Water Quality Monitoring and Analysis for the St. Marys River Area of Concern Technical Report (2014-2015)

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Executive Summary

The St. Marys River is an identified Area of Concern, where ongoing remedial actions have contributed towards its restoration. In the second year of a three-year (2013-2016) water quality monitoring and analysis project, progress was made in the process of re-assessing the status of the Eutrophication and Undesirable Algae and Degradation of Aesthetics beneficial use impairments. Field work, involving monitoring aesthetic, physical and chemical parameters at 5 sites within the Canadian St. Marys River Area of Concern, was conducted on 11 dates from May to October 2014. Analysis of the monitoring data suggests that the conditions that originally led to the beneficial uses being designated as impaired no longer exist. In particular, there was no evidence of oxygen stress, large quantities of algae, or high levels of nutrients typically found in culturally-eutrophic waters. In addition, there was also an absence of characteristics associated with degraded aesthetics. There were no objectionable deposits, unnatural colour, unnatural turbidity, or unnatural odour. Any human impacts observed could best be attributed to localized recreational activities and could not be readily associated with larger-scale industrial or municipal sources. Future work includes monitoring during the 2015 field season and collecting additional data to inform the final decision-making process about the status of the Eutrophication and Undesirable Algae and Degradation of Aesthetics beneficial use impairments.

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Acknowledgements

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Abbreviations

AOC = Area of Concern

BPAC = Bi-National Public Advisory Council for the St. Marys River Area of Concern

BUI = Beneficial Use Impairment

CCME = Canadian Council of Ministers of the Environment

CWQG = Canadian Water Quality Guidelines for the Protection of Aquatic Life

EC = Environment Canada

GLWQA = Great Lakes Water Quality Agreement

GPS = Global Positioning System

IA = Implementation Annex for the Canadian Waters of the St. Marys River Area of Concern

MDEQ = Michigan Department of Environmental Quality

MDL = Method Detection Limit

MOECC = Ontario Ministry of Environment and Climate Change

n = number of samples

NA = Not Applicable

PWQO = Ontario Provincial Water Quality Objectives

RAP = Remedial Action Plan

SD = Secchi Disc

SE = Standard Error

TT = Turbidity Tube

USEPA = United States Environmental Protection Agency

Introduction

Background Information

The St. Marys River is a freshwater ecosystem which connects Lake Superior to Lake Huron, and separates the twin cities of Sault Ste. Marie, Ontario and Michigan (Ripley et al. 2011). In the 1980s, the St. Marys River was identified as one of 43 Areas of Concern (AOCs) in the Great Lakes Basin (RAP 2002). AOCs, as defined by the Great Lakes Water Quality Agreement (GLWQA) between Canada and the United States, are geographically-delineated regions where impairment of beneficial uses has occurred due to human activities (GLWQA 2012).

Remedial Action Plans (RAPs), developed in conjunction with governments, agencies and stakeholders, guide the implementation of ecosystem restoration activities in AOCs (GLWQA 2012). The ultimate goal of the RAP process is the restoration of beneficial uses, leading to the recovery of AOCs (GLWQA 2012). Of the 14 beneficial uses identified in the GLWQA, 9 are recognized as being impaired in the St. Marys River (RAP 2002).

Project Purpose

The purpose of this three-year (2013-2016) water quality monitoring and analysis project is to provide scientifically-defensible information to allow a re-assessment of the Eutrophication and Undesirable Algae and Degradation of Aesthetics beneficial use impairments (BUIs) in the Canadian portion of the St. Marys River AOC.

Eutrophication refers to the nutrient enrichment of a water body (Smith & Smith 2006). This often leads to increased algal growth, especially in the presence of elevated levels of nitrogen and phosphorus (Smith & Smith 2006). This beneficial use was deemed to be impaired in the St. Marys River AOC when, in the past, high levels of nutrients discharged into the river led to noticeable and excessive algal growth (RAP 1992; RAP 2002).

Aesthetics encompasses the visual appearance of the ecosystem (RAP 1992). This beneficial use was identified as being impaired in the St. Marys River AOC when, in the past, visible debris and obvious pollution, including oil slicks, grease, floating scums, oily fibrous material, and woody debris, were observed at the shoreline, on surface waters and sitting on bottom sediments of the river (RAP 1992; RAP 2002).

Report Objective

The objective of this technical report is to summarize the methods used, and results obtained, during the 2014 water quality monitoring field season, as well as to discuss the significance of the findings with respect to the Eutrophication and Undesirable Algae and Degradation of Aesthetics BUIs.

Methods

Monitoring Sites

Five sites, initially identified in 2013, were used for water quality monitoring during the 2014 field season (Figure 1). The monitoring sites were chosen to be representative of the substrates, aquatic habitats, and land uses, found within the Canadian St. Marys River AOC. The sites were named for their locations: Gros Cap, Bellevue Park, Bell's Point, Echo Bay, and Richards Landing.

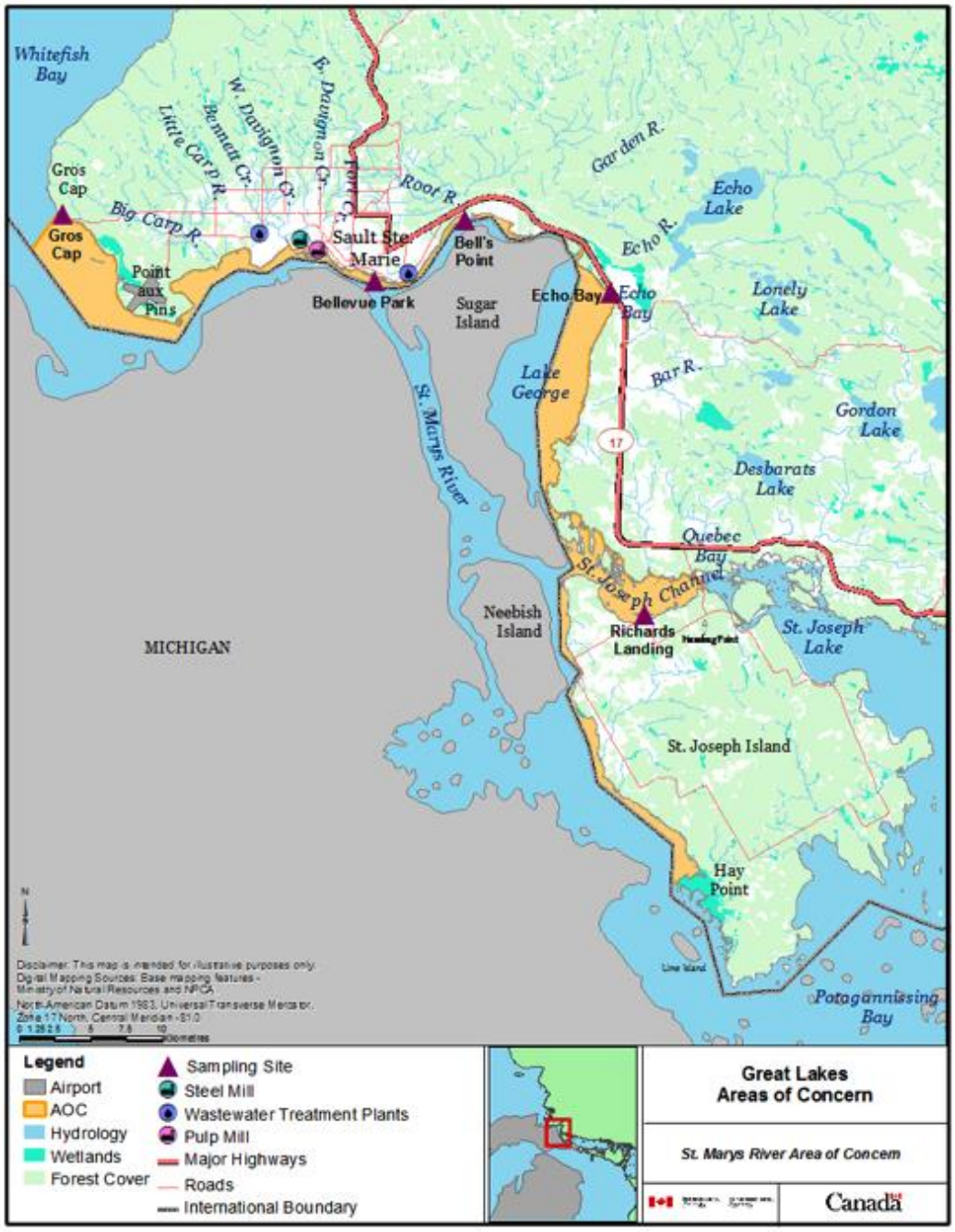

Figure 1: Canadian St. Marys River AOC showing monitoring sites (Map courtesy of EC)

GPS coordinates of the monitoring sites are presented in Table 1. Due to water level changes, there was some variation in the exact locations used throughout the field season. Measurements were taken with a hand-held GPS unit (eTrex 20, Garmin).

Table 1: GPS coordinates of monitoring sites

Site	**GPS coordinates**	
Gros Cap	May 14: N 46°31.721' W 084°35.185' May 27: N 46°31.736' W 084°35.179' June 10: N 46°31.735' W 084°35.179' June 24: N 46°29.708' W 084°17.837' July 14: N 46°31.737' W 084°35.176' July 29: N 46°31.736' W 084°35.174'	Aug 6: N 46°31.737' W 084°35.176' Aug 26: N 46°31.737' W 084°35.175' Sept 10: N 46°31.737' W 084°35.175' Sept 22: N 46°31.736' W 084°35.175' Oct 6: N 46°31.736' W 084°35.177'
Bellevue Park	May 14: N 46°29.706' W 084°17.836' May 27: N 46°29.709' W 084°17.837' June 10: N 46°29.708' W 084°17.838' June 24: N 46°29.708' W 084°17.837' July 14: N 46°29.710' W 084°17.837' July 29: N 46°29.710' W 084°17.837'	Aug 6: N 46°29.710' W 084°17.838' Aug 26: N 46°29.709' W 084°17.836' Sept 10: N 46°29.710' W 084°17.837' Sept 22: N 46°29.709' W 084°17.837' Oct 6: N 46°29.710' W 084°17.839'
Bell's Point	May 14: N 46°32.295' W 084°13.064' May 27: N 46°32.297' W 084°13.065' June 10: N 46°32.299' W 084°13.066' June 24: N 46°32.298' W 084°13.065' July 14: N 46°32.300' W 084°13.063' July 29: N 46°32.300' W 084°13.064'	Aug 6: N 46°32.300' W 084°13.065' Aug 26: N 46°32.300' W 084°13.062' Sept 10: N 46°32.301' W 084°13.064' Sept 22: N 46°32.301' W 084°13.064' Oct 6: N 46°32.303' W 084°13.065'
Echo Bay	May 14: N 46°29.634' W 084°04.698' May 27: N 46°29.632' W 084°04.698' June 10: N 46°29.633' W 084°04.700' June 24: N 46°29.632' W 084°04.698' July 14: N 46°29.362' W 084°04.696' July 29: N 46°29.361' W 084°04.696'	Aug 6: N 46°29.631' W 084°04.696' Aug 26: N 46°29.630' W 084°04.696' Sept 10: N 46°29.631' W 084°04.695' Sept 22: N 46°29.631' W 084°04.698' Oct 6: N 46°29.629' W 084°04.696'
Richards Landing	May 14: N 46°17.558' W 084°02.413' May 27: N 46°17.557' W 084°02.414' June 10: N 46°17.556' W 084°02.410' June 24: N 46°17.555' W 084°02.411' July 14: N 46°17.543' W 084°02.401' July 29: N 46°17.541' W 084°02.405'	Aug 6: N 46°17.541' W 084°02.404' Aug 26: N 46°17.543' W 084°02.401' Sept 10: N 46°17.540' W 084°02.404' Sept 22: N 46°17.543' W 084°02.401' Oct 6: N 46°17.540' W 084°02.401'

Field Work Frequency

Field work was conducted twice a month from May to September 2014, and once in October 2014, for a total of 11 dates. Monitoring, which was originally planned to begin in April, had to be delayed because there was still ice on parts of the St. Marys River until mid-May. It was not possible to monitor twice in October due to a shortage of funds for laboratory analysis. Field dates were scheduled to capture a variety of weather conditions, including rain events.

Monitoring Site Characteristics

At each monitoring site, the names of the field team, date, start and end times, air temperature, and weather conditions were recorded. Observations of substrate type and waterfowl were also made, as well as any other observations deemed relevant to the project's purpose. A copy of the field data collection sheet can be found in Appendix 1.

Field Team

The field team consisted of the Field Technician and the St. Marys River AOC RAP Coordinator.

Figure 2: Field team members Corrina Barrett (left) and Carrie Ginou (right)

Aesthetic Parameters

Parameters relevant to the Eutrophication and Undesirable Algae and Degradation of Aesthetics BUIs were chosen: water clarity, water colour, water odour, presence/absence of algae, and presence/absence of debris (natural, sheens, oil, grease, trash, solids and scums).

Water clarity and colour were determined visually by looking at clear plastic bottles of water samples against a white background (white piece of paper). Descriptors derived from the MDEQ's Aesthetics Monitoring Data Sheet were used to record qualitative observations of water clarity and colour (MDEQ 2011).

Water odour was assessed by taking the top off one of the sampling bottles and smelling. Descriptors derived from the MDEQ's Aesthetics Monitoring Data Sheet were used to record qualitative observations of water odour (MDEQ 2011).

Water clarity was also measured within the river using a 60 cm turbidity tube (78-070 Fieldmaster, Science First) and a Secchi disc (The Science Source) placed at a depth of 50 cm.

Algae presence/absence and its approximate location (e.g. on rocks, floating) was determined by a visual check in the vicinity of each monitoring site.

The presence/absence of debris (natural, sheens, oil, grease, trash, solids and scums) was determined visually by the field team (method adapted from MDEQ) (MDEQ 2011).

In order to more permanently record visual observations, digital photographs were taken systematically at each field site. The photo protocol included digital photographs: upstream of the monitoring site, downstream of the monitoring site, perpendicular to shoreline, a close-up into the water, and three full clear plastic sample bottles against a white background. In addition, any other relevant conditions (e.g. algae) were photographed.

Physical and Chemical Parameters

Field measurements and water samples were taken while wading at a depth of 50 cm. Measurements and samples were gathered at least one minute after the sampler arrived at the site, in order to negate any effect of sampler movement on the parameters investigated.

Water temperature was recorded with a digital thermometer (Traceable, Control Company) and pH was determined using a hand-held meter (pHTestr 30, Oakton).

Once the field measurements were completed, three-replicates of water samples were grab-sampled at each field site, according to the methods of the Protocols Manual for Water Quality Sampling in Canada (CCME 2011). Further procedural direction was provided by Testmark Laboratories, which provided the sampling bottles and performed the chemical analysis on the collected water samples. The bottles used, preservation methods (where applicable), and parameters measured from each sample, are detailed in Table 2. When sulphuric acid was used as a preservative it was added to the sampling bottles at the analytical laboratory, prior to the containers being shipped to Algoma University (pre-charged bottles).

Table 2: Bottles used, preservation methods and parameters measured

Sampling Bottle	**Preservation**	**Parameter(s) Measured**
1 L amber glass	None	Chlorophyll a
500 mL polyethylene terephthalate (PET) plastic	None	Dissolved oxygen
500 mL polyethylene terephthalate (PET) plastic	None	Total Suspended Solids
500 mL polyethylene terephthalate (PET) plastic	None	Nitrite, Nitrate, Turbidity
125 mL high-density polyethylene (HDPE) plastic	Sulphuric Acid	Ammonia, Phosphorus, Total Kjeldahl Nitrogen
125 mL high-density polyethylene (HDPE) plastic	None	Dissolved Organic Carbon

Laboratory Analysis

While in the field, samples were collected and then immediately stored in coolers containing ice packs. At the end of the sampling day, the bottles were stored in a refrigerator at 4°C. The exception to this includes samples collected May 14, May 27 and June 10. These water samples were kept refrigerated at approximately 10-15°C. This was due to the fact that they were stored in an old refrigerator. A new refrigerator was purchased and installed on June 18, 2014.

All sampling bottles were shipped in coolers with ice packs, via Purolator, to Testmark Laboratories in Sudbury, Ontario, within 24 hours of collection. Chain of custody documents, confirm that the coolers were received within 24 hours of shipping.

Testmark Laboratories, Sudbury, Ontario, was chosen for this project as is it accredited by the Canadian Association for Laboratory Accreditation, and is the closest laboratory to Sault Ste. Marie, Ontario, available to perform the necessary chemical analyses.

The methods used for each parameter measured, and the method detection limits are shown in Table 3.

