	<2	<5
1	***CB03***	\	\	\	\	\	\
1	**CB03**	\	\	\	\	\	\
2	CB03	\	\	\	\	\	\
3	***CB03***	\	\	\	\	\	\
3	**CB03**	**366**	**3**	<1	<3	<2	<5
4	CB03	\	\	\	\	\	\
5	CB03	\	\	\	\	\	\
mean		366	3	<1	<3	<2	<5
1	CB04	\	\	\	\	\	\
2	CB04	\	\	\	\	\	\
3	CB04	82	2	<1	<3	<2	<5
4	CB04	\	\	\	\	\	\
5	**CB04**	\	\	\	\	\	\
5	***CB04***	\	\	\	\	\	\
mean		82	2	<1	<3	<2	<5
1	CB05	\	\	\	\	\	\
2	CB05	\	\	\	\	\	\
3	CB05	53	2	<1	<3	<2	<5
4	CB05	\	\	\	\	\	\
5	CB05	\	\	\	\	\	\
mean		53	2	<1	<3	<2	<5

Sweep	Site ID	Al (ug/L)	Ba (ug/L)	Be (ug/L)	Cd (ug/L)	Cr (ug/L)	Co (ug/L)
1	CB06	\	\	\	\	\	\
2	CB06	\	\	\	\	\	\
3	CB06	**262**	**8**	<1	<3	<2	<5
4	**CB06**						
4	***CB06***						
5	CB06	\	\	\	\	\	\
mean		262	8	<1	<3	<2	<5
1	CB07	\	\	\	\	\	\
2	**CB07**	\	\	\	\	\	\
2	***CB07***	\	\	\	\	\	\
3	CB07	**158**	2	<1	<3	<2	<5
4	CB07	\	\	\	\	\	\
5	CB07	\	\	\	\	\	\
mean		158	2	<1	<3	<2	<5
1	CB08	\	\	\	\	\	\
2	CB08	\	\	\	\	\	\
3	CB08	43	<1	<1	<3	<2	<5
4	CB08	\	\	\	\	\	\
5	CB08	\	\	\	\	\	\
mean		43	<1	<1	<3	<2	<5
1	CB09	\	\	\	\	\	\
2	**CB09**	\	\	\	\	\	\
2	***CB09***	\	\	\	\	\	\
3	CB09	57	2	<1	<3	<2	<5
4	CB09	\	\	\	\	\	\
5	CB09	\	\	\	\	\	\
mean		57	2	<1	<3	<2	<5
1	CB10	\	\	\	\	\	\
2	CB10	\	\	\	\	\	\
3	CB10	48	2	<1	<3	<2	<5
4	CB10	\	\	\	\	\	\
5	CB10	\	\	\	\	\	\
mean		48	2	<1	<3	<2	<5

Sweep	Site ID	Al (ug/L)	Ba (ug/L)	Be (ug/L)	Cd (ug/L)	Cr (ug/L)	Co (ug/L)
1	CB11	\	\	\	\	\	\
2	CB11	\	\	\	\	\	\
3	CB11	47	2	<1	<3	<2	<5
4	CB11	\	\	\	\	\	\
5	CB11	\	\	\	\	\	\
mean		47	2	<1	<3	<2	<5
1	CB12	\	\	\	\	\	\
2	CB12	\	\	\	\	\	\
3	CB12	47	3	<1	<3	<2	<5
4	CB12	\	\	\	\	\	\
5	CB12	\	\	\	\	\	\
mean		47	3	<1	<3	<2	<5
1	CB14	\	\	\	\	\	\
3	CB14	**187**	3	<1	<3	<2	<5
mean		187	3	<1	<3	<2	<5
1	CB15	\	\	\	\	\	\
3	CB15	61	2	<1	<3	<2	<5
mean		61	2	<1	<3	<2	<5

