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SLIPP
Shuswap Lake
Integrated
Planning Process

2011 SLIPP Water Quality Report: Shuswap, Little Shuswap and Mara Lakes

Final Report
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nhc
northwest hydraulic consultants

Credits and Acknowledgements

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Certification

Accepted final report to be sealed and retained on file.

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Executive Summary

In 2008, the Shuswap Lake Integrated Planning Process (SLIPP) issued a Strategic Plan that recommended development and implementation of a long-term inter-agency lake, foreshore and tributary water quality monitoring program on Shuswap Lake and Mara Lake to establish their current trophic status, relate this to past trophic states and identify trends in water quality.

The program was to include an annual process for setting monitoring priorities and allocating the resources of SLIPP participating agencies, and was intended to build on the strengths of prior Ministry of Environment, Columbia Shuswap Regional District and Department of Fisheries and Oceans monitoring efforts to ensure maximum continuity. This document reports on the first year (2011) of the Shuswap, Little Shuswap and Mara Lakes SLIPP water quality monitoring program.

The 2011 SLIPP Water Quality Program involved monitoring the Shuswap watershed in four sub-categories at specified sites using a variety of sampling techniques to achieve multiple objectives:

§ Deep Station Monitoring – to monitor main lake basin trophic status and productivity;

§ Near Shore and Littoral Monitoring – to examine local water quality for specific users, sample for local effects from non-point source discharges, seepages and runoff, and act as an early warning for near shore water quality changes;

§ Water Quality Effects of Specific Activities – to monitor the limnological effects of point-source Waste Water Treatment Plant (WWTP) discharges; and

§ Watershed and Tributary Monitoring – to identify sources of nutrients and/or contaminants of concern from selected tributaries.

Deep Station Monitoring dissolved oxygen (DO) profile data in Shuswap Lake showed lower DO in surface waters (expected as warmer water holds less oxygen) but considerable variation with depth, and in general, as an indicator of good water quality, showed little evidence of oxygen deficits that might be a sign of over enrichment with nutrients or a limitation to aquatic life diversity or productivity.

Mara Lake DO profile data showed a slight depression in surface waters but considerable variation with depth depending on the time of year and stations, and had notable decreases in DO at depths near the bottom.This could be an indication of the more biologically productive nature of Mara Lake. No other DO depressions were observed and diatom blooms were noted on surface waters. In Little Shuswap Lake there was less evidence for any DO depletion and the DO profiles, although variable, were typical of an lake with lower primary productivity. This is a result of the lower lake overall volume and high inflows, resulting in a low hydraulic retention time or high flushing rate.

For phosphorus and for Chlorophyll *a* (Chl *a*, the pigment used to measure algal biomass) the data were compared to guidelines to determine the relative percentage of time that these guidelines were exceeded at these stations. For Chlorophyll *a* (the pattern is similar where the Salmon Arm sampling site (Sandy Point) and the Mara Lake sites exceeded the guideline of 2.5 µg/L from 60 to 75% of the time, but the two other Shuswap Lake sites only had sample results above the guideline 16% of the time in 2011.

For total phosphorus (TP), the number of samples that exceeded the criteria was relatively low (7 to 8%), as was the case for Little Shuswap Lake TP samples. The contrast comes with the Salmon Arm sampling site (Sandy Point) where 35% of the TP samples exceeded the BC guideline of 10 µg/L, but the two other Shuswap Lake sites never had any TP sample results above the 10 µg/L guideline/criteria.

The pattern of exceedance for both TP and Chl *a* do not appear to show a trend toward either TP or algal biomass becoming more of a problem, however, the time scale examined here is very short (2005-2011).

Near Shore and Littoral Monitoring was also undertaken in 2011. TP was above the guideline concentration of 10 µg/L at only one of the near-shore sites sampled – on four occasions at the Christmas Island site. The other TP concentrations were typical of lake TP concentrations and only slightly above detection limits and did not show any strong evidence for shore based phosphorus inputs into the lake.