Table 3: Laboratory analytical parameters, methods and detection limits

Parameter	**Analytical Method**	**Method Detection Limit**
Dissolved Oxygen	YSI BOD Meter	0.2 mg/L
Total Phosphorus	Discrete Chemistry Analyzer	0.001 mg/L
Dissolved Organic Carbon	Dohrman TOC Analyzer	0.4 mg/L
Chlorophyll a	Phillips UV/VIS Spectrophotometer	0.5 µg/L
Total Suspended Solids	Mettler Toledo Balance	0.8 mg/L
Turbidity	Hach 2100P	0.1 NTU
Un-ionized Ammonia (as nitrogen)	Calculation	0.002 mg/L
Ammonium (as nitrogen)	Calculation	0.01 mg/L
Total Ammonia (as nitrogen) (un-ionized ammonia and ammonium)	Discrete Chemistry Analyzer	0.01 mg/L
Nitrite (as nitrogen)	Dionex Ion Chromatography	0.03 mg/L
Nitrate (as nitrogen)	Dionex Ion Chromatography	0.1 mg/L
Total Kjeldahl Nitrogen (water digestion) (ammonia and organic nitrogen)	Discrete Chemistry Analyzer	0.2 mg/L
Total Nitrogen (as nitrogen) (all nitrogen sources)	Calculation	NA

Quality Control

Quality control at the field level consisted of following established sampling protocols and taking three replicates of water samples at each monitoring site. Quality control at the laboratory analysis phase included running lab controls, duplicate analyses with field samples, matrix spikes, method blanks and relative percent difference calculations.

Data Analysis

Statistical analysis was performed on replicated laboratory data using Microsoft Excel (Microsoft Office 13) and SPSS (IBM Statistics 22). Mean and standard error (SE) were calculated, and comparisons of parameter measurements between monitoring sites were done using a Kruskal-Wallis test followed by pairwise comparisons ($p < 0.05$).

In cases where only one of the data points in a replicate set of three was below the method detection limit (MDL), the number was set at MDL/2 as per the method recommended in the USEPA's Practical Methods for Data Analysis Guidance Document (USEPA 2000).

Results

Monitoring Site Characteristics

Monitoring site characteristics are summarized in the following section. Complete details of the monitoring dates and times, air temperatures, weather conditions, the presence/absence of waterfowl, and comments related to human uses and specific site conditions at the time of monitoring, are available in Appendix 2.

Shoreline

The shoreline at each site varied considerably. Figures 3 to 7 show representative downstream and upstream photos taken at each monitoring site. At Gros Cap the shoreline was rocky, at Bellevue Park gravelly, at Echo Bay sandy with wetland vegetation, at Bell's Point sandy, and at Richards Landing sandy with an adjacent wetland.

Figure 3: Gros Cap monitoring site

Figure 4: Bellevue Park monitoring site

Figure 5: Bell's Point monitoring site

Figure 6: Echo Bay monitoring site

Figure 7: Richards Landing monitoring site

Substrate

The substrate type at Gros Cap was rocky with large boulders and smaller cobbles, pebbles and some coarse sand. Bellevue Park substrate was cobbles and pebbles with some large rocks within the vicinity of the monitoring area. Bell's Point had a sandy substrate. Echo Bay had primarily a sandy substrate with some small pebbles and rocks. The substrate at Richards Landing was sand.

A representative photograph of the substrate at each site is presented in Figure 8.

Figure 8: Monitoring site substrates

Monitoring Dates and Times
Monitoring for the 2014 field season occurred on: May 14, May 27, June 10, June 24, July 14, July 29, August 6, August 26, September 10, September 22, and October 6. With the exception of May 14, sites were visited in the order (first to last): Richards Landing, Echo Bay, Bell's Point, Bellevue Park and Gros Cap. Monitoring took place approximately from 10:00 am to 5:00 pm.

Air Temperature
Air temperatures ranged from 7.5 °C (October 6 at Richards Landing) to 25.8 °C (June 10 at Bell's Point).

Weather
Monitoring dates encompassed a wide variety of weather conditions (Figure 9), including 3 rain events and 5 dates immediately following rain events. There was rain during monitoring on June 24, July 14 and September 10. Monitoring on May 14, July 14, July 29, September 22 and October 6, took place either the day after rain and/or 2-3 days after substantial heavy rain events. Wave action varied from being non-existent to substantial.

Figure 9: Weather conditions encountered during monitoring

Waterfowl

Waterfowl observed included: gulls, geese, terns, ducks, loons and cormorants. Signs included scat and webbed prints on sandy substrates and sand beaches. Waterfowl were most often observed at Bell's Point. Some of the species and their signs are pictured in Figure 10.

Figure 10: Waterfowl and signs of waterfowl at monitoring sites

Human Uses

A variety of signs of human activity were noted at the monitoring sites (Figure 11). Specific observations appear as comments in Appendix 2.

The site at Gros Cap was used frequently by hikers, sight-seers and dog walkers. On June 10 there was particularly heavy activity at that site as a movie was being filmed in the vicinity. This included people, equipment and recreational vehicles parked along the shoreline directly adjacent to the monitoring site. At Bellevue Park we often came into contact with, and observed, people and their dogs, as well as dog scat, which was sometimes in close proximity to the water. Since Bell's Point is an operational campground, we observed campers there, with use being especially heavy during July and August. At Echo Bay, we saw people engaged in fishing and strong signs of human activity in the presence of a fire pit and garbage at the site throughout the field season. Although we rarely saw swimmers, we observed many signs of recreational activity at the beach at Richards Landing, including human footprints, garbage, and sand castles.

Figure 11: Human uses of areas encompassing monitoring sites

Aesthetic, Physical and Chemical Parameters

Results for aesthetic, physical and chemical parameters are summarized below. Full details are available in Appendices 3 and 4. Although this report presents results from May to October 2014, data from November 2013 has been included in figures to show all information collected.

Water Clarity, Total Suspended Solids and Turbidity

Visual clarity varied from "clear" to "moderately turbid" (Figure 12). Water was always "clear" at Gros Cap, Bellevue Park and Bell's Point. Water was "slightly turbid" at Echo Bay on May 14, May 27, June 10, August 26, September 22 and October 6, and "moderately turbid" on July 29. At Richards Landing, water was "slightly turbid" on May 14 and September 22, and "moderately turbid" on July 29. On all other dates, water was "clear" at Echo Bay and Richards Landing.

Figure 12: Water clarity at monitoring sites

Water clarity, as measured using a Secchi disc (Figure 13), yielded measurements for Secchi depth at each monitoring site. On the majority of dates, Secchi depth was measured to be 50 cm, which is the maximum depth that can be measured at a water depth of 50 cm, and indicates that water at that location was "clear". All exceptions occurred at Echo Bay, where Secchi depth was 45 cm on May 14, and 40 cm on May 27, June 10, and October 6.

Water clarity, as measured by turbidity tube (Figure 13), also yielded mostly "clear" results. A turbidity tube measurement of 60 cm represented clear water, as the turbidity tube could only be filled up to a maximum height of 60 cm. The majority of turbidity tube measurements were 60 cm. Exceptions included a turbidity tube measurement of 23 cm at Gros Cap on June 24, and readings at Richards Landing of 56 cm on May 14 and 49 cm on July 29. Echo Bay had the majority of the readings under 60 cm. At Echo Bay the turbidity tube measured 30 cm on both May 14 and May 27, 33 cm on June 10, and 27 cm on October 6.

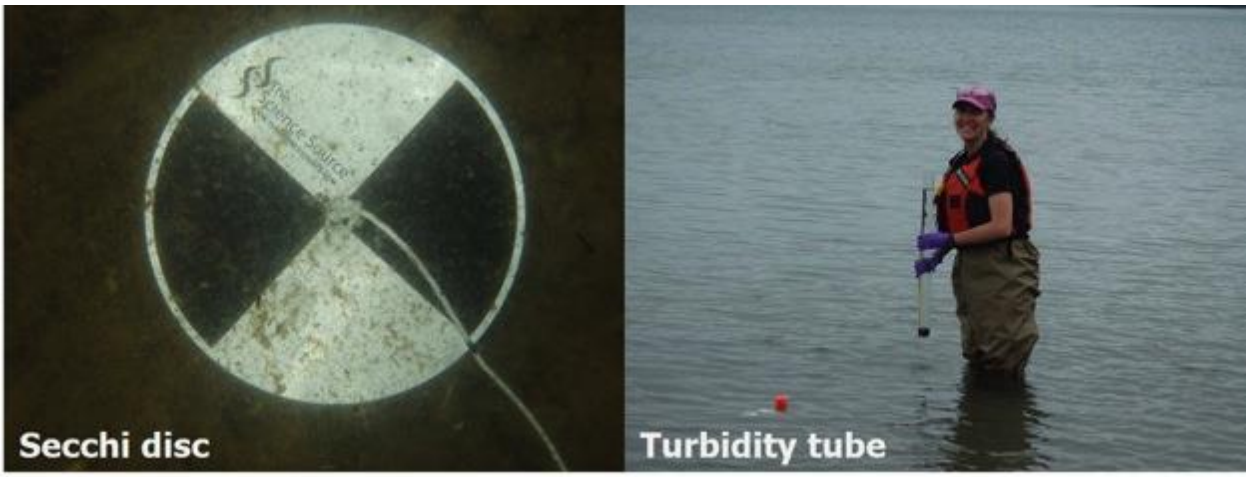

Figure 13: Secchi disc and turbidity tube used to measure water clarity in the field

Water clarity, as measured by the amount of total suspended solids in water samples, ranged in mean values (n=3), from 0.93 mg/L (Bellevue Park on June 10) to 29.33 mg/L (Richards Landing on May 14) (Figure 14). Mean total suspended solids readings, all results included, were: Gros Cap (2.58 mg/L), Bellevue Park (1.99 mg/L), Bell's Point (2.40 mg/L), Echo Bay (7.25 mg/L) and Richards Landing (7.72 mg/L).

Spikes of total suspended solids occurred twice during the monitoring season. Levels were high at Richards Landing on May 14 (range: 16.0-37.2 mg/L) and relatively elevated at Gros Cap on June 24 (range: 2.0-12.4 mg/L). There were several instances in which no suspended solids were detected (MDL=0.8 mg/L). These included: May 14, May 27, June 10, July 14, August 6, August 26 and September 10 at Gros Cap, May 27 and July 14 at Bellevue Park, May 14, June 10, June 24 and August 26 at Bell's Point, July 14 at Echo Bay, and June 10 at Richards Landing.

For measurable results, total suspended solids were significantly lower at Gros Cap than Richards Landing on July 29 ($p=0.028$) and significantly lower at Gros Cap than Echo Bay on October 6 ($p=0.026$). In general, total suspended solids concentrations were higher at Echo Bay and Richards Landing compared to the other three sites.

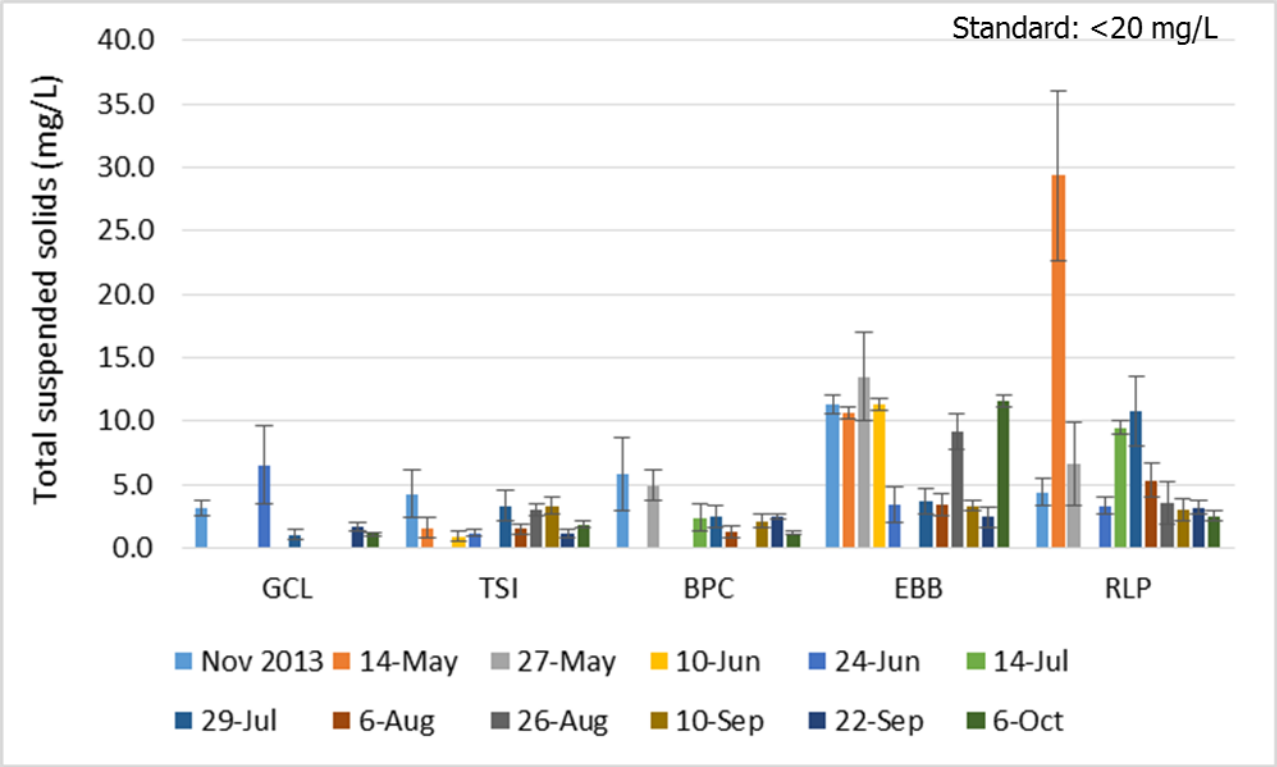

Figure 14: Total suspended solids (mean values, error bars +/- SE)

Laboratory measurements of turbidity, an indicator of water clarity, varied considerably. Mean values for water samples (n=3), ranged from a low of 0.43 NTU (May 14 at Gros Cap) to a high of 23.27 NTU (October 6 at Echo Bay) (Figure 15). Mean turbidity readings, all results included, were: Gros Cap (1.15 NTU), Bellevue Park (1.66 NTU), Bell's Point (1.51 NTU), Echo Bay (9.98 NTU) and Richards Landing (4.30 NTU). In general, turbidity readings tended to be greatest at Echo Bay. Turbidity was also usually higher at Richards Landing than the three most upstream sites. An exception was a relative spike in turbidity at Gros Cap on June 24 (range: 2.0-12.6 NTU).

There was significantly more turbidity at Echo Bay than: Gros Cap on May 14 ($p=0.010$), May 27 ($p=0.040$), June 10 ($p=0.022$), August 26 ($p=0.010$), September 10 ($p=0.010$), September 22 ($p=0.010$) and October 6 ($p=0.010$), Bell's Point on May 27 ($p=0.040$), and Bellevue Park on June 24 ($p=0.026$). Richards Landing had significantly higher turbidity than Gros Cap on July 14 ($p=0.010$), July 29 ($p=0.010$) and August 6 ($p=0.010$).

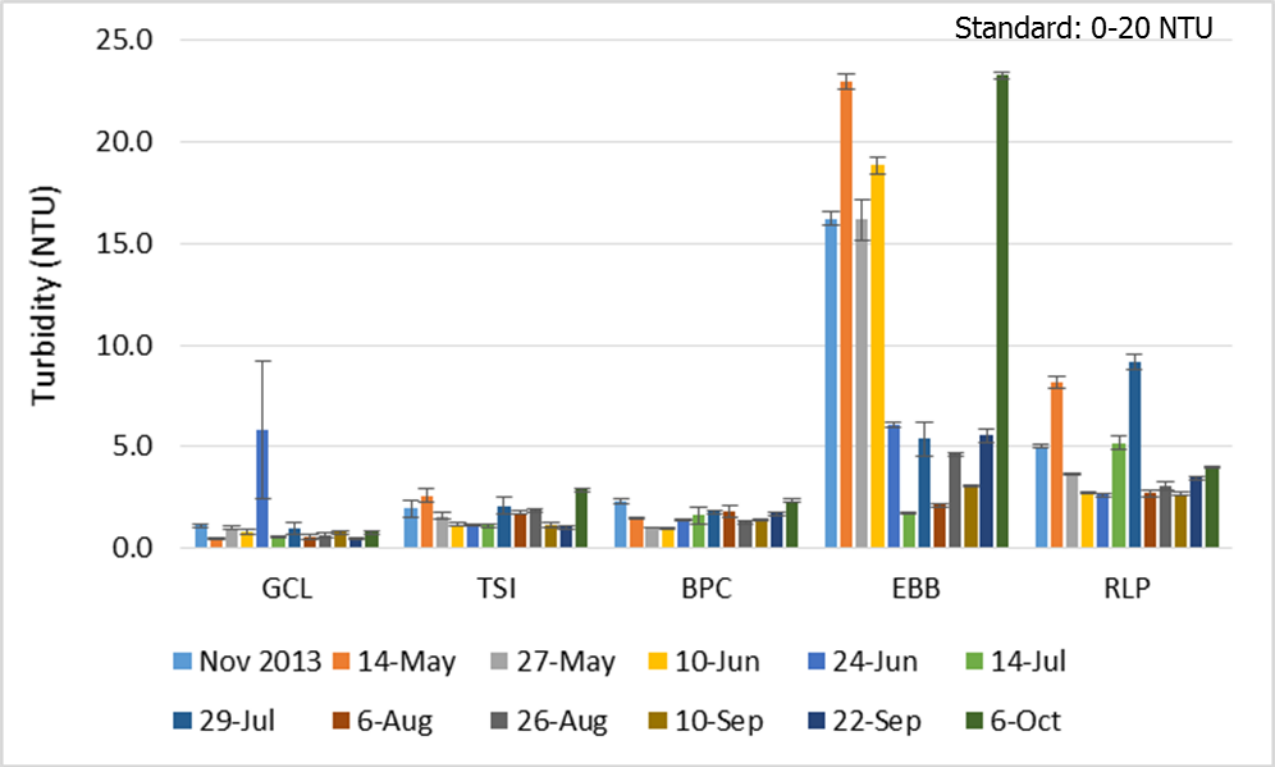

Figure 15: Turbidity (mean values, error bars +/- SE)

Water Colour

Water colour, as determined visually, was "clear" for all monitoring dates at Gros Cap, Bellevue Park and Bell's Point. At Echo Bay water colour varied from "clear" on 4 monitoring dates to being coloured "light yellow" (May 14, May 27, June 10, June 24, September 10, October 6) or "light brown" (July 29) on the other 7 occasions. At Richards Landing water colour was "clear" except on May 14 when it was "light yellow" and July 29 when it was "light brown". Examples of water colour are shown in Figure 16.