Sweep	Site ID	Cu (ug/L)	Fe (mg/L)	Pb (ug/L)	Mn (ug/L)	Mo (ug/L)	Ni (ug/L)
1	CB01	\	\	\	\	\	\
2	CB01	\	\	\	\	\	\
3	CB01	<2	**1.67**	<10	128	<5	<6
4	CB01	\	\	\	\	\	\
5	CB01	\	\	\	\	\	\
mean		<2	1.67	<10	128	<5	<6
1	CB02	\	\	\	\	\	\
2	CB02	\	\	\	\	\	\
3	CB02	<2	**1.48**	<10	96	<5	<6
4	CB02						
5	CB02	\	\	\	\	\	\
mean		<2	1.48	<10	96	<5	<6

Sweep	Site ID	Cu (ug/L)	Fe (mg/L)	Pb (ug/L)	Mn (ug/L)	Mo (ug/L)	Ni (ug/L)
1	***CB03***	\	\	\	\	\	\
1	**CB03**	\	\	\	\	\	\
2	CB03	\	\	\	\	\	\
3	***CB03***	\	\	\	\	\	\
3	**CB03**	<2	**1.51**	<10	93	<5	<6
4	CB03	\	\	\	\	\	\
5	CB03	\	\	\	\	\	\
mean		<2	1.51	<10	93	<5	<6
1	CB04	\	\	\	\	\	\
2	CB04	\	\	\	\	\	\
3	CB04	<2	0.46	<10	219	<5	<6
4	CB04	\	\	\	\	\	\
5	**CB04**	\	\	\	\	\	\
5	***CB04***	\	\	\	\	\	\
mean		<2	0.46	<10	219	<5	<6
1	CB05	\	\	\	\	\	\
2	CB05	\	\	\	\	\	\
3	CB05	<2	0.16	<10	74	<5	<6
4	CB05	\	\	\	\	\	\
5	CB05	\	\	\	\	\	\
mean		<2	0.16	<10	74	<5	<6
1	CB06	\	\	\	\	\	\
2	CB06	\	\	\	\	\	\
3	CB06	<2	**3.82**	<10	**836**	<5	<6
4	**CB06**						
4	***CB06***						
5	CB06	\	\	\	\	\	\
mean		<2	3.82	<10	836	<5	<6
1	CB07	\	\	\	\	\	\
2	**CB07**	\	\	\	\	\	\
2	***CB07***	\	\	\	\	\	\
3	CB07	<2	**0.94**	<10	123	<5	<6
4	CB07	\	\	\	\	\	\
5	CB07	\	\	\	\	\	\
mean		<2	0.94	<10	123	<5	<6

Sweep	Site ID	Cu (ug/L)	Fe (mg/L)	Pb (ug/L)	Mn (ug/L)	Mo (ug/L)	Ni (ug/L)
1	CB08	\	\	\	\	\	\
2	CB08	\	\	\	\	\	\
3	CB08	<2	0.08	<10	12	<5	<6
4	CB08	\	\	\	\	\	\
5	CB08	\	\	\	\	\	\
mean		<2	0.08	<10	12	<5	<6
1	CB09	\	\	\	\	\	\
2	**CB09**	\	\	\	\	\	\
2	***CB09***	\	\	\	\	\	\
3	CB09	<2	0.17	<10	230	<5	<6
4	CB09	\	\	\	\	\	\
5	CB09	\	\	\	\	\	\
mean		<2	0.17	<10	230	<5	<6
1	CB10	\	\	\	\	\	\
2	CB10	\	\	\	\	\	\
3	CB10	<2	0.09R	<10	76	<5	<6
4	CB10	\	\	\	\	\	\
5	CB10	\	\	\	\	\	\
mean		<2	0.09R	<10	76	<5	<6
1	CB11	\	\	\	\	\	\
2	CB11	\	\	\	\	\	\
3	CB11	<2	0.07R	<10	56	<5	<6
4	CB11	\	\	\	\	\	\
5	CB11	\	\	\	\	\	\
mean		<2	0.07R	<10	56	<5	<6
1	CB12	\	\	\	\	\	\
2	CB12	\	\	\	\	\	\
3	CB12	<2	0.08R	<10	68	<5	<6
4	CB12	\	\	\	\	\	\
5	CB12	\	\	\	\	\	\
mean		<2	0.08R	<10	68	<5	<6