Christmas Island is a shallow control site for the Salmon Arm STP. It is located high on the foreshore. During low water periods the late summer it is approximately 1m deep. In the winter it may be exposed. The Near Shore sites from the Drinking water (IHA) sampling are raw water samples from the intakes. These intakes are deep (in the hypolimnion during stratification) except for Crescent Bay Sicamous. This shallow intake has been decommissioned.

However, elevated concentrations (above deep water sites)of nitrate were detected early in the season at several locations. At least four samples had concentrations above 80 µg/L and should receive attention as potential sources of nitrogen to the lake (two from Cedar Heights, one from Crescent Bay and one from Eagle Bay). Elevated concentrations of chloride and specific conductance were detected at the Sorrento Water Systems site and at the Christmas Island site that are likely significant. Crescent Bay was decommissioned. The other samples are in deep late summer water samples.

On the North Shore, a high number of samples exceeding the *E. coli* and Fecal Coliform guideline were detected at the Horseshoe Bay site east of Park and Scotch Creek sites, and deserve further attention. On the South Shore, a higher number of samples exceeding the *E. coli* and Fecal Coliform guideline were detected at the Wild Rose Bay and Sorrento near shore sites. This sampling was a result of the NHC reporting on the potential water quality of house boats (NHC, 2009).

Directed sampling examines the potential effects of point sources discharged from the Salmon Arm Wastewater Treatment Plant (WWTP). Using the average concentration for total phosphorus sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and the two sites affected by the Salmon Arm WWTP is quite different. At Sandy Point the average TP concentration was about 11 µg/L, and so these two sites were much higher.

Elevated concentrations of nitrate, ammonia, chloride, specific conductance and sulphate sampled at the Sandy Point site (epilimnion) during 2011 as a reference also showed consistently higher values at the two WWTP sites.

Watershed and tributary monitoring included the small creeks around Salmon Arm of Shuswap Lake (Canoe, Tappen and White) and Newsome Creek (along Highway 1) had exceptionally high levels of *E. coli* with average values between 60 and 170 CFU/100 mL and maximum values in White Creek of 780 CFU/100 mL. The recommended long term average is not above 10 colonies/100 mL and less than 77 CFU/100 mL (geometric mean) for primary contact recreation which was exceeded considerably by these streams.

This area around Shuswap Lake has the highest population and the Trans-Canada highway (Highway 1) runs right around this area of Shuswap Lake where there is considerable human activity, especially in the summer recreational season. There is also considerable land use in agriculture in the Canoe Creek, Newsome Creek and Tappen Creek watersheds.

The Salmon River had an average value of *E. coli* of 31 CFU/100 mL with a maximum of 130 CFU/100 mL which is lower than the four more contaminated creeks, but there is cause for concern since there is considerable agricultural activity in this watershed which is probably one of the main factors contributing to this microbial contamination.

Other creeks and rivers (Celesta, Adams, Eagle, Hummingbird, Scotch, Seymour, Sicamous, West Anstey and Shuswap) had average *E. coli* values of 10 CFU/100 mL or less with many average values less than 5 CFU/100 mL which is attributable to the lower population densities and activity in these watersheds. There is considerable agricultural activity in the lower reaches of the Shuswap River but the large size of this watershed, with considerable drainage at higher elevations, probably helps to keep the *E. coli* values somewhat lower (average of 8.8 CFU/100 mL).

It is evident that two larger rivers (Shuswap and Salmon) and three smaller streams (Canoe, Newsome and White Creeks) are major sources of nonpoint phosphorus and could contribute to any signs of eutrophication that are apparent in Shuswap Lake. It is obvious that the Shuswap River is the largest cumulative source of total phosphorus to Shuswap Lake with a peak May/June loading approximately 1.5 times higher than the Salmon River. The Salmon River has twice the peak May loading of total phosphorus as the combined four contaminated creeks.