Figure 16: Water colour in samples collected at monitoring sites

Water Odour
No water odours were detected at any of the monitoring sites during any of the monitoring dates.

Algae and Chlorophyll a
Algae were observed floating in the water column, on the substrate, and/or attached to rocks or submerged plants (Figures 17a, 17b). No large clumps or mats of algae were ever encountered.

At Gros Cap, algal strands were frequently observed (9/11 trips) attached to rocks and/or floating in the vicinity of the monitoring site. It is likely that algae were present on all trips although not always noted. Algae were also often seen (5/11 trips) attached to rocks and submerged vegetation, at Bellevue Park. At Bell's Point, algae were only observed on July 14, attached to a cement step that had become submerged when water levels rose. At Echo Bay small amounts of algae were seen floating in the water column on June 24 and on July 14 a little clump was seen resting on the substrate. Algae were observed floating on May 14, and on the substrate on May 27, at Richards Landing.

Chlorophyll a, a photosynthetic pigment, provides a method to measure algal density, particularly when the algae are not readily visible. Mean chlorophyll a values (n=3), measured in water samples were between 0.58 µg/L (July 14 at both Bell's Point and Echo Bay) and 5.60 µg/L (May 27 at Bellevue Park) (Figure 18). Mean chlorophyll a readings, all results included, were: Gros Cap (0.94 µg/L), Bellevue Park (1.71 µg/L), Bell's Point (1.03 µg/L), Echo Bay (1.48 µg/L) and Richards Landing (1.68 µg/L).

Results are missing for May 14 because chlorophyll a analysis was not performed on samples collected on that date. There was a spike in chlorophyll a at Bellevue Park on May 27 (range: 1.40-8.34 µg/L) as well as a smaller peak in levels at Richards Landing on that same date (range: 1.4-3.6 µg/L). No detectable amounts (MDL=0.5 µg/L) of chlorophyll a were found in samples from Gros Cap on June 10. Significantly higher chlorophyll a was found at Richards Landing compared to Bell's Point on July 29 ($p=0.013$).

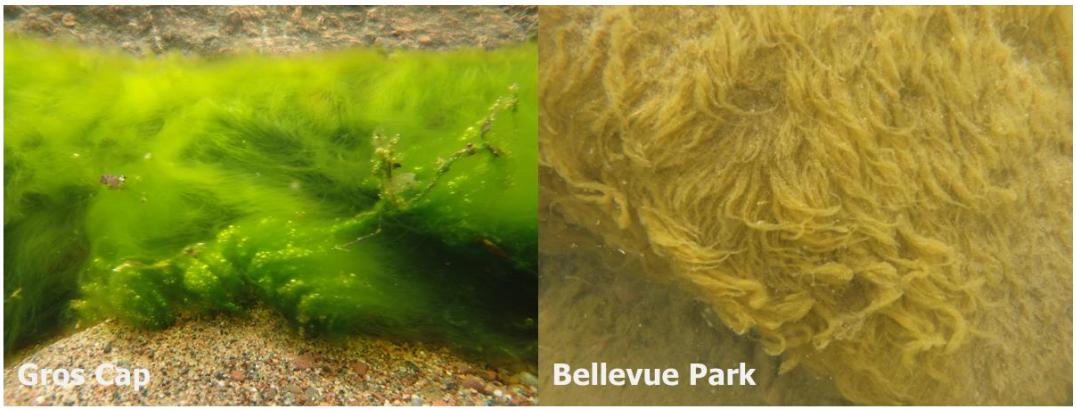

Figure 17a: Algae observed at monitoring sites

Figure 17b: Algae observed at monitoring sites

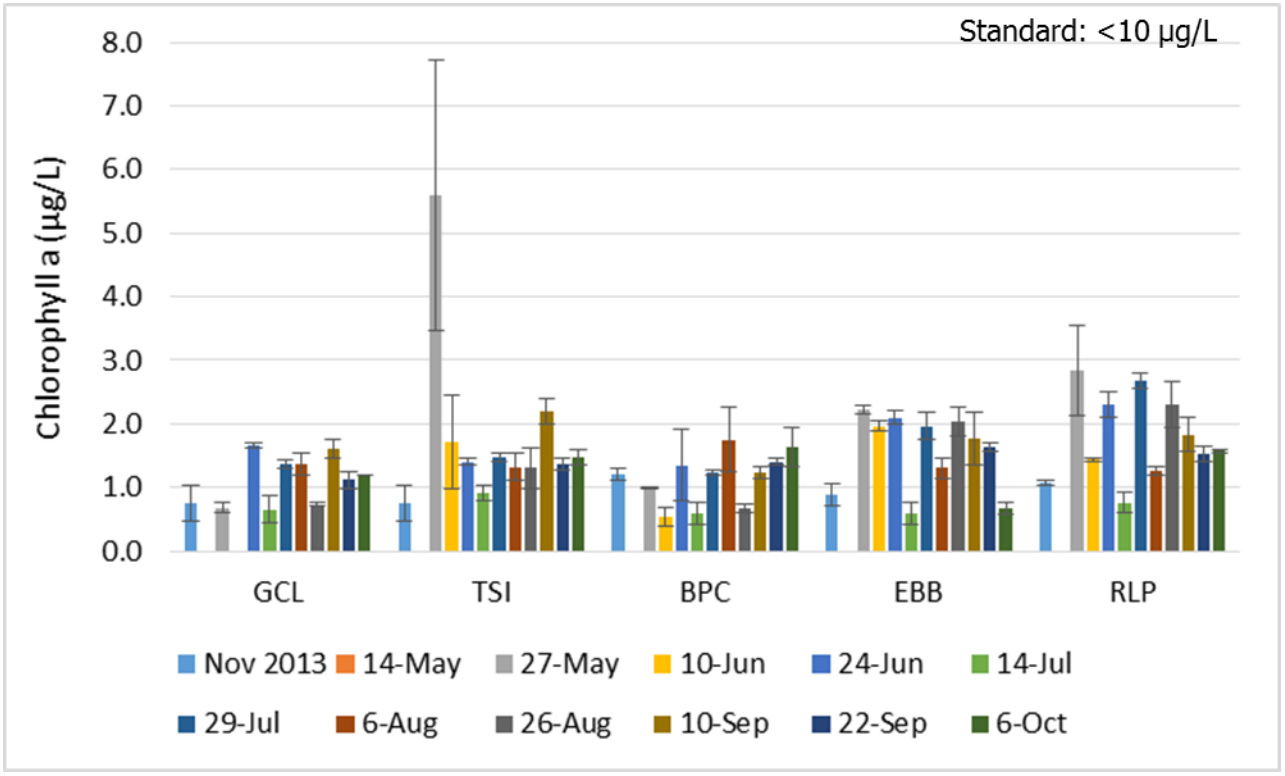

Figure 18: Chlorophyll a (mean values, error bars +/- SE)

Debris

Forms of natural debris, including leaves, sticks, and plants, were observed at all of the monitoring sites. Their presence/absence is noted in Appendix 3. There were no sheens, oil, grease, solids or scums detected at any time. Any garbage seen was generally on the shoreline and deemed to be the result of localized human activity. Garbage is noted in the comments of Appendix 2. Representative photographs of natural debris are shown in Figure 19.

Figure 19: Natural debris at monitoring sites

Field Water pH

Field water pH values ranged from 7.3 (October 6 at Echo Bay) to 8.7 (May 27 at Bellevue Park) (Figure 20). These numbers represent one pH measurement per site per monitoring date.

Mean pH values for each site, using values collected during the entire field season, were: Gros Cap (8.2), Bellevue Park (8.2), Bell's Point (8.0), Echo Bay (7.9) and Richards Landing (8.1).

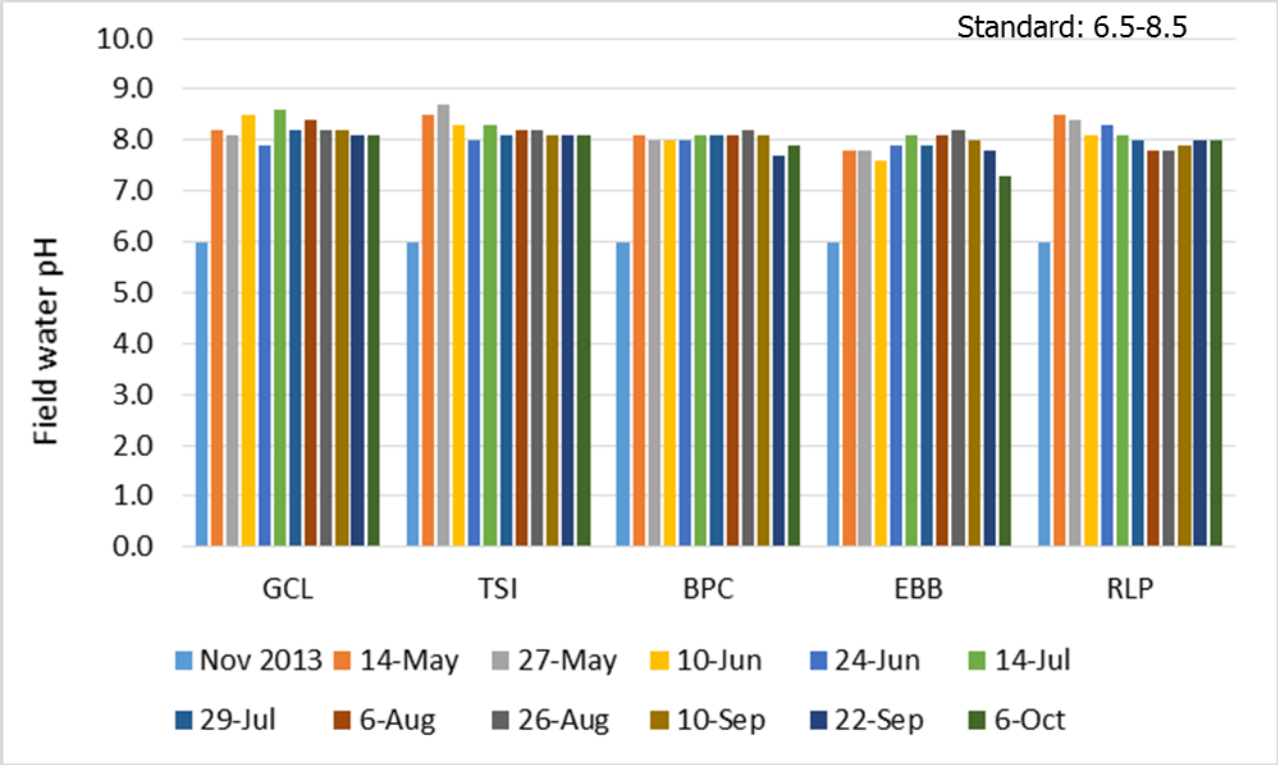

Figure 20: Field water pH (single values)

Field Water Temperature

Field water temperature varied throughout the months of the field season (Figure 21). The minimum value was 2.8 °C (Gros Cap on May 14) and the maximum was 20.4 °C (Richards Landing on August 6). One temperature measurement was made per site per monitoring date.

Mean temperatures, all dates included, were: Gros Cap (12.0°C), Bellevue Park (13.5°C), Bell's Point (14.0°C), Echo Bay (16.7°C) and Richards Landing (16.0°C).

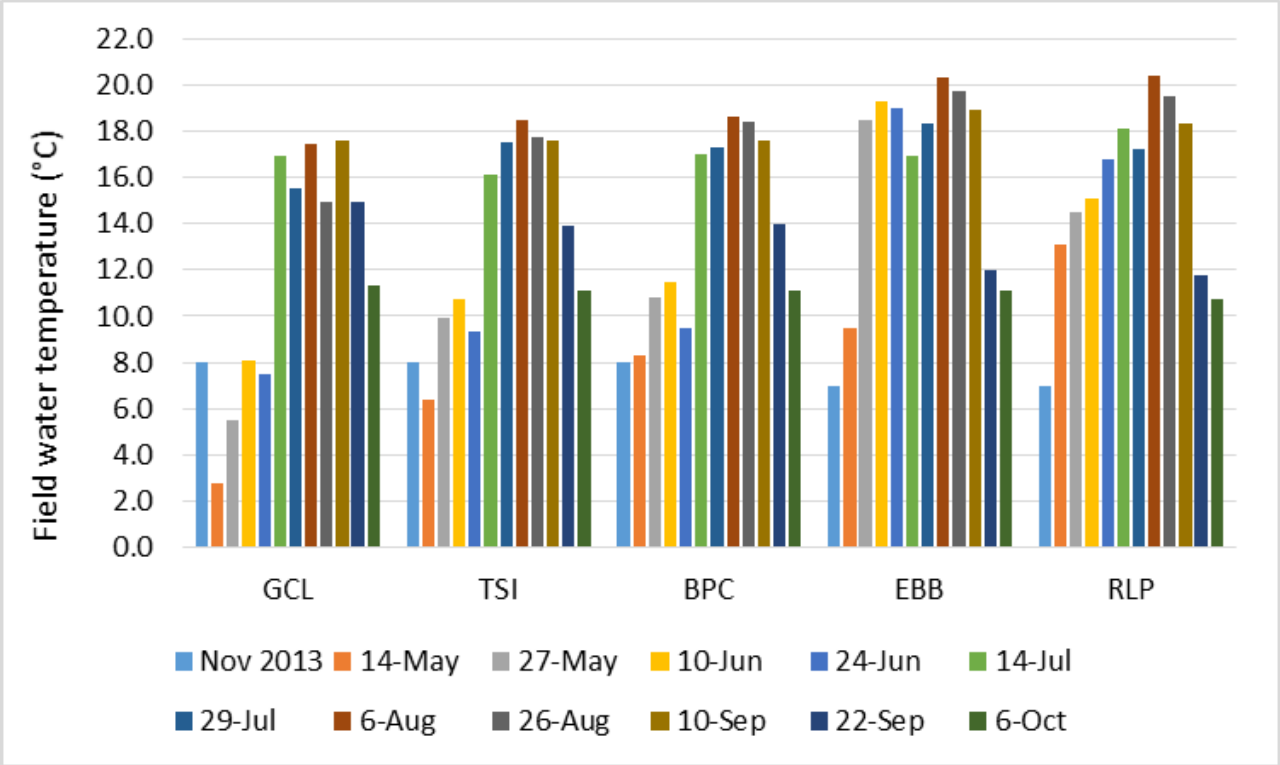

Figure 21: Field water temperature (single values)

Dissolved Oxygen

Dissolved oxygen mean values (n=3), measured from 8.58 mg/L (Richards Landing on July 29) to 13.62 mg/L (Bell's Point on June 24) (Figure 22). Mean dissolved oxygen readings, all results included, were: Gros Cap (11.2 mg/L), Bellevue Park (11.1 mg/L), Bell's Point (11.1 mg/L), Echo Bay (9.9 mg/L) and Richards Landing (10.4 mg/L).

Dissolved oxygen was significantly higher at Bellevue Park than Echo Bay on May 14 (p=0.017), May 27 (p=0.015) and June 10 (p=0.039). There was also significantly more dissolved oxygen at Gros Cap than Richards Landing on July 29 (p=0.032) and August 6 (p=0.008), and at Gros Cap than Echo Bay on August 26 (p=0.043).