Sweep	Site ID	Cu (ug/L)	Fe (mg/L)	Pb (ug/L)	Mn (ug/L)	Mo (ug/L)	Ni (ug/L)
1	CB14	\	\	\	\	\	\
3	CB14	<2	**1.03**	<10	117	<5	<6
mean		<2	1.03	<10	117	<5	<6
1	CB15	\	\	\	\	\	\
3	CB15	<2	0.16	<10	68	<5	<6
mean		<2	0.16	<10	68	<5	<6

Sweep	Site ID	Ag (ug/L)	Sr (ug/L)	Ti (ug/L)	V (ug/L)	Zn (ug/L)	Na (mg/L)
1	CB01	\	\	\	\	\	\
2	CB01	\	\	\	\	\	\
3	CB01	<2	16	6	<4	6	22.26
4	CB01	\	\	\	\	\	\
5	CB01	\	\	\	\	\	\
mean		<2	16	6	<4	6	22.26
1	CB02	\	\	\	\	\	\
2	CB02	\	\	\	\	\	\
3	CB02	<2	10	5	<4	3	17.7
4	CB02						
5	CB02	\	\	\	\	\	\
mean		<2	10	5	<4	3	17.7
1	***CB03***	\	\	\	\	\	\
1	**CB03**	\	\	\	\	\	\
2	CB03	\	\	\	\	\	\
3	***CB03***	\	\	\	\	\	\
3	**CB03**	<2	12	5	<4	3	8.62
4	CB03	\	\	\	\	\	\
5	CB03	\	\	\	\	\	\
mean		<2	12	5	<4	3	8.62
1	CB04	\	\	\	\	\	\
2	CB04	\	\	\	\	\	\
3	CB04	<2	5	<1	<4	<2	3.36
4	CB04	\	\	\	\	\	\
5	**CB04**	\	\	\	\	\	\
5	***CB04***	\	\	\	\	\	\
mean		<2	5	<1	<4	<2	3.36

Sweep	Site ID	Ag (ug/L)	Sr (ug/L)	Ti (ug/L)	V (ug/L)	Zn (ug/L)	Na (mg/L)
1	CB05	\	\	\	\	\	\
2	CB05	\	\	\	\	\	\
3	CB05	<2	6	<1	<4	<2	9.58
4	CB05	\	\	\	\	\	\
5	CB05	\	\	\	\	\	\
mean		<2	6	<1	<4	<2	9.58
1	CB06	\	\	\	\	\	\
2	CB06	\	\	\	\	\	\
3	CB06	<2	14	3	<4	<2	42.96
4	**CB06**						
4	***CB06***						
5	CB06	\	\	\	\	\	\
mean		<2	14	3	<4	<2	42.96
1	CB07	\	\	\	\	\	\
2	**CB07**	\	\	\	\	\	\
2	***CB07***	\	\	\	\	\	\
3	CB07	<2	4	2	<4	<2	3.62
4	CB07	\	\	\	\	\	\
5	CB07	\	\	\	\	\	\
mean		<2	4	2	<4	<2	3.62
1	CB08	\	\	\	\	\	\
2	CB08	\	\	\	\	\	\
3	CB08	<2	4	<1	<4	<2	2.97
4	CB08	\	\	\	\	\	\
5	CB08	\	\	\	\	\	\
mean		<2	4	<1	<4	<2	2.97
1	CB09	\	\	\	\	\	\
2	**CB09**	\	\	\	\	\	\
2	***CB09***	\	\	\	\	\	\
3	CB09	<2	6	<1	<4	<2	7.89
4	CB09	\	\	\	\	\	\
5	CB09	\	\	\	\	\	\
mean		<2	6	<1	<4	<2	7.89