The discharge of the Salmon River and Canoe, Tappen and White Creeks into Salmon Arm are contribute to nutrient enrichment conditions that have been measured in this arm of Shuswap Lake, and Salmon River provides the largest cumulative loading. Some selected sewage treatment plant (Salmon Arm) and houseboat greywater total phosphorus loadings were compared to the tributary loadings. These anthropogenic sources of total phosphorus are similar to some of the peak seasonal loadings from the small creeks (Newsome and White) but are several orders of magnitude lower than the total phosphorus discharged from the Shuswap and Salmon Rivers. In all cases, cumulative total loadings should be the metric used for comparative purposes.

The nutrient-enriched waters within the eastern most sectors of Shuswap Lake - Sicamous Arm, Mara Lake, and in upper Salmon Arm - Shuswap Lake have a trophic status that ranges from oligotrophic to mesotrophic to eutrophic. Mara Lake should be considered oligo-mesotrophic while upper Salmon Arm is shallower and richer – meso-eutrophic. Sicamous Arm receives the Shuswap River, the largest inflow and highest annual nutrient load by inflow rivers to Shuswap Lake. Salmon Arm of Shuswap is shallow and nutrient-enriched both from past discharges from the Salmon Arm WWTP, and from internal loading from reductive organic sediments in the shallow basin.

It is this region of Shuswap Lake that has the highest abundance and biomass of filamentous cyanobacteria and largest areas of aquatic macrophytes among all basins of Shuswap Lake. Mara Lake, within the last few decades, has likely been subjected to gradually increasing annual nutrient loads and is slowly responding to the influence of anthropogenic induced changes to the Shuswap River drainage basin, e.g. forestry, agricultural and urbanization that have collectively added more dissolved organic and total phosphorus and nitrogen to the lake.

Without efforts to stabilize nutrient inputs from the rivers' drainage basins it is very likely that Mara Lake, in future years, will continue to exhibit annual flagellate blooms of growing amplitude and duration, perhaps yielding to late summer/fall blue-green algal blooms within a few decades which would have severe implications for drinking water quality and public health issues.

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1 Introduction

Shuswap Lake, Little Shuswap, Adams and Mara Lakes are the centerpiece of the economic, social and environmental sustainability of the Shuswap region of British Columbia. These lakes support a thriving market for tourism, angling, residential and recreational property development, and are the center of Canada's houseboat industry. Shuswap Lake is the nursery lake for the famous Adams River sockeye salmon and associated world class rainbow trout fishery.

Since the 1990s, the pace and scale of largely unregulated near-shore residential, commercial and industrial development and upland agricultural activities in the Shuswap drainage has threatened the water quality and recreational attractiveness of the Shuswap Lakes. A large, noxious algal bloom occurred on Shuswap Lake in June 2008 and on Mara Lake in May 2010. This generated considerable media attention and demonstrated that Shuswap and Mara Lakes, despite their large size and rapid flushing rates, are susceptible to water quality degradation due to increased anthropogenic loading of limiting nutrients from within their respective watersheds.