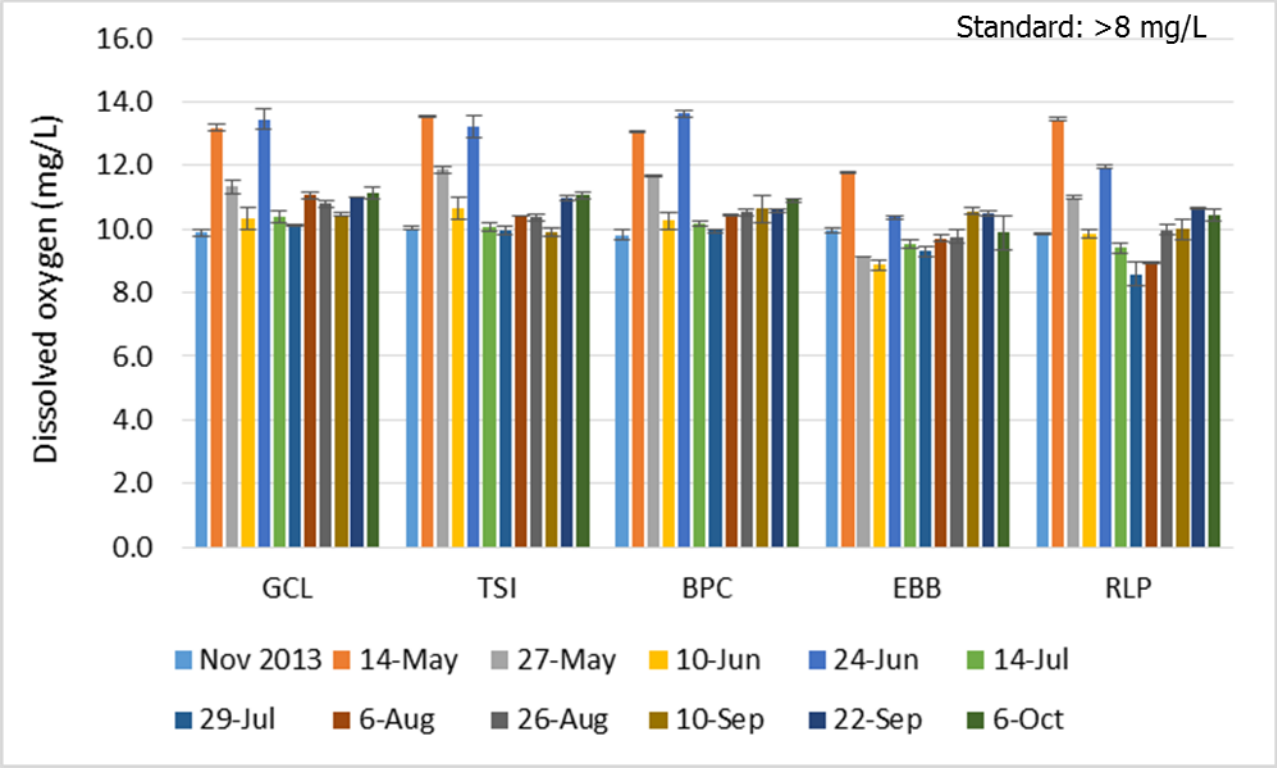

Figure 22: Dissolved oxygen (mean values, error bars +/- SE)

Total Phosphorus

Mean total phosphorus in water samples (n=3), ranged from 0.002 mg/L (May 14 at Bell's Point) to 0.035 mg/L (June 10 at Echo Bay) (Figure 23). Mean total phosphorus readings, all results included, were: Gros Cap (0.004 mg/L), Bellevue Park (0.006 mg/L), Bell's Point (0.004 mg/L), Echo Bay (0.012 mg/L) and Richards Landing (0.007 mg/L).

There was a spike in total phosphorus at Echo Bay on June 10 (range: 0.026-0.058 mg/L). No detectable amounts of total phosphorus (MDL=0.002 mg/L) were found in samples collected on July 29 and October 6 at Gros Cap, and at all sites, except Echo Bay, on September 22.

Total phosphorus was significantly lower at Echo Bay than Richards Landing on July 14 (p=0.035), and also significantly lower at Gros Cap than Echo Bay on August 6 (p=0.029).

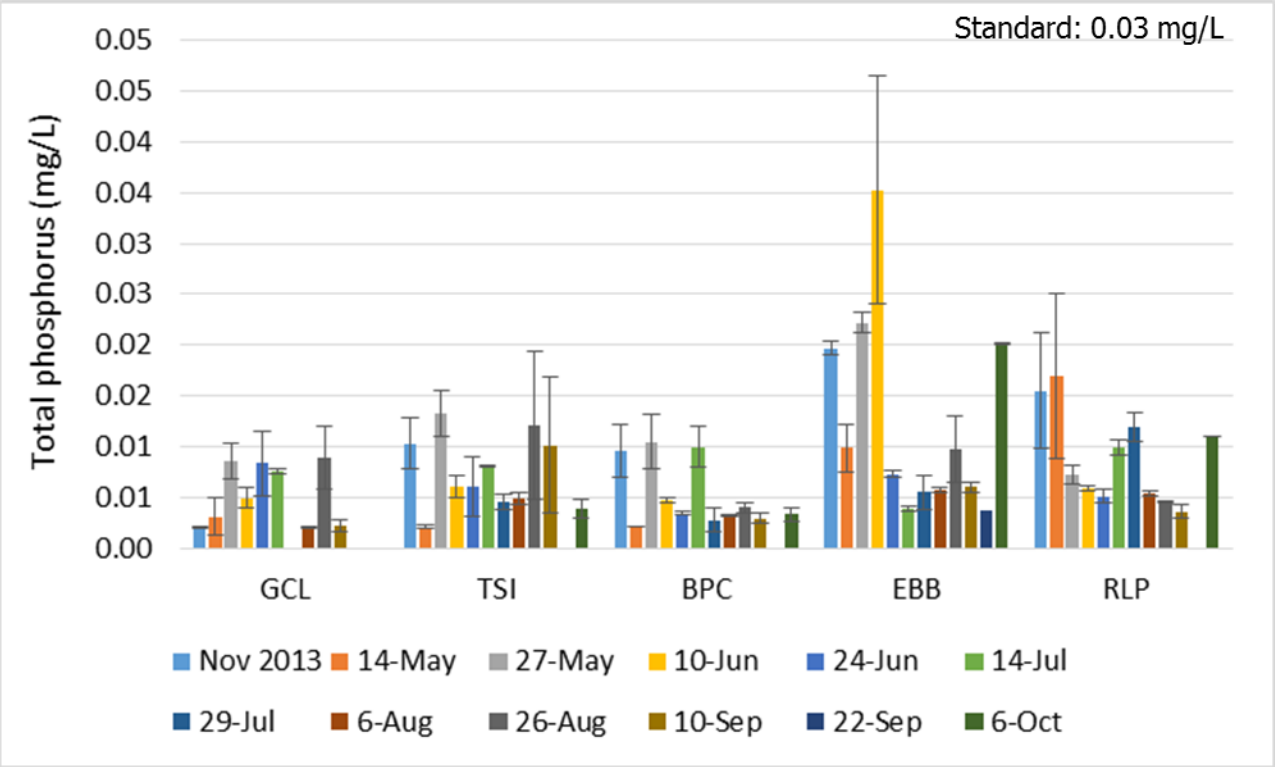

Figure 23: Total phosphorus (mean values, error bars +/- SE)

Dissolved Organic Carbon

Dissolved organic carbon mean concentrations (n=3), varied from 1.50 mg/L (Gros Cap on August 26) to 7.27 mg/L (Echo Bay on June 10) (Figure 24). Mean dissolved organic carbon readings, all results included, were: Gros Cap (2.17 mg/L), Bellevue Park (1.91 mg/L), Bell's Point (1.96 mg/L), Echo Bay (4.08 mg/L) and Richards Landing (2.35 mg/L).

There was a relative spike in dissolved organic carbon at Gros Cap on June 24 (mean value: 5.47 mg/L, range of values: 2.3-10.8 mg/L).

Levels of dissolved organic carbon were significantly lower at Gros Cap than Echo Bay on May 14 (p=0.014), May 27 (p=0.013), July 29 (p=0.006) and October 6 (p=0.009). They were also significantly lower at Bell's Point than at Echo Bay on June 10 (p=0.029). However, dissolved organic carbon was significantly higher at Gros Cap, compared to Bell's Point, on June 24 (p=0.037) and July 14 (p=0.012).

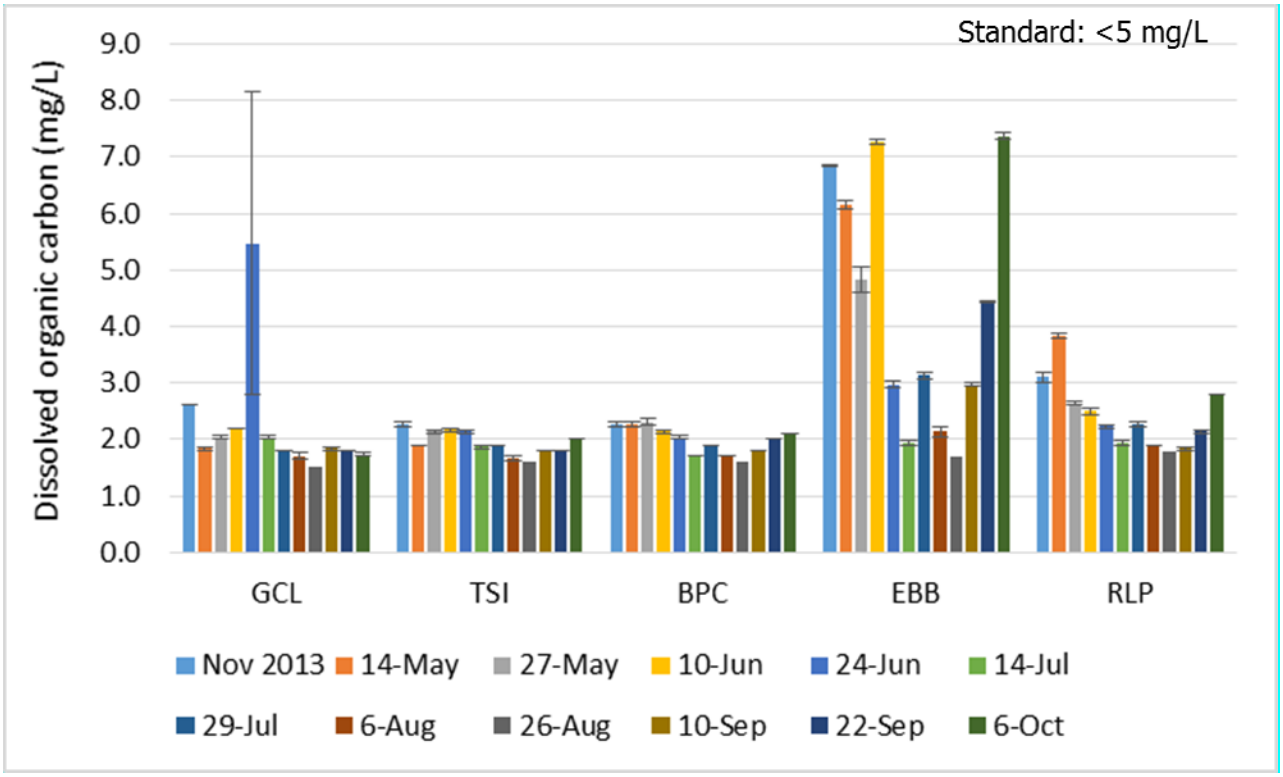

Figure 24: Dissolved organic carbon (mean values, error bars +/- SE)

Un-ionized Ammonia, Ammonium and Total Ammonia

Detectable amounts of un-ionized ammonia were only found once during the field season. A mean value of 0.006 mg/L was found in samples collected at Gros Cap on June 10 (Figure 25). The range of values was: 0.005-0.007 mg/L.

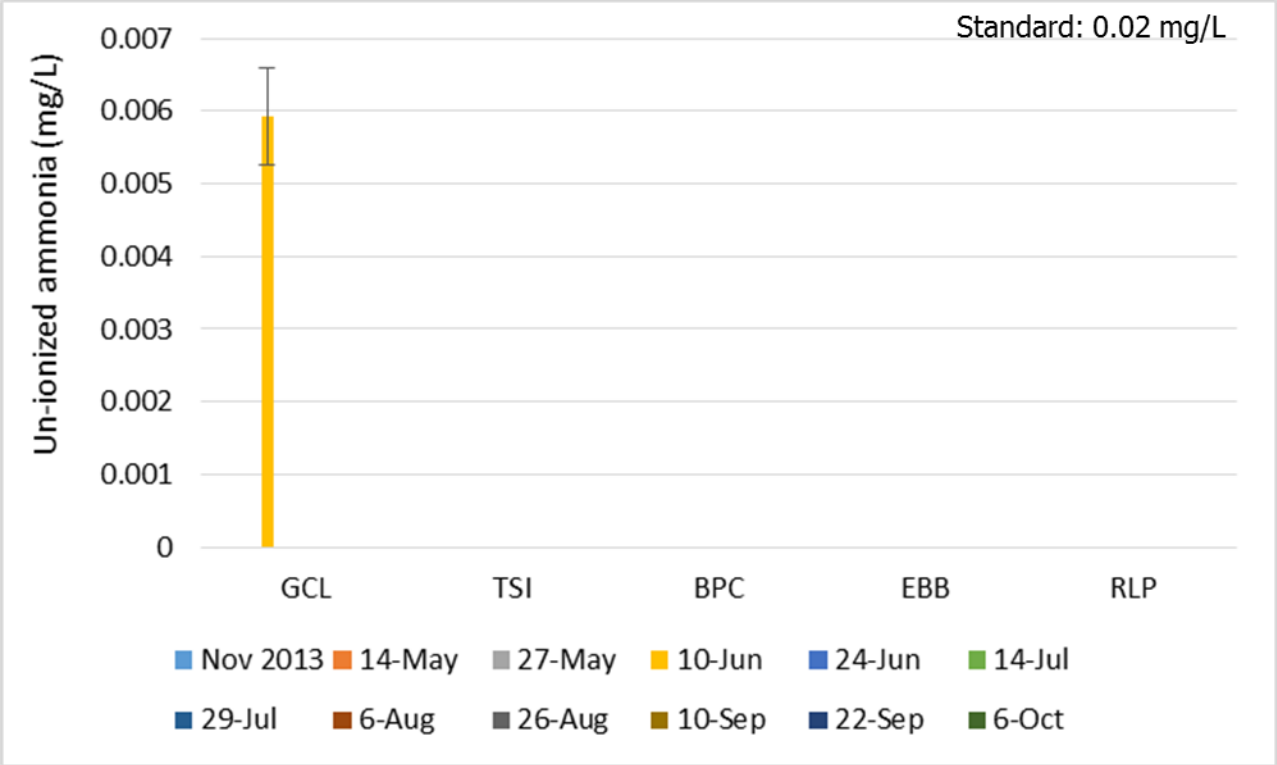

Figure 25: Un-ionized ammonia (mean value, error bar +/- SE)

Since un-ionized ammonia was only detected once during the field season, the results for total ammonia (un-ionized ammonia + ammonium) are almost identical to those for ammonium. Mean values of total ammonia (n=3), ranged from 0.009 mg/L (August 6 at Gros Cap) to 0.123 mg/L (June 10 at Gros Cap) (Figure 26). The minimum mean value for ammonium was the same but the maximum mean value was 0.117 mg/L (June 10 at Gros Cap).

Mean total ammonia concentrations, all results included, were: Gros Cap (0.020 mg/L), Bellevue Park (0.019 mg/L), Bell's Point (0.019 mg/L), Echo Bay (0.013 mg/L) and Richards Landing (0.015 mg/L). The only mean result that differed for ammonium was Gros Cap (0.019 mg/L).

There was a spike in total ammonia at Gros Cap on June 10 (range: 0.098-0.145 mg/L). Smaller, but also noticeable, relative spikes occurred at Bellevue Park on June 10 (range: 0.029-0.117 mg/L) and July 29 (range: 0.031-0.084 mg/L)

Total ammonia was not detected (MDL=0.01 mg/L) in any water samples except those from Bell's Point on May 27. Levels were also below method detection limits at all sites on August 6 and October 6, as well as being undetectable in samples from both Gros Cap and Echo Bay on September 10, and Gros Cap, Echo Bay, and Richards Landing on September 22.

On June 10 total ammonia was significantly higher at Gros Cap than Bell's Point (p=0.028). On August 6, total ammonia was significantly lower at Gros Cap than Richards Landing (p=0.044). However, in general, total ammonia levels were greater at the upstream (Gros Cap, Bellevue Park and Bell's Point) versus the downstream (Echo Bay and Richards Landing) locations.

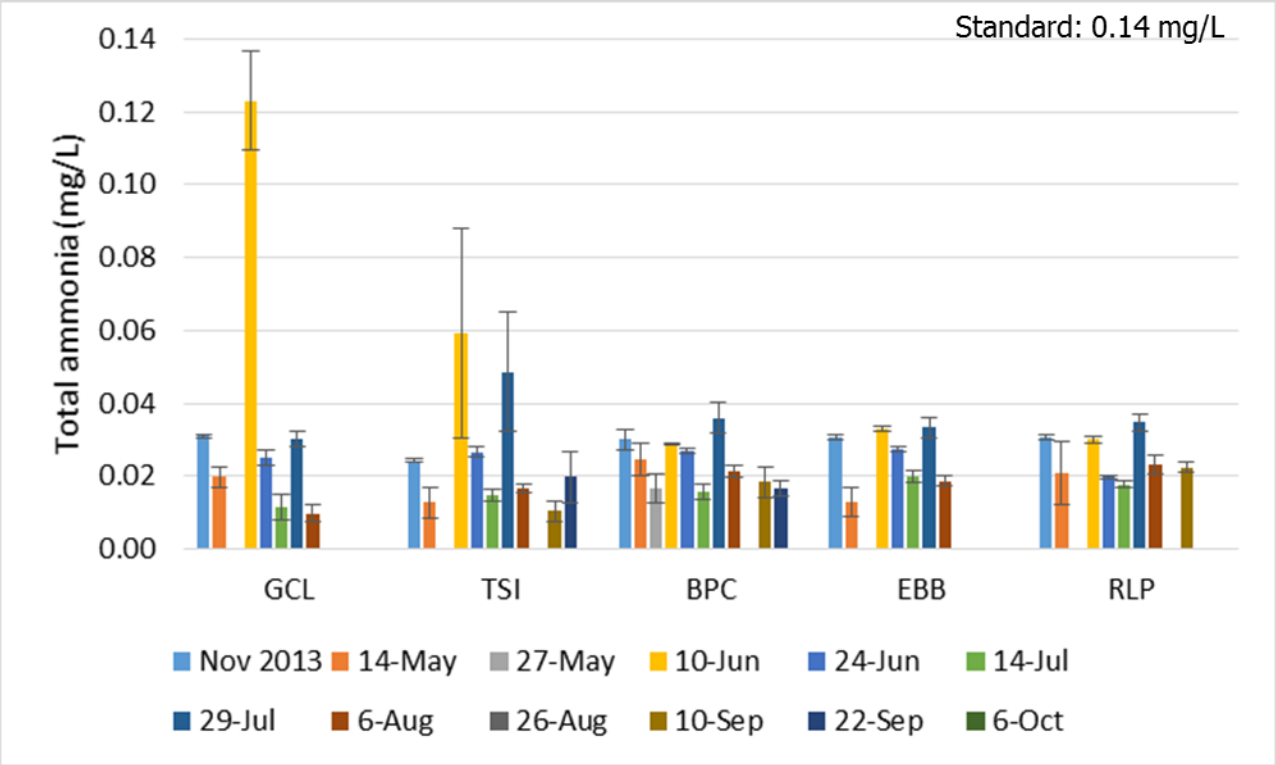

Figure 26: Total ammonia (mean values, error bars +/- SE)

Nitrite and Nitrate
Nitrite was not found at detectable levels (MDL=0.03 mg/L) in any of the water samples collected.