Sweep	Site ID	Ag (ug/L)	Sr (ug/L)	Ti (ug/L)	V (ug/L)	Zn (ug/L)	Na (mg/L)
1	CB10	\	\	\	\	\	\
2	CB10	\	\	\	\	\	\
3	CB10	<2	6	<1	<4	<2	7.99
4	CB10	\	\	\	\	\	\
5	CB10	\	\	\	\	\	\
mean		<2	6	<1	<4	<2	7.99
1	CB11	\	\	\	\	\	\
2	CB11	\	\	\	\	\	\
3	CB11	<2	7	<1	<4	<2	11.44
4	CB11	\	\	\	\	\	\
5	CB11	\	\	\	\	\	\
mean		<2	7	<1	<4	<2	11.44
1	CB12	\	\	\	\	\	\
2	CB12	\	\	\	\	\	\
3	CB12	<2	7	<1	<4	<2	12.03
4	CB12	\	\	\	\	\	\
5	CB12	\	\	\	\	\	\
mean		<2	7	<1	<4	<2	12.03
1	CB14	\	\	\	\	\	\
3	CB14	<2	5	2	<4	<2	4.85
mean		<2	5	2	<4	<2	4.85
1	CB15	\	\	\	\	\	\
3	CB15	<2	6	<1	<4	<2	9.4
mean		<2	6	<1	<4	<2	9.4

Sweep	Site ID	K (mg/L)	Ca (mg/L)	As (ug/L) ICPMS	Cr (ug/L) ICPMS
1	CB01	\	\	\	\
2	CB01	\	\	\	\
3	CB01	**0.80**	4.25	1.3	0.8
4	CB01	\	\	\	\
5	CB01	\	\	\	\
mean		0.8	4.25	1.3	0.8
1	CB02	\	\	\	\
2	CB02	\	\	\	\
3	CB02	0.20	2.65	0.8	0.6
4	CB02				
5	CB02	\	\	\	\
mean		0.2	2.65	0.8	0.6
1	***CB03***	\	\	\	\
1	**CB03**	\	\	\	\
2	CB03	\	\	\	\
3	***CB03***	\	\	\	\
3	**CB03**	**0.70**	3.08	1.3	0.6
4	CB03	\	\	\	\
5	CB03	\	\	\	\
mean		0.7	3.08	1.3	0.6
1	CB04	\	\	\	\
2	CB04	\	\	\	\
3	CB04	0.30	1.34	0.7	<0.4
4	CB04	\	\	\	\
5	**CB04**	\	\	\	\
5	***CB04***	\	\	\	\
mean		0.3	1.34	0.7	<0.4
1	CB05	\	\	\	\
2	CB05	\	\	\	\
3	CB05	0.30	1.55	0.2	<0.4
4	CB05	\	\	\	\
5	CB05	\	\	\	\
mean		0.3	1.55	0.2	<0.4

Sweep	Site ID	K (mg/L)	Ca (mg/L)	As (ug/L) ICPMS	Cr (ug/L) ICPMS
1	CB06	\	\	\	\
2	CB06	\	\	\	\
3	CB06	0.30	3.73	1.4	<0.4
4	**CB06**				
4	***CB06***				
5	CB06	\	\	\	\
mean		0.3	3.73	1.4	<0.4
1	CB07	\	\	\	\
2	**CB07**	\	\	\	\
2	***CB07***	\	\	\	\
3	CB07	<0.10	1.11	0.5	<0.4
4	CB07	\	\	\	\
5	CB07	\	\	\	\
mean		<0.10	1.11	0.5	<0.4
1	CB08	\	\	\	\
2	CB08	\	\	\	\
3	CB08	0.20	0.91	0.3	<0.4
4	CB08	\	\	\	\
5	CB08	\	\	\	\
mean		0.2	0.91	0.3	<0.4
1	CB09	\	\	\	\
2	**CB09**	\	\	\	\
2	***CB09***	\	\	\	\
3	CB09	0.20	1.45	0.3	<0.4
4	CB09	\	\	\	\
5	CB09	\	\	\	\
mean		0.2	1.45	0.3	<0.4
1	CB10	\	\	\	\
2	CB10	\	\	\	\
3	CB10	0.20	1.66	0.2	<0.4
4	CB10	\	\	\	\
5	CB10	\	\	\	\
mean		0.2	1.66	0.2	<0.4