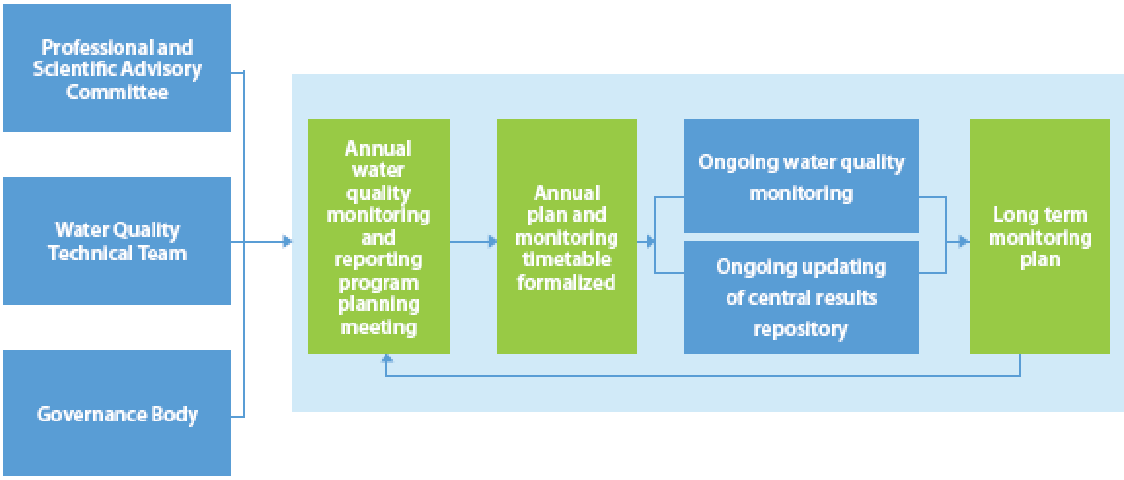
In 2008, the Shuswap Lake Integrated Planning Process (SLIPP) issued a Strategic Plan (BCMOE *et al*., 2008) that recommended development and implementation of a long-term inter-agency lake, foreshore and tributary water quality monitoring program (Figure 1-1) on Shuswap and Mara Lakes to establish their current trophic status, relate this to past trophic states and identify trends in water quality. The program was to include an annual process for setting monitoring priorities and allocating the resources of SLIPP participating agencies. Multiple agencies have historically and are currently monitoring various water quality dimensions including lake, ground water and water clarity.

While a degree of inter-agency coordination already existed, public agencies have recognized that a more integrated assessment of water quality, as it relates to public and environmental health, could be achieved through improved integration of their existing information, monitoring activities and resources. Stewardship groups and the business community will be engaged to leverage their resources, knowledge and monitoring efforts.

The monitoring program is intended to build on the strengths of prior BC Ministry of Environment (BCMOE), Columbia Shuswap Regional District (CSRD) and Fisheries and Oceans Canada (DFO) monitoring efforts to ensure maximum continuity. The SLIPP Strategic Plan states the implementation of a basin-wide in-lake and tributary water quality monitoring program will result in:

- Improved access to credible and scientific knowledge on water quality to support decision making;
- Increased efficiency and coordination in the allocation of monitoring resources, with priority areas receiving necessary attention;
- Enhanced understanding of water quality issues and trends to support decision making; and
- Increased collective access to and management of water quality and monitoring data.

Figure 1-1 Flow chart of the SLIPP annual water quality monitoring process



1.1 Integrated Water Quality Monitoring Plan for the Shuswap Lakes

In 2010, Northwest Hydraulic Consultants Ltd. (NHC) received a contract from SLIPP to develop an integrated water quality monitoring plan for the Shuswap Lakes. NHC reviewed numerous draft and published water quality reports on Shuswap Lake and Mara Lake, and concluded that most deep water stations in Shuswap Lake remained oligotrophic, with the exception of Salmon Arm/Tappen Bay, which has been mesotrophic/eutrophic since at least the 1970s (NHC, 2010a).

However, the trend analysis indicated the concentration of limiting nutrients was increasing slightly lake-wide, even in the deep water stations, which had previously been unaffected. This finding caused concern, given the large volume and rapid flushing rate in Shuswap Lake, and was indicative of the requirement for a more comprehensive water quality monitoring program to protect water quality and public health.

NHC (2010a) acknowledged that their preliminary conclusions on water quality trends had several caveats, namely that the number of monitoring sites had been inadequate until recently, monitoring efforts had been on again/off again over the years, methodologies and the timing/frequency of sample collection had changed, and monitoring for some parameters had not been conducted at all. The trend in shallow water monitoring stations warrants attention, and is indicative of near-shore eutrophication at multiple sites.