Mean nitrate values (n=3), ranged from 0.08 mg/L (Echo Bay on June 10) to 0.40 mg/L (Bellevue Park on August 26) (Figure 27). Mean nitrate levels, all results included, were: Gros Cap (0.28 mg/L), Bellevue Park (0.28 mg/L), Bell's Point (0.27 mg/L), Echo Bay (0.14 mg/L) and Richards Landing (0.20 mg/L).

Nitrate was not detected (MDL=0.1 mg/L) in samples taken from Echo Bay or Richards Landing on July 29 and those from at Echo Bay on September 22. Significantly more nitrate was found on June 10 at Bell's Point than Echo Bay (p=0.014) and on October 6 at Bellevue Park than Echo Bay (p=0.024). In general, nitrate levels were lower at Echo Bay and Richards Landing compared with the other three monitoring sites.

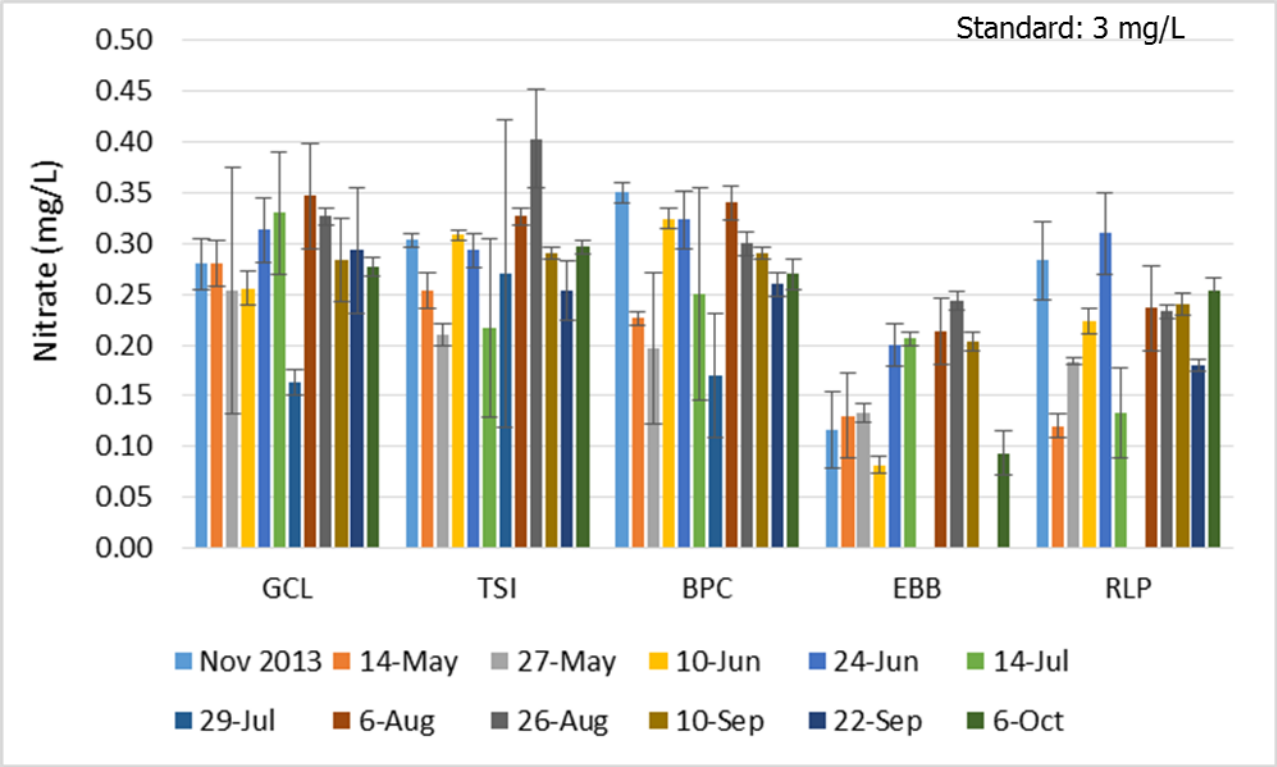

Figure 27: Nitrate (mean values, error bars +/- SE)

Total Kjeldahl Nitrogen and Total Nitrogen

Total Kjeldahl nitrogen mean concentrations (n=3) varied from 0.28 mg/L (Gros Cap on October 6) to 1.27 mg/L (Bellevue Park on August 6) (Figure 28), while mean total nitrogen values (n=3), including all nitrogen sources, ranged from 0.52 mg/L (Gros Cap on October 6) to 1.59 mg/L (August 6 at Bellevue Park) (Figure 29).

Mean total Kjeldahl nitrogen values, all results included, were: Gros Cap (0.53 mg/L), Bellevue Park (0.57 mg/L), Bell's Point (0.48 mg/L), Echo Bay (0.58 mg/L) and Richards Landing (0.56 mg/L). Mean total nitrogen readings, all values and nitrogen sources included, were: Gros Cap (0.81 mg/L), Bellevue Park (0.85 mg/L), Bell's Point (0.75 mg/L), Echo Bay (0.72 mg/L) and Richards Landing (0.76 mg/L). Readings were lowest for total nitrogen on September 10 (range: 0.20-0.35 mg/L) as Total Kjeldahl nitrogen was not detected (MDL=0.2 mg/L) in any samples taken on that date.

In general, mean levels of both total Kjeldahl nitrogen (Gros Cap 1.20 mg/L, Bellevue Park 1.27 mg/L, Bell's Point 0.74 mg/L, Echo Bay 0.80 mg/L and Richards Landing 0.84 mg/L) and total nitrogen (Gros Cap 1.55 mg/L, Bellevue Park 1.59 mg/L, Bell's Point 1.08 mg/L, Echo Bay 1.02 mg/L and Richards Landing 1.08 mg/L) were elevated on August 6. There were also relative spikes of total Kjeldahl nitrogen (range: 0.54-1.30 mg/L) and total nitrogen (range: 0.75-1.49 mg/L) at Bellevue Park on May 27. Significantly lower levels of total Kjeldahl nitrogen were found at Gros Cap than Echo Bay on June 10 ($p=0.010$) and at Bell's Point than Bellevue Park on August 6 ($p=0.014$).

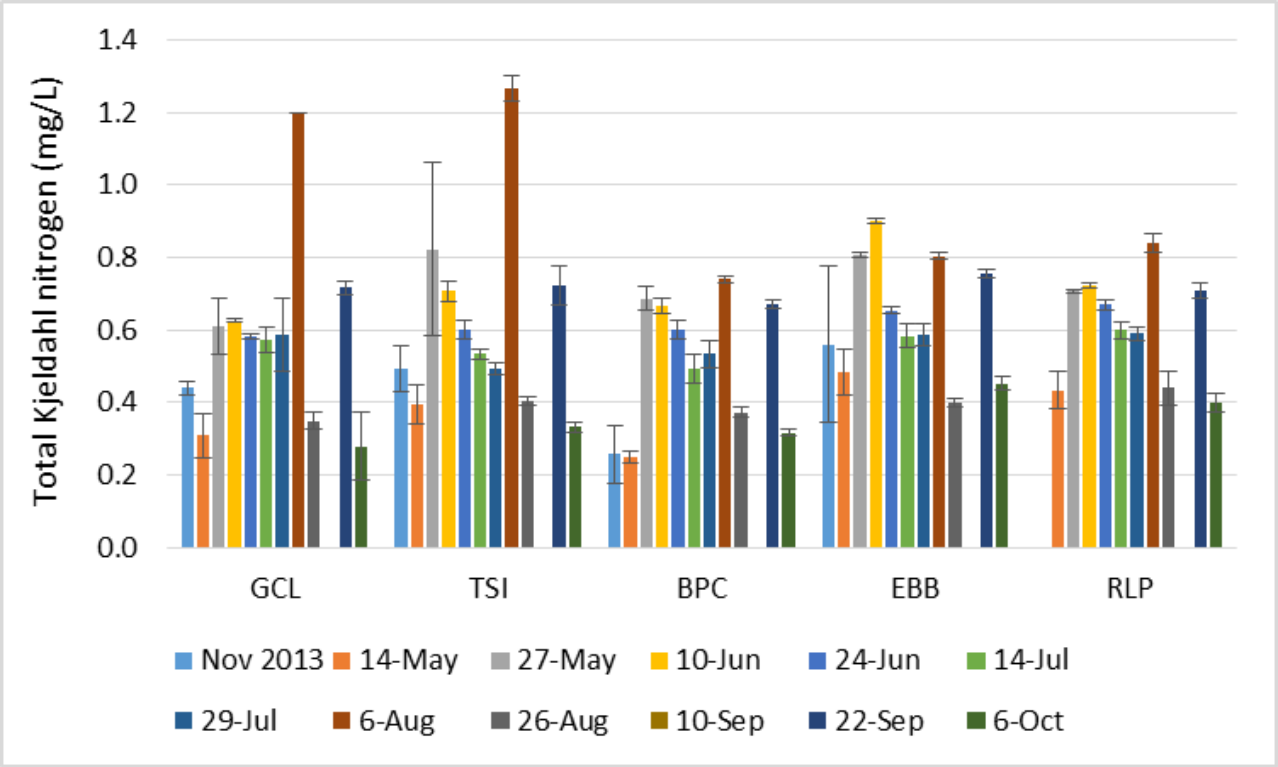

Figure 28: Total Kjeldahl nitrogen (mean values, error bars +/- SE)

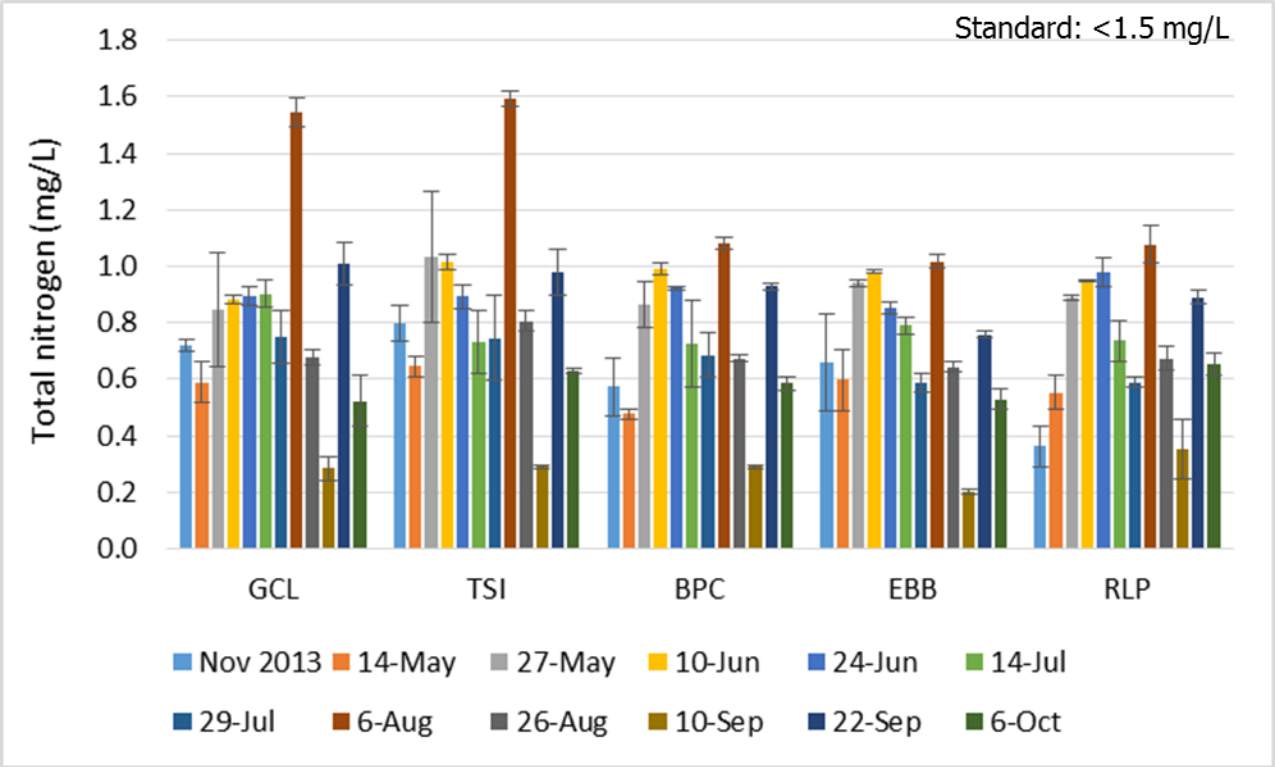

Figure 29: Total nitrogen (mean values, error bars +/- SE)

Comparing total Kjeldahl nitrogen, which measures ammonia and organic nitrogen, to total nitrogen, which includes ammonia, organic nitrogen and nitrates, it can be observed that the majority of total nitrogen in water samples was in the form of either nitrate or organic nitrogen. Further comparisons to total ammonia levels demonstrate that the majority of nitrogen detected was organic. Approximate mean values of total nitrogen, based on relative mean amounts of ammonia, organic nitrogen, and nitrate, were calculated and are shown in Figure 30.

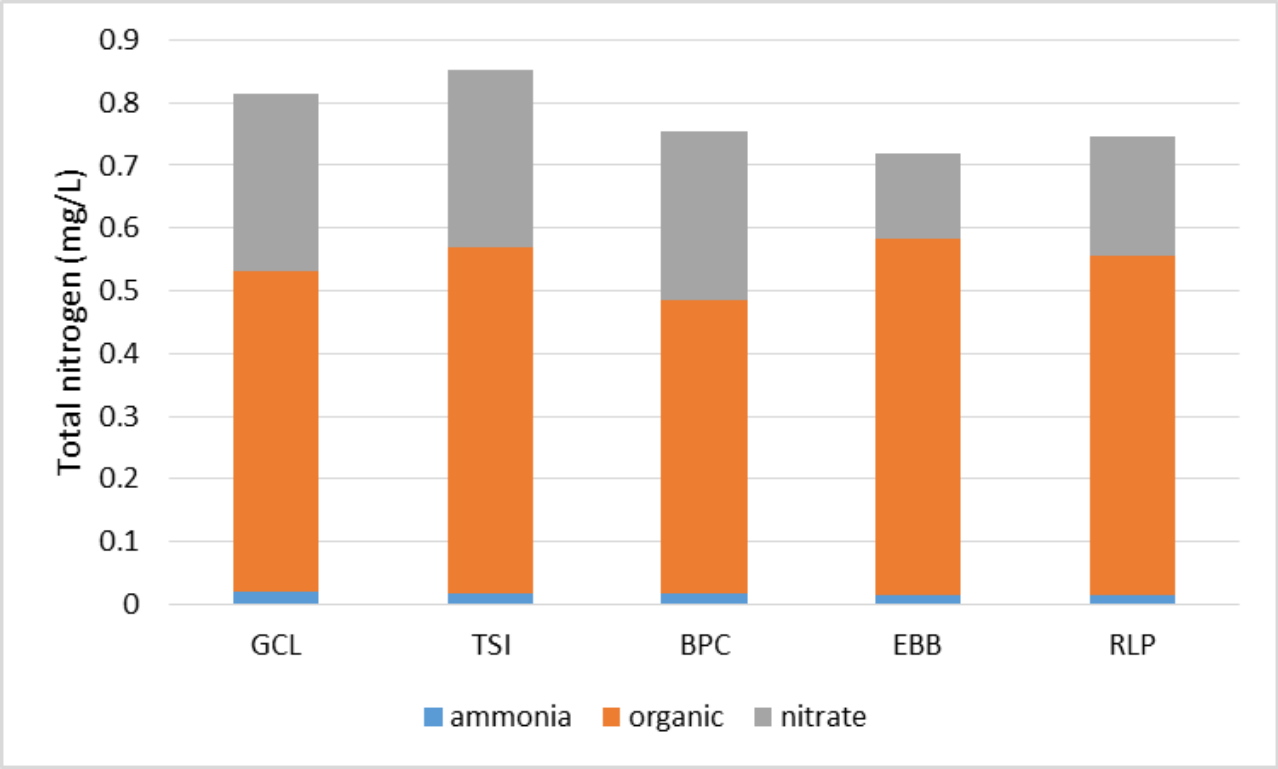

Figure 30: Approximate total nitrogen by source (mean values)

Discussion

Methods and Monitoring Site Characteristics

The 2014 field season was successful and proceeded according to plan. The monitoring sites remained accessible and had characteristics appropriate for the purpose of the study. The protocols used for the collection of aesthetic, physical and chemical parameters worked well and yielded good results. The laboratory analysis was done in a professional and timely manner.