Sweep	Site ID	K (mg/L)	Ca (mg/L)	As (ug/L) ICPMS	Cr (ug/L) ICPMS
1	CB11	\	\	\	\
2	CB11	\	\	\	\
3	CB11	0.30	2.03	0.2	<0.4
4	CB11	\	\	\	\
5	CB11	\	\	\	\
mean		0.3	2.03	0.2	<0.4
1	CB12	\	\	\	\
2	CB12	\	\	\	\
3	CB12	0.30	2.06	0.3	<0.4
4	CB12	\	\	\	\
5	CB12	\	\	\	\
mean		0.3	2.06	0.3	<0.4
1	CB14	\	\	\	\
3	CB14	<0.10	1.31	0.5	<0.4
mean		<0.10	1.31	0.5	<0.4
1	CB15	\	\	\	\
3	CB15	0.30	1.48	0.3	<0.4
mean		0.3	1.48	0.3	<0.4

Sweep	Site ID	Cu (ug/L) ICPMS	Pb (ug/L) ICPMS	Mo (ug/L) ICPMS	Zn (ug/L) ICPMS	P (mg/L) ICPMS
1	CB01	\	\	\	\	**0.277**
2	CB01	\	\	\	\	**0.434**
3	CB01	0.4	0.5	<0.1	7.2	**0.306**
4	CB01	\	\	\	\	**0.338**
5	CB01	\	\	\	\	**0.185**
mean		0.4	0.5	<0.1	7.2	0.308
1	CB02	\	\	\	\	0.022
2	CB02	\	\	\	\	0.026
3	CB02	0.4	0.5	<0.1	4.5	0.021
4	CB02					0.016
5	CB02	\	\	\	\	0.017
mean		0.4	0.5	<0.1	4.5	0.020

Sweep	Site ID	Cu (ug/L) ICPMS	Pb (ug/L) ICPMS	Mo (ug/L) ICPMS	Zn (ug/L) ICPMS	P (mg/L) ICPMS
1	***CB03***	\	\	\	\	***0.285***
1	**CB03**	\	\	\	\	**0.291**
2	CB03	\	\	\	\	**0.477**
3	***CB03***	\	\	\	\	\
3	**CB03**	0.3	0.4	<0.1	4.9	**0.337**
4	CB03	\	\	\	\	**0.305**
5	CB03	\	\	\	\	**0.181**
mean		0.3	0.4	<0.1	4.9	0.318
1	CB04	\	\	\	\	0.015
2	CB04	\	\	\	\	0.016
3	CB04	0.5	0.1	<0.1	2.1	0.016
4	CB04	\	\	\	\	0.010
5	**CB04**	\	\	\	\	\
5	***CB04***	\	\	\	\	*0.010*
mean		0.5	0.1	<0.1	2.1	0.0134
1	CB05	\	\	\	\	**0.048**
2	CB05	\	\	\	\	0.032
3	CB05	0.3	<0.1	<0.1	1.8	0.022
4	CB05	\	\	\	\	**0.055**
5	CB05	\	\	\	\	0.016
mean		0.3	<0.1	<0.1	1.8	0.0346
1	CB06	\	\	\	\	**0.036**
2	CB06	\	\	\	\	**0.092**
3	CB06	0.5	0.5	<0.1	2.9	**0.119**
4	**CB06**					**0.078**
4	***CB06***					\
5	CB06	\	\	\	\	**0.043**
mean		0.5	0.5	<0.1	2.9	0.0736
1	CB07	\	\	\	\	0.012
2	**CB07**	\	\	\	\	0.017
2	***CB07***	\	\	\	\	
3	CB07	0.3	0.2	0.3	1.9	0.017
4	CB07	\	\	\	\	0.015
5	CB07	\	\	\	\	0.028
mean		0.3	0.2	0.3	1.9	0.0178