This creates a scenario for potential public health/water quality impairment due to leachate breakthrough from poorly constructed/maintained domestic wastewater treatment systems, and where large numbers of houseboats congregate on beaches for extended periods and discharge untreated grey water into the receiving environment (NHC, 2010b).

A five year water quality monitoring plan was proposed to serve as a guiding framework for the development of annual water quality monitoring plans by SLIPP partners (NHC, 2010a). The five year plan included a historical review of lake water quality and a discussion of previous and current monitoring programs, examined trends in water quality, and discussed concerns surrounding existing and emerging threats to water quality in the Shuswap lakes (**Table 1-1**).

Table 1-1 List of existing and emerging* threats to sources of drinking water and aquatic ecosystem health in Shuswap basin lakes (from NHC, 2010a)

Threat to sources of drinking water quality and aquatic ecosystem health	Importance in the Shuswap basin (low, medium, high or variable)	Trend direction (increasing, stable, decreasing or variable)
1. Waterborne Pathogens	High, depending on location, time of year and flushing rate, hundreds of domestic water licenses and water contact recreation	Increasing, based on preliminary houseboat grey water sampling, West Arm fluorometer monitoring and unregulated increasing near-shore development
2. Algal Toxins, Taste and Odour	High, hundreds of domestic water licenses and world class fisheries resources	Increasing, annual algal blooms in Tappen Bay, and first widespread algal bloom in June 2008
3. Pesticides	High, hundreds of domestic water licenses and world class fisheries resources	Unknown, likely stable or decreasing
4. Persistent Organic Pollutants (POP) and Mercury	High, hundreds of domestic water licenses and world class fisheries resources	Unknown for mercury and POPs, likely some POPs decreasing (PCBs) and some increasing (PBDEs)
5. Endocrine Disrupting Substances* (Note: this category includes Personal Care Products such as antibiotics, birth control pills and other Endocrine Disrupting Compounds)	High, depending on location, time of year and flushing rate, hundreds of domestic water licenses, water contact recreation and world class fisheries resources	Unknown, likely increasing based on rate of residential development in watershed and increasing grey water discharges from larger and more numerous houseboats and power boats
6. Nutrients – Nitrogen and Phosphorus	High, lakes are phosphorus and nitrogen limited	Increasing in all areas of Shuswap Lake, first widespread algal bloom in 2008
7. Aquatic Acidification	Low, lakes are all well buffered	Stable
8. Ecosystem Effects of Genetically Modified Organisms*	Low, minimal exposure to GMO crops	Unknown, likely stable
9. Municipal Wastewater Effluents	High, lakes are phosphorus and nitrogen limited	Increasing, but Salmon Arm WWTP has state-of-the-art nutrient removal process
10. Non-municipal Private Residence Wastewater Effluents	High, lakes are phosphorus and nitrogen limited	Increasing in all areas, main concern is poorly constructed and operated non-municipal discharges
11. Grey Water Discharges from Vessels*	High, depending on location, time of year and flushing rate, hundreds of domestic water licenses and water contact recreation	Increasing, based on rapid expansion of houseboat industry, lack of grey water retention and pump-out facilities and preliminary site monitoring
12. Industrial Point Source Discharges	High, depending on location, time of year and flushing rate, hundreds	Unknown, likely stable or increasing