The only deviations from the workplan were related to field work frequency. Monitoring did not occur in April, due to cold weather conditions, and for a second time in October, due to financial constraints. It is recommended that future monitoring be scheduled from May to October.

Aesthetic, Physical and Chemical Parameters

Water Clarity, Total Suspended Solids and Turbidity

Visual water clarity was always "clear" at Gros Cap, Bellevue Park and Bell's Point. These results were confirmed by almost exclusively maximum measurements for both the Secchi disc and turbidity tube at these locations, as well as consistently low readings for both total suspended solids and turbidity.

An exception was June 24 at Gros Cap, when the turbidity tube measurement was low, and both total suspended solids and turbidity levels were uncharacteristically high. These results can be explained by the conditions that were encountered on that date. It was raining and a temporary stream was washing into the water column immediately upstream of the sampling location, producing intermittent waves of suspended particulate matter (Figure 31). Since the wind was blowing in a northwesterly direction (downstream), water clarity was impaired to various degrees while sampling was occurring. This accounts for the visual observation of water being "clear" while having a low turbidity tube reading. It also explains the variability in laboratory results for total suspended solids and turbidity, because replicates, which were collected at slightly different times, caught different amounts of suspended material.

Figure 31: Precipitation events, runoff, and water clarity at Gros Cap

Similar runoff was observed when it was raining heavily on September 10 (Figure 31). Therefore, it is expected that particulate matter enters the water at Gros Cap every time there is a significant precipitation event. However, water clarity measurements for this study were not impacted on September 10 because the wind was blowing in a southeasterly direction (upstream), moving waves of suspended material away from the sampling location.

Visual estimations of "slight" to "moderate turbidity", combined with lower Secchi disc and turbidity tube measurements, as well as higher total suspended solids and turbidity readings, indicate that water was not as clear at Echo Bay and Richards Landing. The decreased water clarity at the two most downstream sites, can be explained by weather conditions, substrate type, water velocity and localized recreational activities, and are not likely due to factors, such as industrial and municipal wastewater discharges, which were linked with decreased water clarity in the St. Marys River in the past (CCME 2002; RAP 1992).

The decreased water clarity and higher total suspended solids at Echo Bay and Richards Landing on May 14 may be explained by wind and wave action, as well as runoff from rain which fell the previous day. The extreme peak in total suspended solids at Richards Landing on that date was surprising, given the rest of the season's results, however, it may be partially explained by the fact that the site was visited last on that day, when wind and wave action was greatest. For the remainder of the field season, the sites were monitored in the opposite direction, so that Richards Landing was visited first. All other occasions in which visual water clarity was lowered, and total suspended solids and turbidity were elevated, there was noticeable wind and wave action, often combined with rain events having occurred during the previous few days. An exception was June 10 at Echo Bay, where disturbance by recreational users (boating and fishing) was noted instead.

The substrate type at both Echo Bay and Richards Landing undoubtedly contributed, with weather conditions, to the results for water clarity. Unlike Gros Cap and Bellevue Park, the substrate at both the downstream sites was sand, which is more easily re-suspended in the water column than larger particles like rocks and pebbles (CCME 2002). The fact that water clarity was not decreased at Bell's Point, which also had a sandy substrate, can be explained by the observed higher velocity of water at that site compared to both Echo Bay and Richards Landing. Lower water velocities, combined with shoreline features like wetland vegetation, likely contribute to increased sediment retention at Echo Bay and Richards Landing.

The total suspended solids values for all sites were almost exclusively below 20 mg/L, which is considered to be clear water (Michigan 2013). In addition, turbidity levels were almost all below 20 NTU, the range of 0-20 NTU being considered normal (CCME 2002). When compared to the PWQO for turbidity, that "suspended matter should not be added to surface water in concentrations that will change the natural Secchi disc reading by more than 10%" (MOECC 1999, Appendix B, page 27), all monitoring sites meet this criterion, with the exception of Echo Bay on May 27, June 10, and October 6. If it is considered that there is naturally more turbidity at Echo Bay, then the Degradation of Aesthetics beneficial use delisting criterion of river waters being free of "unnatural turbidity" has been met (RAP IA 2015).

Water Colour

Colour was always "clear" at Gros Cap, Bellevue Park and Bell's Point, with "light yellow" to "light brown" colouration noted in several samples from Echo Bay and Richards Landing. Many natural factors contribute to water colour, including minerals, plant debris, plankton and suspended sediments (CCME 2001). Sources directly attributable to human activities, such as fertilizers, eroded soil, and industrial and municipal effluents, also influence water colour (CCME 2001).

Given that both Echo Bay and Richards Landing had relatively higher total suspended solids, turbidity, and chlorophyll a levels, as well as sandy substrates and adjacent wetland vegetation, it is suspected that the observed water colour can be attributed mainly to plant debris, plankton and suspended sediments. The yellow-brown colour of some phytoplankton, particularly diatoms and dinoflagellates (CCME 2001), may help to explain the yellow-brown colouration of the water samples. It also offers a reason why chlorophyll a readings were typically higher at Echo Bay and Richards Landing, although algae were rarely observed.

Given that the water colours detected were likely of natural origin, the river water samples investigated during this project meet the Degradation of Aesthetics beneficial use delisting criterion of being free of "unnatural colour" (RAP IA 2015).

Water Odour

No water odours were detected at any of the monitoring sites during any of the field work dates. This meets the delisting criterion for the Degradation of Aesthetics beneficial use which states that the river should be devoid of substances which produce a persistent "unnatural odour" (RAP IA 2015).

Algae and Chlorophyll a

Algae were observed attached to large rocks at both Gros Cap and Bellevue Park. Since the substrates at Bell's Point, Echo Bay, and Richards Landing were sandy, this may be the reason why very little algae were observed at those monitoring sites. Any algae seen at Echo Bay and Richards Landing were usually floating. The supposition that attachment sites may limit visible algal growth may be supported by the fact that, when a cement block was submerged by rising water levels at Bell's Point, algae grew on it.

Chlorophyll a levels did not seem to be closely connected to visual observations of algae. In fact, although the majority of visual observations of algae were made at Gros Cap, it had the lowest mean level of chlorophyll a. Perhaps decreased water clarity at the downstream sites, indicated increased concentrations of microscopic algae. This might explain the significantly higher level of chlorophyll a at Richards Landing on July 29. Although there were no visual observations of algae on that date, water was more turbid than usual. Generally warmer water temperatures (CCME 2002) combined with higher phosphorus levels (CCME 2004) at Echo Bay and Richards Landing, would allow for greater algal productivity at those sites.

The spike in chlorophyll a at Bellevue Park on May 27 can be explained by floating algae entering the sampling bottles. The observed algae were likely dislodged from the surrounding rocks by strong wave action and dogs playing in the water on that date. Wave action and visible algae probably also account for the smaller peak in chlorophyll a also measured May 27 from samples taken at Richards Landing.

Values for chlorophyll a were all under the 10 µg/L recommended in the Stage 2 Remedial Action Plan (RAP 2002). In addition, no large clumps or mats of algae were seen. This meets the Eutrophication and Undesirable Algae beneficial use delisting criterion of the river being free from persistent or re-occurring "large algal blooms" (RAP IA 2015).

Debris
Only natural types of debris were observed. There were no sheens, oil, grease, solids, or scums detected at any time. Any shoreline garbage could be attributed to local recreational use, not municipal or industrial sources.

These observations meet the PWQO, for oil and grease, of not having oil or petrochemicals present in concentrations that "can be detected as a visible film, sheen or discolouration on the surface" or "form deposits on shorelines and bottoms sediments that are detectable by site" (MOECC 1999, Appendix B, page 22). The river conditions also meet the Degradation of Aesthetics beneficial use delisting criterion of being free of "objectionable deposits" (RAP IA 2015) and support the language in the Stage 2 Remedial Action Plan which indicates that river waters should be devoid of oil slicks and surface scums (RAP 2002).

Field Water pH
Only one field pH value fell outside the PWQO range of 6.5 to 8.5 which is recommended to "protect aquatic life" and avoid "irritation to anyone using the water for recreational purposes" (MOECC 1999, Appendix B, page 22). The unusually high level of 8.7 measured on May 27 at Bellevue Park was accompanied by a greater than normal amount of human disturbance.

Field Water Temperature
Field water temperature (2.8-20.4 °C) varied correspondingly with air temperature (7.5-25.8 °C) and fell within the range of expected values (0-22 °C) for the St. Marys River (RAP 1992). The PWQO for temperature states that "the natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment", environmental quality referring to "the diversity, distribution and abundance of plant and animal life" (MOECC 1999, Appendix B, page 25). Although it was beyond the scope of this study to monitor species composition, the thermal regime, as measured by field water temperatures at the sites investigated, was normal.

Dissolved Oxygen
The dissolved oxygen content of surface waters can be influenced by factors such as temperature, turbulence and biological processes (CCME 1999). Mean dissolved oxygen readings for all sites varied as predicted, with the greatest dissolved oxygen levels being found at the sites with the lowest temperatures. This result was expected since oxygen saturation increases with decreased water temperature (CCME 1999). Temperature measurements help to explain why dissolved oxygen was found to be significantly greater at Gros Cap than both Echo Bay and Richards Landing, and at Bellevue Park compared to Echo Bay. Increased turbulence, accompanied by greater incorporation of oxygen into surface waters, also explains the differences in dissolved oxygen levels, particularly those between Bellevue Park and Echo Bay. In addition, since Echo Bay and Richards Landing both had lower water clarity, possibly indicative of organic material and microbiological activity, as well as higher chlorophyll a levels, showing the presence of phytoplankton, and visible wetland vegetation, it is likely that biological processes, requiring oxygen, contributed to the lower dissolved oxygen levels at those sites.

Although dissolved oxygen concentrations varied between monitoring sites, all measurements were greater than the PWQO of 8 mg/L required for waters containing the most sensitive cold water species, including salmonids (MOECC 1999). Having adequate dissolved oxygen levels, therefore, it can be concluded that the Eutrophication and Undesirable Algae beneficial use delisting criterion of the river being free from "oxygen stress" was met (RAP IA 2015).

Total Phosphorus

Phosphorus is often the limiting nutrient in terms of productivity in aquatic ecosystems (CCME 2004). Excess inputs of phosphorus, often of human origin, have been demonstrated to lead to dramatic increases in plant and algal biomass (CCME 20014). Undesirable effects of these "blooms" include decreased ecosystem biodiversity, increased turbidity, and oxygen depletion in affected waters (CCME 2004). Degraded aesthetics, restricted recreational activities, and human health effects, are also linked to high levels of phosphorus in aquatic systems (CCME 2004).

The significantly higher levels of phosphorus at Echo Bay compared to both Gros Cap and Richards Landing may be explained by the flushing of agricultural-based inputs (e.g. fertilizers containing phosphorus) from Echo Bay into Lake George, where water samples were collected. This may be supported by the fact that most high readings were taken during the spring months and usually after periods of runoff-inducing rain. Often when phosphorus was elevated above levels measured during other sampling dates, there was wind and wave action. This type of perturbation could lead to disturbed sediments releasing phosphorus into the water column. However, it is difficult to explain the spike in phosphorus at Echo Bay on June 10. There were no rain events or wave action noted around that date. However, the stirring up of nutrients on bottom sediments may have happened due to the increased intensity of human activity (boating and fishing) observed on that day.

The majority of total phosphorus readings fell below the PWQO of 0.030 mg/L for rivers and streams (MOECC 1999). In fact only one of the three readings at Echo Bay on June 10 (0.058 mg/L) fell above that number. Phosphorus levels above 0.035 mg/L are typical of eutrophic environments while readings from 0.004 to 0.035 mg/L indicate oligotrophic to mesotrophic conditions (CCME 2004). However, although fluctuations of phosphorus levels above normal background conditions should be monitored (CCME 2004), evidence indicates that phosphorus inputs are not leading to eutrophication at the sites investigated.

Dissolved Organic Carbon

Dissolved organic carbon refers to the fraction of total organic carbon in a water sample, which has been passed through a 0.45 µM filter (personal communication 2015, Testmark Laboratories) to remove the larger particulate organic carbon (BC 2015). The amount of dissolved organic carbon in aquatic ecosystems is influenced by the amount of available organic material, which may come directly from within a water body (e.g. phytoplankton or aquatic plants) or be transported from the nearby landscape (e.g. leaves or soil) (BC 2015). Human activities such as shoreline alteration, agriculture, and the release of industrial and municipal wastewaters, may also contribute to the dissolved organic carbon fraction (BC 2015). Since dissolved organic carbon plays a role in pH regulation, may influence the bioavailability of certain toxicants (such as metals), and is a nutrient source, which helps to sustain aquatic organisms, changes in dissolved organic carbon concentrations may constitute a negative environmental impact (BC 2015).

The highest dissolved organic carbon levels measured at the monitoring sites corresponded with rain events as well as wind and wave action. In the case of the elevated dissolved organic carbon levels at Gros Cap on June 24, runoff was seen directly entering the river near the sampling site. Generally higher levels of dissolved organic carbon at both Echo Bay and Richards Landing, including significantly higher levels at Echo Bay than both Gros Cap and Bell's Point, were also often accompanied by lower water clarity and the presence of a water colour, both characteristics which are correlated with increased dissolved organic carbon (BC 2015). Possible sources of dissolved organic carbon at the two most downstream sites include: phytoplankton, aquatic plants and agricultural runoff.

With one exception at Gros Cap, dissolved organic carbon values at Gros Cap, Bellevue Park, Bell's Point and Richards Landing, were less than 5 mg/L, concentrations which are considered normal in many lakes and rivers (BC 2015). However, dissolved organic carbon values may be very site-specific and vary according to seasonal inputs and short-term events such as storms (BC 2015). It is suspected that weather events had an influence on the dissolved organic carbon concentrations at Echo Bay, although it appeared that they were more influential there than at the other sites. Perhaps this indicates that there are more sources of dissolved organic carbon at Echo Bay than the other monitoring sites. There are no PWQO for dissolved organic carbon in Ontario. The recommended criterion for the protection of aquatic life in British Columbia includes provisions against changes above or below the seasonally-adjusted median levels (BC 2015). After only one season of monitoring it is difficult to determine what constitutes appropriate seasonal levels. Therefore, it is suggested that the 2014 data be compared to the 2015 numbers in order to enable conclusions about levels of dissolved organic carbon, particularly at Echo Bay.

Un-ionized Ammonia, Ammonium and Total Ammonia

Ammonia is readily soluble in water and can be found as un-ionized ammonia and/or the ammonium ion (CCME 2010). Sources of ammonia in aquatic environments may include, agricultural fertilizers, as well as industrial (e.g. steel mills), municipal (e.g. wastewater treatment plants) and residential releases (CCME 2010). The natural breakdown of organic wastes also leads to the production of ammonia and other forms of nitrogen (CCME 2010; Smith & Smith 2006).

Levels of total ammonia tended to be greatest at the two most upstream monitoring sites, Gros Cap and Bellevue Park. The dates in which there were the highest ammonia levels coincided with human activities at both sites. A peak in total ammonia at Gros Cap on June 10 (0.10-0.15 mg/L) resulted from spikes in both un-ionized ammonia and ammonium on that date. It is suspected that releases from movie crew trailers that were seen parked at Gros Cap on that day may have been responsible for the uncharacteristically high levels. According to the CWQG for ammonia, concentrations of greater than 0.1 mg/L are indicative of organic pollution (CCME 2010). This is also supported by the fact that organic nitrogen made up the majority of total nitrogen calculated at all sites. Although less spectacular, peaks of total ammonia at Bellevue Park on both June 10 and July 29 can also be best explained by human activity, particularly dog-walking. On both occasions, dogs were observed swimming in nearby waters.

The PWQO for un-ionized ammonia is 0.02 mg/L. Despite the one peak in un-ionized ammonia, this level was not exceeded. Ammonia toxicity is pH and temperature dependent, with higher pH values and warmer temperatures increasing toxicity (CCME 2010). When considering the

CWQG for total ammonia, at a worst case scenario using the range of temperatures and pH values encountered during monitoring (pH 8.5, 20°C), the water quality standard is 0.14 mg/L. This was only exceeded for one measurement (rounded to 0.15 mg/L), therefore, despite the evidence of anthropogenic inputs, total ammonia levels generally met the water quality guidelines.

Nitrite and Nitrate

Since nitrite was not found at detectable levels in any of the water samples collected, if present, it must have been at concentrations lower than 0.03 mg/L (the method detection limit). Given that the CWQG for nitrite as nitrogen is 0.06 mg/L (CCME 2015), nitrite levels met the water quality standard. The low concentrations of nitrite may be explained by active nitrification or denitrification processes, which would have transformed any nitrite into either nitrate or ammonium, both of which were found at measurable concentrations (CCME 2012).

Nitrate is often the predominant form of nitrogen found in surface waters, so it is not surprising that it was detected at measurable concentrations (CCME 2012). Although there are natural sources of nitrates, including the decomposition products of organic material, inputs are often a direct result of, or enhanced by, human activities (CCME 2012). Human sources include atmospheric deposition, agricultural runoff (e.g. manure and fertilizers), municipal wastewaters and industrial effluents (e.g. steel and pulp and paper mills) (CCME 2012).