Sweep	Site ID	Cu (ug/L) ICPMS	Pb (ug/L) ICPMS	Mo (ug/L) ICPMS	Zn (ug/L) ICPMS	P (mg/L) ICPMS
1	CB08	\	\	\	\	0.013
2	CB08	\	\	\	\	0.013
3	CB08	0.4	<0.1	0.1	1.8	0.010
4	CB08	\	\	\	\	0.009
5	CB08	\	\	\	\	0.007
mean		0.4	<0.1	0.1	1.8	0.0104
1	CB09	\	\	\	\	0.018
2	**CB09**	\	\	\	\	0.017
2	***CB09***	\	\	\	\	*0.017*
3	CB09	0.4	<0.1	0.1	2.3	0.014
4	CB09	\	\	\	\	0.014
5	CB09	\	\	\	\	0.013
mean		0.4	<0.1	0.1	2.3	0.0155
1	CB10	\	\	\	\	0.016
2	CB10	\	\	\	\	0.019
3	CB10	0.4	<0.1	<0.1	1.7	0.011
4	CB10	\	\	\	\	0.007
5	CB10	\	\	\	\	0.010
mean		0.4	<0.1	<0.1	1.7	0.0126
1	CB11	\	\	\	\	0.012
2	CB11	\	\	\	\	0.012
3	CB11	0.4	<0.1	<0.1	1.6	0.008
4	CB11	\	\	\	\	0.008
5	CB11	\	\	\	\	0.007
mean		0.4	<0.1	<0.1	1.6	0.0094
1	CB12	\	\	\	\	0.012
2	CB12	\	\	\	\	0.009
3	CB12	0.5	<0.1	<0.1	2.2	0.008
4	CB12	\	\	\	\	0.010
5	CB12	\	\	\	\	0.007
mean		0.5	<0.1	<0.1	2.2	0.0092

Sweep	Site ID	Cu (ug/L) ICPMS	Pb (ug/L) ICPMS	Mo (ug/L) ICPMS	Zn (ug/L) ICPMS	P (mg/L) ICPMS
1	CB14	\	\	\	\	0.013
3	CB14	0.3	0.3	<0.1	1.7	0.018
mean		0.3	0.3	<0.1	1.7	0.0155
1	CB15	\	\	\	\	0.026
3	CB15	0.4	<0.1	<0.1	1.5	0.021
mean		0.4	<0.1	<0.1	1.5	0.0235

Appendix C

Data collected from sediment samples sent to the lab for all sites on all sampling dates.

Site ID	Date	Al	Sb	As	Ba	Be	Cd	Cr
CB01	9/3/2008	11730 R	<5	**6**	23.8	0.4	**0.79**	8.8
CB02	9/3/2008	10114 R	<5	4	13.1	0.3	**0.84**	11.6
CB03	9/3/2008	12364	<5	4	18.7	0.5	**0.85**	8.0
CB04	9/3/2008	12947 R	<5	**7**	18.6	0.5	**1.16**	14.6
CB05	9/3/2008	12012 R	<5	5	23.6	0.3	**1.07**	6.7
CB06	9/3/2008	10328 R	<5	***23***	39.1	0.6	**1.49**	5.4
CB07	9/3/2008	11166 R	<5	3	20.5	0.4	**0.79**	5.5
CB08	9/3/2008	10200 R	<5	4	14.7	0.4	**0.76**	6.2
CB09	9/3/2008	11253	<5	4	16.2	0.4	**0.80**	6.0
CB10	9/3/2008	12099 R	<5	4	37.2	0.5	**1.01**	6.0
CB11	9/3/2008	10332 R	<5	**6**	13.8	0.5	**0.92**	4.9
CB12	**9/3/2008**	10556 R	<5	3	12.6	0.4	**0.86**	18.2
CB12	***9/3/2008***	*11176 R*	*<5*	*3*	*12.7*	*0.4*	***0.85***	*17.1*