Threat to sources of drinking water quality and aquatic ecosystem health	Importance in the Shuswap basin (low, medium, high or variable)	Trend direction (increasing, stable, decreasing or variable)
	of domestic water licenses and water contact recreation	
13. Urban Runoff	High, depending on location, time of year and flushing rate, hundreds of domestic water licenses and water contact recreation	Unknown, likely increasing based on urbanization of watershed and lack of rainwater management plans by municipalities
14. Landfills and Waste Disposal	High, depending on location, time of year and flushing rate, hundreds of domestic water licenses and water contact recreation	Unknown, likely increasing based on urbanization of watershed
15. Agricultural and Forestry Land Use Impacts	High, lakes are phosphorus and nitrogen limited	Likely increasing based on forest harvesting, ranching and densification of dairy industry
16. Natural Sources of Trace Element Contaminants	High, depending on location, time of year and flushing rate, hundreds of domestic water licenses and water contact recreation	Unknown, likely stable
17. Impacts of Dams, Diversion and Climate Change*	High, fisheries resources sensitive to timing and amount of runoff and water temperature	Increasing, based on observed trend and die-off of Lodgepole pine and Ponderosa pine
18. Nanoparticles*	High, hundreds of domestic water licenses and world class fisheries resources	Unknown, likely increasing slowly based on increased product availability
19. Invasive Species*	High, fisheries resources sensitive to habitat disruption and competition/predation from invasive species	Increasing, based on Eurasian milfoil and introduction of non-native species of fish in the Shuswap watershed

The five year plan also discussed possible nutrient sources and loadings and proposed a framework for monitoring the lakes and tributaries in the Shuswap watershed over the five year period (**Table 1-2**). The program was designed to monitor the known and emerging threats to drinking water quality and ecosystem health in the Shuswap and Mara lakes and surrounding tributaries.

The plan stated that the best strategy for preventing further water quality degradation is a detailed assessment and analysis of the nutrients and contaminants being discharged, followed by the development of concrete action plans to reduce or eliminate nutrients and/or contaminant loading as required. It was endorsed by the SLIPP Steering Committee, and is available on-line at www.slippbc.com.

Table 1-2 **Initial five year comprehensive monitoring plan for Shuswap and Mara Lakes (from NHC, 2010a)**

	Type of Monitoring Program				
Sampling Year	**Main Lake deep stations**	**Main Lake littoral stations**	**Watershed tributaries**	**Nutrient Sources and Loadings**	**Point and Non-Point Source Tracking of Contaminants**
Year 1 (2010)	Intensive deep station monitoring	Baseline littoral station monitoring	n/a	n/a	Chemical tracing of sewage and grey water contamination
Year 2 (2011)	Baseline deep station monitoring	Intensive littoral station monitoring	Watershed and tributary monitoring, land use and agricultural trends	Septic systems, sewage treatment plant contaminant loading, boat and houseboat discharges	Chemical tracing of sewage and grey water contamination
Year 3 (2012)	Baseline deep station monitoring	Intensive littoral station monitoring	Watershed and tributary monitoring, land use and agricultural trends	Septic systems, sewage treatment plant contaminant loading, boat and houseboat discharges	Chemical tracing of sewage and grey water contamination
Year 4 (2013)	Baseline deep station monitoring	Intensive littoral station monitoring	As required	As required	Chemical tracing of sewage and grey water contamination, Nitrogen stable isotopes, microbial source tracking
Year 5 (2014)	Baseline deep station monitoring	Intensive littoral station monitoring	As required	As required	Chemical tracing of sewage and grey water contamination, Nitrogen stable isotopes, microbial source tracking

1.2 2011 SLIPP Water Quality Monitoring Program

The 2011 (i.e., Year 2) detailed annual SLIPP water quality monitoring program was developed collaboratively by SLIPP partners on the SLIPP Water Quality and Waste Management Technical Team, with support from scientific experts. It was aligned with the NHC monitoring framework proposed in the five year water quality monitoring plan (NHC, 2010a) and builds upon the water quality programs conducted by SLIPP agencies prior to SLIPP formation.