Nitrate levels were highest at the three most upstream sites, compared to the two most downstream locations, indicating perhaps that, although nitrates were present at all sites, biological assimilation was greater downstream (CCME 2012). This is supported by the fact that there was more aquatic vegetation, and evidence of plankton, at both Echo Bay and Richards Landing. In fact, nitrates are the primary source of nitrogen for aquatic plants (CCME 2012). The levels of nitrates found at Gros Cap (mean: 0.28 mg/L) correspond with the published mean value of 0.30 mg/L of nitrate as nitrogen for Lake Superior (CCME 2012). Since levels downstream at Bellevue Park and Bell's Point were similar to those at Gros Cap, it can be assumed that industrial, urban and municipal sources are not contributing greatly to surface water nitrate concentrations at those sites. This is not completely surprising given the stronger industrial effluent regulations, closure of the pulp and paper mill, and upgrades to municipal wastewater treatment, which have led to reduced anthropogenic nutrient inputs since the St. Marys River was first designated as an Area of Concern (RAP IA 2015).

Although, given the land uses surrounding them, it was more probable for there to be nitrates from agricultural runoff at Echo Bay and Richards Landing, both showed comparatively lower concentrations. This suggests that agricultural inputs are not important at those sites, or if they are present, the processes of assimilation and sedimentation are removing nitrates from the water column (CCME 2012). Unmeasurable levels of nitrates at Echo Bay and Richards Landing on July 29, correspond with the finding that nitrate levels may be lowest in the spring and summer due to increased biological uptake (CCME 2012).

All measured values of nitrate were well below the CWQG of 3.0 mg/L for nitrate as nitrogen (CCME 2012). The concentrations generally fell within the range (0.09-0.90 mg/L) for mesotrophic waters and never exceeded the 0.90 mg/L indicative of eutrophic conditions (CCME 2012).

Total Kjeldahl Nitrogen and Total Nitrogen

The total Kjeldahl nitrogen method measures ammonia and organic nitrogen in water samples (MOECC 2006). When comparing total Kjeldahl nitrogen values to total ammonia concentrations, it can be seen that organic nitrogen makes up the greatest amount of this measurement for all monitoring sites. High levels of total Kjeldahl nitrogen on August 6 may be explained by the fact that this was a warm and sunny day and many people were engaged in recreational activities near the water. Research has shown that non-point sources may contribute almost twice as much as point sources to human inputs of nitrogen into aquatic ecosystems, and that small but concentrated releases may have large localized effects (CCME 2012). This may be the case for the monitoring sites investigated, as the spike at Gros Cap on August 6 was accompanied by an unusually high amount of recreational users, and peaks on May 27 and August 6 at Bellevue Park happened when many people and dogs were observed near the shoreline and entering the water. Direct deposits of organic nitrogen (especially from dogs) and/or the disturbing of sediments containing organic nitrogenous material, are possible methods whereby increased recreational use may have contributed to elevated total Kjeldahl nitrogen concentrations.

Total nitrogen is a calculation of all of the nitrogen sources available: ammonia, anions and organic nitrogen. Peaks in total nitrogen mirrored those for total Kjeldahl nitrogen and confirm that organic nitrogen was the primary form detected at all sites. The amount of organic carbon was approximately the same at Bellevue Park, Echo Bay and Richards Landing (~0.6 mg/L) and approximately equal but slightly lower at Gros Cap and Bell's Point (~0.5 mg/L). This suggests that there are greater inputs of organic nitrogen at Bellevue Park, Echo Bay and Richards Landing, than at Gros Cap and Bell's Point.

When compared to average total nitrogen levels in streams, with only two exceptions, values were within the ranges expected in oligotrophic (< 0.7 mg/L) or mesotrophic (0.7-1.5 mg/L) environments (CCME 2012). Levels of greater than 1.5 mg/L may indicate eutrophication (CCME 2012). Readings of more than 1.5 mg/L at both Gros Cap and Bellevue Park, accompanied by high recreational use, suggest impact from localized human activities.

Conclusion

Eutrophication and Undesirable Algae

The revised delisting criterion for the Eutrophication and Undesirable Algae beneficial use impairment states that:

"*This beneficial use will no longer be impaired when comprehensive tests of the Area of Concern's water quality demonstrate the river is free from persistent or reoccurring problems associated with oxygen stress (eutrophication) and large algal blooms, as determined through a comparison to established guidelines for the relevant physical and chemical parameters* (RAP IA 2015)."

Results of the second field season (2014) of water quality monitoring within the Canadian St. Marys River Area of Concern, indicate that, at the sites investigated, oxygen stress is absent, large algal blooms and high concentrations of microscopic algae are non-existent, and the vast majority of nutrients measured (phosphorus, carbon and nitrogen) always fell below the recommended guidelines and within the levels typically found in either oligotrophic or mesotrophic, but not eutrophic, waters.

Degradation of Aesthetics

The revised delisting criterion for the Degradation of Aesthetics beneficial use impairment states that:

"*This beneficial use will no longer be impaired when comprehensive tests of the Area of Concern's water quality demonstrate that the river is devoid of any substances that produce a persistent objectionable deposit, unnatural colour or turbidity, or unnatural odour, and is free from persistent or reoccurring problems associated with degraded aesthetics* (RAP IA 2015)."

Results of the second field season (2014) of water quality monitoring within the Canadian St. Marys River Area of Concern, indicate that, at the sites investigated, there was no evidence of objectionable deposits, unnatural colour, unnatural turbidity, or unnatural odour, and therefore, no problems associated with degraded aesthetics.

Future Work

The second year of the project (2014-2015) was successful and we look forward to continuing the work in the third and final year of the endeavour, using the same methods and protocols.

One of the themes that emerged from the data collected in 2014 was small, localized, human impacts, particularly when people were engaging in recreational activities near the water. It appears that large-scale improvements in environmental regulations and infrastructure have helped to dramatically improve the trophic status and aesthetic conditions in the Canadian St. Marys River Area of Concern. However, although there is still work ahead for the project partners and the BPAC to review the data collected during this study, it appears that there is also a role for interested parties to play in continuing water stewardship education in a local context.

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Appendices

Appendix 1: Field Data Collection Sheet

FIELD DATA SHEET: Aesthetics Monitoring and Field Measurements

Area of Concern: St. Marys River **Site Description:**_____

Field Team:_____

Date:_____ **Start Time:** _____**End Time:**_____

GPS: _____ **Elevation:** _____

Weather (check all that apply): Rain Today ☐ Clear ☐ Windy ☐

Air temp.:_____ °C Rain Yesterday ☐ Cloudy ☐ Other _____

WATER CLARITY (pick one)
Clear ☐
Slightly Turbid ☐
Moderately Turbid ☐
Highly Turbid ☐
Opaque ☐

WATER COLOUR (pick one colour and one qualifier)
Clear ☐ Brown ☐ Green ☐ Yellow ☐
Grey ☐ Black ☐ Milky-White ☐ Other_____
Light ☐ Medium ☐ Dark ☐

VISIBLE DEBRIS/OBVIOUS POLLUTION (pick all applicable)
None ☐ Natural ☐ (leaves, limbs, weeds)
Algae ☐ Film ☐ Sheen ☐ Oil ☐ Grease ☐

ODOUR (pick all applicable)
None/Natural ☐
Musty:
Faint ☐ Strong ☐ None ☐
Sewage/Fishy:
Faint ☐ Strong ☐ None ☐
Anaerobic/Septic:
Faint ☐ Strong ☐ None ☐

Trash:
Floating ☐ Fixed ☐ None ☐
Solids:
Floating ☐ Fixed ☐ None ☐
Scum:
Floating ☐ None ☐

Waterfowl:_____

Comments:_____

_____

Substrate type:_____

Water pH:_____ **Water temperature:**_____°C

Water depth:_____ **Secchi Disc:**_____cm **Turbidity Tube:**_____cm

Number of replicates sampled:_____

Comments:_____

_____

_____

FIELD PHOTO LOG

At minimum the following photographs will be taken:

1. Upstream of the monitoring site
2. Downstream of the monitoring site
3. Perpendicular to the shoreline
4. Three full sample jars against a white backdrop
5. Close-up looking directly into the water
6. Any other items of interest (algae, oil sheens, scum, foam, debris etc.)

Photograph ID	Subject/Comments

Appendix 2: Monitoring Site Characteristics

Table 4: Monitoring site characteristics

Site	Date/ Time	Air Temp (°C)	Weather	Waterfowl
Gros Cap	**May 14** 11:01-11:47 am	8.5	Clear, slight wind, rain yesterday, some cloud, medium sized waves	None
	May 27 4:05 -4:40 pm	17.1	Clear and sunny, slightly windy causing constant wave action	None
	June 10 4:25 -5:05 pm	22.8	Clear, cloudy, quite a bit of cloud now, slight wind, increasing wave action	None
	Comment: movie crew trailers along adjacent shore, sampling upstream of active filming			
	June 24 3:55 -4:35 pm	13.1	Rain today, cloudy, rain moderate to heavy, fog and mist	None
	Comment: water column was occasionally visually turbid due to a temporary stream entering the river just upstream of the sampling site			
	July 14 3:19 -3:40 pm	18.7	Rain today, rain yesterday, cloudy, white-capped waves offshore, wind	None
	July 29 3:19 -3:42 pm	17.1	Clear, windy, waves, substantial rain 2 and 3 days ago	None
	Aug 6 3:31-3:51 pm	21.6	Clear and slightly windy with some wave action	None
	Comment: well-used recreational area, many people at site today			
	Aug 26 3:47-4:13 pm	23.5	Cloudy, windy, large white-capped waves	None
	Sept 10 3:35-4:00 pm	18.0	Rain with periods of HEAVY rainfall, cloudy, very windy, waves, wind direction from the EAST today	Gulls
	Sept 22 3:21-3:48 pm	17.3	Clear with sunny periods, very light wind but large waves present, rained 2 and 3 day ago	None
	Comment: 2 dogs in water upstream just prior to sampling replicate 3			
	Oct 6 3:35-4:03 pm	12	Cloudy but clearing with sunny periods, rain this morning, rain yesterday and substantial heavy rain over the last 3 days, high winds and big waves	Scat
	Comment: human garbage on shore, dog scat, 2 dogs entered the water during sampling			
Bellevue Park	**May 14** 12:40-1:15 pm	14.7	Clear, slight wind, rain yesterday, some clouds, medium-sized waves	Gull
	Comment: 3 dogs in water prior to sampling, dog scat and human garbage on shore			
	May 27 2:40 -3:11 pm	20.4	Clear and sunny, slightly windy causing small white caps	Terns, Gulls Loon Cormorant
	Comment: dogs and owners nearby, dogs in the water at site prior to replicate 3, dog scat and human garbage on shore			
	June 10 2:40-3:15 pm	24.2	Clear and cloudy, slight cloud cover has started to roll in	None nearby
	Comment: dogs playing in the water nearby			
	June 24 2:30 -3:10 pm	19.1	Rain today, cloudy, significantly less wind and wave action than usual, fog	None nearby
	Comment: human garbage on shore			

	July 14 1:57-2:17 pm	20.9	Rain yesterday, clear and cloudy periods, increasing cloud, light wind	None nearby
	Comment: water levels up significantly, sampling at approximate shoreline of 3 weeks previous, 1 dog in water prior to replicate 1, 1 pleasure boat offshore, wave action during replicate 3, kayaker in downstream bay			
	July 29 2:00-2:27 pm	20.7	Cloudy but clearing up, substantial rain 2 and 3 days ago	Scat nearby
	Comment: dogs and owners nearby			
	Aug 6 2:13-2:36 pm	25.6	Clear and slightly windy with some wave action	None
	Comment: people and dogs in the water downstream of sampling site			
	Aug 26 2:30-2:57 pm	20.5	Cloudy, windy, waves on water	None
	Comment: water level looks high, surrounding shoreline flooded			
	Sept 10 2:03-2:31 pm	18.3	Rain with periods of HEAVY rainfall, cloudy, very windy, waves, wind direction from the EAST today	None
	Sept 22 2:03-2:28 pm	15.6	Clear with sunny periods, very light wind, feels much warmer, rained 2 and 3 day ago	None
	Oct 6 2:30-2:53 pm	17.5	Cloudy with brief sunny periods, rain this morning, rain yesterday and substantial heavy rain over the last 3 days, quite windy with wave action	None
	Comment: water level has come up substantially, downstream marsh area flooded			
	Sept 10 10:34-11:01 am	18.7	Light rain, cloudy, windy, small waves	10 gulls, scat
	Sept 22 10:25-10:56 am	10.2	Clear with clouds, windy causing small waves, rained 2 and 3 days ago	Tracks, scat
	Comment: human garbage on shore			
	Oct 6 10:49-11:25 am	7.8	Cloudy, raining currently, rain yesterday and heavy the last 3 days	Scat
	Comment: dog tracks			
Bell's Point	**May 14** 2:30-2:58 pm	12.9	Clear, constant wind, rain yesterday, some clouds, small waves	5 geese, tracks, scat
	Comment: dog and deer tracks on beach within 1-2 m of water, campground not open			
	May 27 1:15-1:55 pm	17.7	Clear and sunny, slightly windy causing wave action	4 geese, tracks, scat
	Comment: deer tracks on beach			
	June 10 1:25-1:55 pm	25.8	clear with clouds	26 geese, tracks, scat
	Comment: canoers in the nearby bay, campers in the campground			
	June 24 1:08-1:52 pm	20.3	Rain today, cloudy, slight wind, rained heavily just prior to sampling and lightly during sampling	40 geese, 20 gulls, loon
	July 14 12:58-1:19 pm	19.4	Rain yesterday, clear and cloudy periods, increasing cloud, some wind getting stronger to windy, small waves	21+ gulls, scat
	Comment: water levels have come up significantly, pools on beach, 3 large pleasure craft (motor boats) came by before replicate 2 and created large wave action			

	July 29 12:42-1:08 pm	20.3	Cloudy, windy, small waves, substantial rain 2 and 3 days ago	20+ gulls and geese, feathers, scat, ducks
	Comment: puddles on shore, human and animal footprints, dogs on beach			
	Aug 6 12:58-1:21 pm	22.0	Clear and slightly windy just starting to cause small waves	20+ geese, 20+ gulls, feathers, tracks, scat
	Comment: children playing on the beach and in the water			
	Aug 26 1:24-1:52 pm	20.2	Cloudy, windy, wavy	Many gulls, scat
	Comment: water level looks high, kids playing at the beach			
	Sept 10 12:55-1:25 pm	18.0	Rain with periods of heavy rainfall, cloudy, windy	5 geese, scat
	Comment: puddles along beach have mostly dried up but water levels are still high, campground still full of trailers but no recreational users were observed			
	Sept 22 12:56-1:20 pm	14.0	Clear with clouds, quite windy causing waves, feels cold, rained 2 and 3 days ago	20+ gulls, tracks, scat
	Comment: deer tracks on beach			
	Oct 6 1:12-1:48 pm	10.8	Cloudy, rain this morning, rain yesterday and substantial heavy rain over the 3 previous days, quite windy with wave action	5 geese, 20+ gulls, tracks, scat
Echo Bay	**May 14** 3:51-4:25 pm	12.3	Windy, rain yesterday, cloudy, small waves	Terns offshore
	Comment: human garbage on shore			
	May 27 11:50 am- 2:30 pm	20.9	Clear, light wispy clouds, sunny, slight wind causing wave action	Terns, 10+ cormorants offshore
	Comment: people fishing nearby, motor boat went by just prior to sampling, human garbage on shore			
	June 10 11:50 am- 12:28 pm	23.3	Clear with clouds	None
	Comment: a couple fishing nearby, cars and boat trailers parked, personal water craft went by just after sampling, human garbage on shore			
	June 24 11:50 am- 12:30 pm	19.9	Rain today, cloudy, slight wind	Terns
	Comment: canoe went by just prior to sampling replicate 1, human garbage on shore			
	July 14 11:44 am- 12:09 pm	20.5	Rain yesterday, clear, some big clouds on the horizon, still (no wind)	Gulls, cormorants offshore
	Comment: human garbage on shore			
	July 29 11:37 am- 12:00 pm	18.3	Cloudy but sun is coming out, windy, small waves, substantial rain 2 and 3 days ago	None
	Comment: human garbage on shore			