All values in (ug/g) or ppm

R = recheck done

CCME exceedances in **bold**

Site ID	Date	Co	Cu	Fe	Pb	Mn	Mo	Ni
CB01	9/3/2008	8.5	16.55	22552	**67.8**	567.5	<0.5	9.05
CB02	9/3/2008	5.6	7.78	21459	13.6	625.8	0.9	5.52
CB03	9/3/2008	7.6	16.34	21612	13.4	532.7	<0.5	7.99
CB04	9/3/2008	13.1	15.05	28920	12.5	976.1	<0.5	12.23
CB05	9/3/2008	8.4	6.73	27405	26.8	692.4	<0.5	4.98
CB06	9/3/2008	29.4	6.91	38743	14.2	2440.0	0.8	4.09
CB07	9/3/2008	7.2	6.11	21110	16.5	868.6	<0.5	4.08
CB08	9/3/2008	5.8	13.35	21699	9.3	721.0	<0.5	4.07
CB09	9/3/2008	6	10.96	21424	10.7	708.0	<0.5	5.52
CB10	9/3/2008	15.5	10.90	23486	12.2	3748.0	<0.5	5.72
CB11	9/3/2008	6.4	11.21	22152	12.4	1218.0	<0.5	4.49
CB12	**9/3/2008**	7.8	17.08	21420	11.5	772.0	<0.5	12.59
CB12	***9/3/2008***	*8.6*	*19.15*	*21527*	*11.4*	*701.4*	<0.5	*12.13*

All values in (ug/g)
or ppm

R = recheck done

CCME exceedances
in **bold**

Site ID	Date	Se	Ag	Sr	Tl	Sn	Ti	Va	Zn
CB01	9/3/2008	<5	<0.25	8.21	<2.5	10.5	1111.0	14.0	83.9
CB02	9/3/2008	<5	<0.25	5.11	<2.5	<2.5	803.4	12.1	47.7
CB03	9/3/2008	<5	<0.25	5.95	<2.5	<2.5	1257.0	13.7	58.3
CB04	9/3/2008	<5	<0.25	12.03	<2.5	<2.5	1305.0	24.8	65.1
CB05	9/3/2008	<5	<0.25	5.76	<2.5	<2.5	894.5	13.2	49.7
CB06	9/3/2008	<5	<0.25	9.51	<2.5	<2.5	954.0	15.1	81.4
CB07	9/3/2008	<5	<0.25	4.77	<2.5	<2.5	1057.0	13.5	59.1
CB08	9/3/2008	<5	<0.25	7.39	<2.5	<2.5	773.3	11.3	61.6
CB09	9/3/2008	<5	<0.25	7.26	<2.5	<2.5	1226.0	12.2	58.3
CB10	9/3/2008	<5	<0.25	7.89	<2.5	<2.5	1116.0	13.2	83.1
CB11	9/3/2008	<5	<0.25	7.20	<2.5	<2.5	981.4	12.3	83.7
CB12	**9/3/2008**	<5	<0.25	8.28	<2.5	<2.5	737.4	17.2	58.9
CB12	***9/3/2008***	<5	<0.25	*7.78*	<2.5	<2.5	*871.8*	*21.6*	*62.7*

All values in (ug/g)
or ppm

R = recheck done

CCME exceedances
in **bold**