The 2011 program included mandated or proposed monitoring activities by SLIPP partners and was intended to make data from these sampling projects available, if relevant, to the program's objective. The 2011 SLIPP water quality program involved monitoring the Shuswap watershed in four sub-categories at specified sites using a variety of sampling techniques (**Table 1-3**):

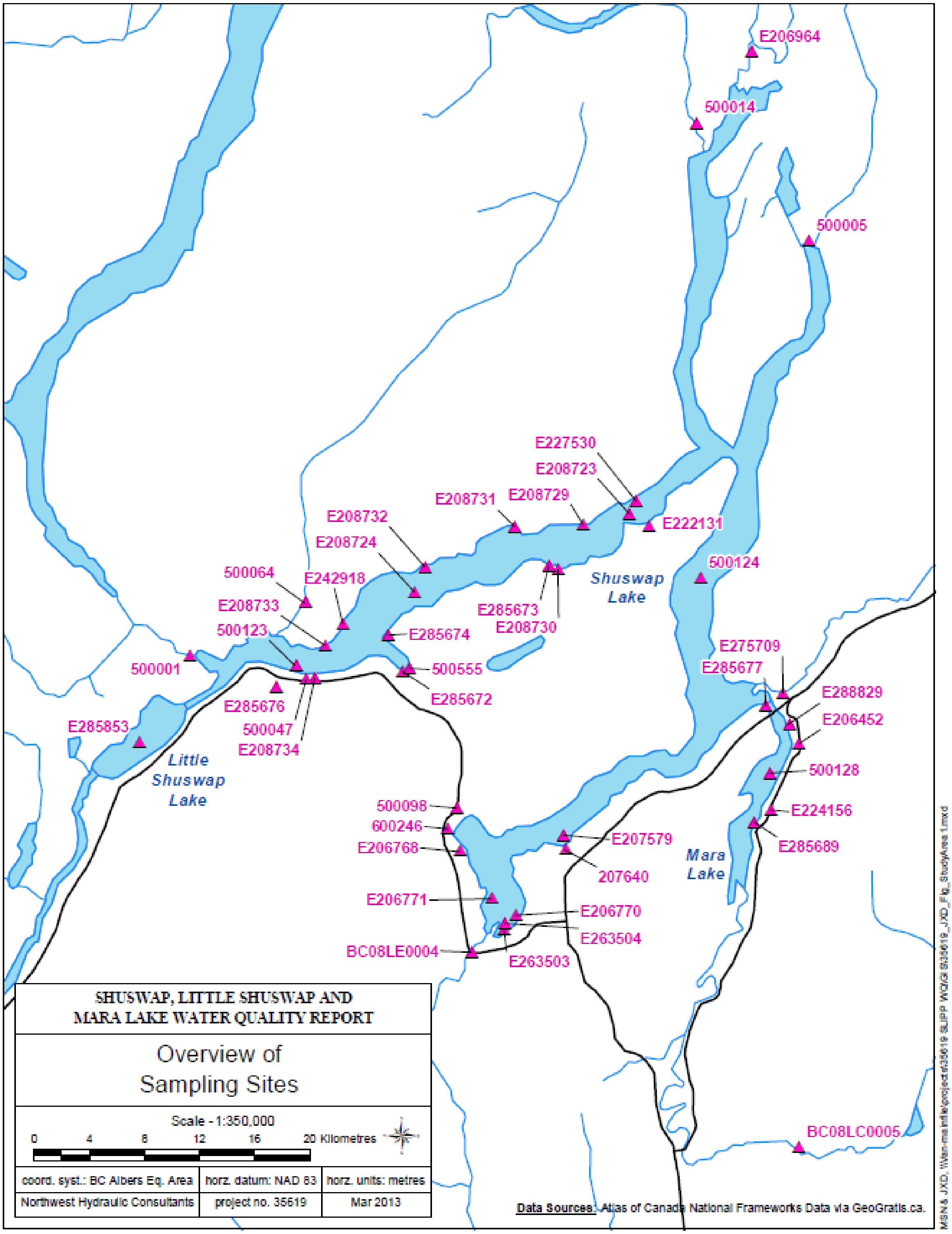
1. **Deep Station Monitoring** – examine main lake basin trophic status and productivity;
2. **Near Shore and Littoral Monitoring** – examine local water quality for specific users; sample for local effects from non-point source discharges, seepages and runoff; act as an early warning for near shore water quality changes;
3. **Water Quality Effects of Specific Activities** – examine specific activities/land uses/water uses, point-source Waste Water Treatment Plant (WWTP) discharges; and
4. **Watershed and Tributary Monitoring** – identify sources of nutrients and/or contaminants of concern from selected tributaries.