	Aug 6 12:00-12:22 pm	21.6	Clear	Terns, gulls, offshore
	Comment: human garbage on shore			
	Aug 26 12:28-12:50 pm	19.9	Cloudy, windy, lots of waves	Gull, cormorant
	Comment: water level looks high, human garbage on shore			
	Sept 10 11:45 am- 12:10 pm	18.1	Rain with periods of heavy rainfall, cloudy, windy	None
	Comment: runoff from the road (highway 17) entering the river from drains on the bridge adjacent to the sampling site, human garbage on shore			
	Sept 22 11:39 am – 12:05 pm	13.7	clear with clouds, windy causing waves, rained 2 and 3 days ago	12 ducks
	Comment: human garbage on shore			
	Oct 6 12:10- 12:40 pm	9.5	Cloudy, rain this morning, rain yesterday and substantial rain over the last 3 days, slight wind and waves	None
	Comment: human garbage on shore			
Richards Landing	**May 14** 5:02-5:34 pm	11.8	Windy, rain yesterday, cloudy, constant small waves	4 (species unidentified)
	Comment: dog and human tracks			
	May 27 10:20 -11:07 am	18.5	Clear, light wispy clouds, sunny	5 geese, terns, scat
	Observations: docks (for swimmers) have been put into the water, the beach has been recently graded, there are dog and human tracks in the sand			
	June 10 10:20-11:05 am	21.8	Clear, very sunny with clouds	Tracks, scat
	Comment: deer tracks			
	June 24 10:25-11:05 am	20.6	Rain today, cloudy, slight wind	Feathers, scat, tracks
	Comments: deer and human tracks, tire tracks, sand castles			
	July 14 10:33-11:03 am	19.6	Rain yesterday, clear, slight wind and light clouds	5 geese, tracks
	Comment: human garbage on shore			
	July 29 10:30-10:56 am	14.4	Cloudy, light wind, some wave action, substantial rain 2 and 3 days ago	Scat
	Comment: human tracks, human garbage on shore			
	Aug 6 10:39-11:07 am	19.3	Clear	
	Comment: two humans entered the water just prior to sampling			
	Aug 26 11:11-11:40 am	19.7	Cloudy, windy, waves on water	Gulls, tracks
	Sept 10 10:34-11:01 am	18.7	Light rain, cloudy, windy, small waves	10 gulls, scat
	Sept 22 10:25-10:56 am	10.2	Clear with clouds, windy causing small waves, rained 2 and 3 days ago	Tracks, scat
	Comment: human garbage on shore			
	Oct 6 10:49-11:25 am	7.8	Cloudy, raining currently, rain yesterday and heavy the last 3 days	Scat
	Comment: dog tracks			

Appendix 3: Aesthetic Parameters

Table 5: Aesthetic Parameters

Site	Date	Visual Clarity	SD, TT (cm)	Visual Colour	Odour	Algae	Debris
Gros Cap	May 14	Clear	50, 60	Clear	None	None observed	None
	May 27	Clear	50, 60	Clear	None	On rocks	None
	June 10	Clear	50, 60	Clear	None	On rocks, floating	None
	June 24	Clear	50, 23	Clear	None	On rocks, floating	Natural
	July 14	Clear	50, 60	Clear	None	On rocks	Natural
	July 29	Clear	50, 60	Clear	None	On rocks	Natural
	Aug 6	Clear	50, 60	Clear	None	On rocks, floating	None
	Aug 26	Clear	50, 60	Clear	None	On rocks	None
	Sept 10	Clear	50, 60	Clear	None	None observed	None
	Sept 22	Clear	50, 60	Clear	None	On rocks	Natural
	Oct 6	Clear	50, 60	Clear	None	On rocks, floating	Natural
Bellevue Park	May 14	Clear	50, 60	Clear	None	None	Natural
	May 27	Clear	50, 60	Clear	None	Floating, on plants	Natural
	June 10	Clear	50, 60	Clear	None	On rocks	Natural
	June 24	Clear	50, 60	Clear	None	On rocks	Natural
	July 14	Clear	50, 60	Clear	None	On rocks	Natural
	July 29	Clear	50, 60	Clear	None	None	None
	Aug 6	Clear	50, 60	Clear	None	None	None
	Aug 26	Clear	50, 60	Clear	None	None	None
	Sept 10	Clear	50, 60	Clear	None	None	Natural
	Sept 22	Clear	50, 60	Clear	None	On plants	None
	Oct 6	Clear	50, 60	Clear	None	None	Natural

Bell's Point	May 14	Clear	50, 60	Clear	None	None	Natural
	May 27	Clear	50, 60	Clear	None	Floating	Natural
	June 10	Clear	50, 60	Clear	None	Floating	Natural
	June 24	Clear	50, 60	Clear	None	None	Natural
	July 14	Clear	50, 60	Clear	None	On cement steps	Natural
	July 29	Clear	50, 60	Clear	None	None	Natural
	Aug 6	Clear	50, 60	Clear	None	None	None
	Aug 26	Clear	50, 60	Clear	None	None	Natural
	Sept 10	Clear	50, 60	Clear	None	None	Natural
	Sept 22	Clear	50, 60	Clear	None	None	Natural
	Oct 6	Clear	50, 60	Clear	None	None	Natural
Echo Bay	May 14	Slightly turbid	45, 30	Light yellow	None	None	Natural
	May 27	Slightly turbid	40, 30	Light yellow	None	None	Natural
	June 10	Slightly turbid	40, 33	Light yellow brown	None	None	Natural
	June 24	Clear	50, 60	Very light yellow brown	None	Floating	Natural
	July 14	Clear	50, 60	Clear	None	On substrate	Natural
	July 29	Moderately turbid	50, 60	Very light brown	None	None	Natural
	Aug 6	Clear	50, 60	Clear	None	None	None
	Aug 26	Slightly turbid	50, 60	Clear	None	None	Natural
	Sept 10	Clear	50, 60	Very light yellow	None	None	Natural
	Sept 22	Slightly turbid	50, 60	Clear	None	None	Natural
	Oct 6	Slightly turbid	40, 27	Light yellow brown	None	None	Natural

Richards Landing	May 14	Slightly turbid	50, 56	Very light yellow	None	Floating	Natural
	May 27	Clear	50, 60	Clear	None	On substrate	Natural
	June 10	Clear	50, 60	Clear	None	None	Natural
	June 24	Clear	50, 60	Clear	None	None	Natural
	July 14	Clear	50, 60	Clear	None	None	Natural
	July 29	Moderately turbid	50, 49	Very light brown	None	None	Natural
	Aug 6	Clear	50, 60	Clear	None	None	None
	Aug 26	Clear	50, 60	Clear	None	None	Natural
	Sept 10	Clear	50, 60	Clear	None	None	Natural
	Sept 22	Slightly turbid	50, 60	Clear	None	None	Natural
	Oct 6	Clear	50, 60	Clear	None	None	Natural

Appendix 4: Physical and Chemical Parameters

The monitoring sites are represented by the following abbreviations: Gros Cap (GCL), Bellevue Park (TSI), Bell's Point (BPC), Echo Bay (EBB) and Richards Landing (RLP).

Single values are expressed for pH and temperature (Temp). Mean values are presented for dissolved oxygen (DO), total phosphorus (Total P), dissolved organic carbon (DOC), chlorophyll a (Chloro a), total suspended solids (TSS), turbidity (Turb), un-ionized ammonia (NH_3), ammonium (NH_4^+), total ammonia (NH_3 + NH_4^+), nitrite (NO_2), nitrate (NO_3), total Kjeldahl nitrogen (TKN) and total nitrogen (Total N).

Readings denoted as below the method detection limits (<MDL) were not measurable using the analytical methods available. Levels of chlorophyll a were not measured (NA) for May 14 samples.

Table 6: Physical and chemical parameters (part I)

Site	Date	pH	Temp (°C)	DO (mg/L)	Total P (mg/L)	DOC (mg/L)	Chloro a (µg/L)	TSS (mg/L)	Turb (NTU)
Gros Cap	May 14	8.2	2.8	13.20	0.003	1.83	NA	<MDL	0.43
	May 27	8.1	5.5	11.33	0.009	2.03	0.67	<MDL	0.99
	June 10	8.5	8.1	10.33	0.005	2.20	<MDL	<MDL	0.77
	June 24	7.9	7.5	13.47	0.008	5.47	1.67	6.53	5.83
	July 14	8.6	16.9	10.40	0.008	2.03	0.65	<MDL	0.52
	July 29	8.2	15.5	10.13	<MDL	1.80	1.37	1.03	0.96
	Aug 6	8.4	17.4	11.07	0.002	1.70	1.37	<MDL	0.52
	Aug 26	8.2	14.9	10.80	0.009	1.50	0.73	<MDL	0.62
	Sept 10	8.2	17.6	10.47	0.002	1.83	1.60	<MDL	0.76
	Sept 22	8.1	14.9	11.00	<MDL	1.80	1.12	1.67	0.44
	Oct 6	8.1	11.3	11.13	<MDL	1.73	1.20	1.10	0.77
Bellevue Park	May 14	8.5	6.4	13.53	0.002	1.90	NA	1.60	2.58
	May 27	8.7	9.9	11.87	0.013	2.13	5.60	<MDL	1.56
	June 10	8.3	10.7	10.67	0.006	2.17	1.72	0.93	1.17
	June 24	8.0	9.3	13.23	0.006	2.13	1.40	1.20	1.14
	July 14	8.3	16.1	10.06	0.008	1.87	0.92	<MDL	1.09

	July 29	8.1	17.5	9.98	0.005	1.90	1.47	3.33	2.08
	Aug 6	8.2	18.5	10.40	0.005	1.67	1.32	1.50	1.75
	Aug 26	8.2	17.7	10.37	0.012	1.60	1.30	3.00	1.85
	Sept 10	8.1	17.6	9.90	0.010	1.80	2.20	3.33	1.14
	Sept 22	8.1	13.9	10.97	<MDL	1.80	1.37	1.13	1.01
	Oct 6	8.1	11.1	11.07	0.004	2.00	1.47	1.87	2.87
Bell's Point	May 14	8.1	8.3	13.07	0.002	2.27	NA	<MDL	1.45
	May 27	8.0	10.8	11.67	0.011	2.30	0.99	4.93	0.99
	June 10	8.0	11.5	10.27	0.005	2.13	0.54	<MDL	0.99
	June 24	8.0	9.5	13.63	0.003	2.03	1.35	<MDL	1.37
	July 14	8.1	17.0	10.17	0.010	1.70	0.58	2.37	1.60
	July 29	8.1	17.3	9.94	0.003	1.90	1.23	2.43	1.76
	Aug 6	8.1	18.6	10.43	0.003	1.70	1.75	1.23	1.80
	Aug 26	8.2	18.4	10.53	0.004	1.60	0.68	<MDL	1.26
	Sept 10	8.1	17.6	10.63	0.003	1.80	1.23	2.13	1.39
	Sept 22	7.7	14.0	10.60	<MDL	2.00	1.40	2.47	1.69
	Oct 6	7.9	11.1	10.90	0.003	2.10	1.63	1.20	2.32
Echo Bay	May 14	7.8	9.5	11.77	0.010	6.16	NA	10.67	22.97
	May 27	7.8	18.5	9.13	0.022	4.83	2.23	13.47	16.17
	June 10	7.6	19.3	8.88	0.035	7.27	1.97	11.33	18.83
	June 24	7.9	19.0	10.37	0.007	2.97	2.10	3.47	6.09
	July 14	8.1	16.9	9.53	0.004	1.93	0.58	<MDL	1.73
	July 29	7.9	18.3	9.29	0.006	3.13	1.97	3.70	5.38
	Aug 6	8.1	20.3	9.70	0.006	2.13	1.30	3.37	2.11
	Aug 26	8.2	19.7	9.76	0.010	1.70	2.03	9.17	4.63

	Sept 10	8.0	18.9	10.57	0.006	2.97	1.77	3.33	3.06
	Sept 22	7.8	12.0	10.50	0.004	4.43	1.63	2.43	5.53
	Oct 6	7.3	11.1	9.89	0.020	7.37	0.68	11.57	23.27
Richards Landing	May 14	8.5	13.1	13.47	0.017	3.83	NA	29.33	8.16
	May 27	8.4	14.5	11.00	0.007	2.63	2.83	6.63	3.63
	June 10	8.1	15.1	9.87	0.006	2.50	1.43	<MDL	2.72
	June 24	8.3	16.8	11.97	0.005	2.23	2.30	3.33	2.61
	July 14	8.1	18.1	9.41	0.010	1.93	0.76	9.49	5.18
	July 29	8.0	17.2	8.58	0.012	2.27	2.67	10.77	9.15
	Aug 6	7.8	20.4	8.93	0.005	1.90	1.27	5.33	2.69
	Aug 26	7.8	19.5	9.98	0.005	1.80	2.30	3.57	3.05
	Sept 10	7.9	18.3	10.00	0.004	1.83	1.83	3.00	2.67
	Sept 22	8.0	11.8	10.67	<MDL	2.13	1.53	3.20	3.46
	Oct 6	8.0	10.7	10.43	0.011	2.80	1.57	2.53	4.00

Table 7: Physical and chemical parameters (part II)

Site	**Date**	**NH_3 (mg/L)**	**NH_4^+ (mg/L)**	**$NH_3 + NH_4^+$ (mg/L)**	**NO_2 (mg/L)**	**NO_3 (mg/L)**	**TKN (mg/L)**	**Total N (mg/L)**
Gros Cap	May 14	<MDL	0.020	0.020	<MDL	0.28	0.31	0.59
	May 27	<MDL	<MDL	<MDL	<MDL	0.25	0.61	0.85
	June 10	0.006	0.117	0.123	<MDL	0.26	0.63	0.88
	June 24	<MDL	0.025	0.025	<MDL	0.31	0.58	0.90
	July 14	<MDL	0.011	0.011	<MDL	0.33	0.57	0.90
	July 29	<MDL	0.030	0.030	<MDL	0.16	0.59	0.75
	Aug 6	<MDL	0.010	0.010	<MDL	0.35	1.20	1.55
	Aug 26	<MDL	<MDL	<MDL	<MDL	0.33	0.35	0.68
	Sept 10	<MDL	<MDL	<MDL	<MDL	0.28	<MDL	0.28
	Sept 22	<MDL	<MDL	<MDL	<MDL	0.29	0.72	1.01

	Oct 6	<MDL	<MDL	<MDL	<MDL	0.28	0.28	0.52

Bellevue Park	May 14	<MDL	0.013	0.013	<MDL	0.25	0.39	0.65
	May 27	<MDL	<MDL	<MDL	<MDL	0.21	0.82	1.03
	June 10	<MDL	0.058	0.059	<MDL	0.31	0.71	1.01
	June 24	<MDL	0.027	0.027	<MDL	0.29	0.60	0.89
	July 14	<MDL	0.015	0.015	<MDL	0.22	0.53	0.73
	July 29	<MDL	0.049	0.050	<MDL	0.27	0.49	0.75
	Aug 6	<MDL	0.017	0.017	<MDL	0.33	1.27	1.59
	Aug 26	<MDL	<MDL	<MDL	<MDL	0.40	0.40	0.81
	Sept 10	<MDL	0.010	0.010	<MDL	0.29	<MDL	0.29
	Sept 22	<MDL	0.020	0.020	<MDL	0.25	0.72	0.98
	Oct 6	<MDL	<MDL	<MDL	<MDL	0.30	0.33	0.63
Bell's Point	May 14	<MDL	0.025	0.025	<MDL	0.23	0.25	0.48
	May 27	<MDL	0.017	0.017	<MDL	0.20	0.69	0.87
	June 10	<MDL	0.029	0.029	<MDL	0.32	0.67	0.99
	June 24	<MDL	0.027	0.027	<MDL	0.32	0.60	0.92
	July 14	<MDL	0.016	0.016	<MDL	0.25	0.49	0.73
	July 29	<MDL	0.036	0.036	<MDL	0.17	0.53	0.69
	Aug 6	<MDL	0.021	0.021	<MDL	0.34	0.74	1.08
	Aug 26	<MDL	<MDL	<MDL	<MDL	0.30	0.37	0.67
	Sept 10	<MDL	0.018	0.018	<MDL	0.29	<MDL	0.29
	Sept 22	<MDL	0.017	0.017	<MDL	0.26	0.67	0.93
	Oct 6	<MDL	<MDL	<MDL	<MDL	0.27	0.32	0.59
Echo Bay	May 14	<MDL	0.013	0.018	<MDL	0.13	0.48	0.60
	May 27	<MDL	<MDL	<MDL	<MDL	0.13	0.81	0.94

	June 10	<MDL	0.033	0.033	<MDL	0.08	0.90	0.98
	June 24	<MDL	0.027	0.027	<MDL	0.20	0.65	0.85
	July 14	<MDL	0.020	0.020	<MDL	0.21	0.58	0.79
	July 29	<MDL	0.033	0.033	<MDL	<MDL	0.59	0.59
	Aug 6	<MDL	0.019	0.019	<MDL	0.21	0.80	1.02
	Aug 26	<MDL	<MDL	<MDL	<MDL	0.24	0.40	0.64
	Sept 10	<MDL	<MDL	<MDL	<MDL	0.20	<MDL	0.20
	Sept 22	<MDL	<MDL	<MDL	<MDL	<MDL	0.76	0.76
	Oct 6	<MDL	<MDL	<MDL	<MDL	0.09	0.45	0.53
Richards Landing	May 14	<MDL	0.021	0.022	<MDL	0.12	0.43	0.55
	May 27	<MDL	<MDL	<MDL	<MDL	0.18	0.71	0.89
	June 10	<MDL	0.030	0.030	<MDL	0.22	0.72	0.95
	June 24	<MDL	0.020	0.020	<MDL	0.31	0.67	0.98
	July 14	<MDL	0.018	0.018	<MDL	0.13	0.60	0.74
	July 29	<MDL	0.035	0.035	<MDL	<MDL	0.59	0.59
	Aug 6	<MDL	0.023	0.023	<MDL	0.24	0.84	1.08
	Aug 26	<MDL	<MDL	<MDL	<MDL	0.23	0.44	0.67
	Sept 10	<MDL	0.022	0.022	<MDL	0.24	<MDL	0.35
	Sept 22	<MDL	<MDL	<MDL	<MDL	0.18	0.71	0.89
	Oct 6	<MDL	<MDL	<MDL	<MDL	0.25	0.40	0.65