Table 1-3 Overview of SLIPP Annual Water Quality Monitoring Plan

Monitoring Year	Activities by Category			
	Deep Station Monitoring	**Near Shore Monitoring**	**Effects of Specific Activities**	**Watershed Monitoring**
1st (start March 2011)	Intensive monitoring of key sites affected by nutrient loading from salmon run. Intensive monitoring of Pico- plankton and food web parameters for algal bloom investigation. Lake productivity determination using ^{14}C uptake studies.	Guided by outcome of current fluorometer study: Lake water sampling at sites where seepage has been detected and at critical drinking water intakes (as indicated by Interior Health Authority). Attached algae study in partnership with residents. Consult First Nations and community groups around Little Shuswap, Mable and Adams Lakes for their interest in a lake-wide Secchi Disk Program.	Questionnaire about septic system maintenance and dye tests as determined by Columbia-Shuswap Regional District (CSRD). Lake water sampling at beaches highly frequented by houseboats - to confirm 2008/09 results and measure changes due to source management actions.	Determine nutrient and contaminant loading from major tributaries into Shuswap and Mara Lakes. Start monitoring contaminants of concern in specific stream sections of Lower Shuswap River.

2nd (start March 2012)	Intensive monitoring of key sites affected by nutrient loading from salmon run. Intensive monitoring of Pico- plankton and food web parameters for algal bloom investigation.	Lake water sampling in shallow areas if applicable. Sites determined by IHA, CSRD and from outcomes of last year's samples. Attached algae study in partnership with residents. Initiate lake wide Secchi Disk Program where interested volunteer groups have formed (including a volunteer organizer).	Summarize permitted and non-permitted discharges into Shuswap and Mara Lakes, where known. Characterization of typical boat greywater (through analysis of content of at least 10 tanks; identification of typical greywater flow per person, per day. Boat distribution throughout Shuswap and Mara Lakes using BC Parks data. Calculation of average nutrient and contaminant loadings to areas of concern.	Continue determination of nutrient and contaminant loading from major tributaries into Shuswap and Mara Lakes. Finish land use mapping for the entire Shuswap Lake Watershed. Identify animal units by sub-watershed and stream sections. Start monitoring contaminants of concern (as identified in yr. 1-2 through loading study) in specific stream sections of 1-2 watersheds that contribute highest loadings.
3rd (start March 2013)	Guided by outcome of the previous two years the following projects may be changed or reduced: Intensive monitoring of key sites affected by nutrient loading from salmon run. Intensive monitoring of Pico- plankton and food web parameters for algal bloom investigation.	Lake water sampling in shallow areas where needed. Attached algae study in partnership with residents. Continue Secchi Disk Program where volunteer are interested. Collate data to populate lake wide nutrient and contaminant model.	a) Collate data to populate lake wide nutrient and contaminant model.	Monitor contaminants of concern (as identified in yr. 1-2 through loading study) in specific stream sections of 1-2 watersheds that contribute highest loadings. Collate data to populate lake wide nutrient and contaminant model

Figure 1-2 Map of all SLIPP annual water quality monitoring stations in Shuswap, Little Shuswap and Mara Lakes



2 Deep Station Water Quality – Pelagic Monitoring

Historical deep station water quality monitoring conducted by SLIPP partners provided a record of water quality for each arm of Shuswap Lake and Mara Lake (**Figure 2-1**). Ten new deep stations were added as part of the 2011 SLIPP water quality monitoring program. Deep station sites were chosen to assess the potential influence from decaying salmon in addition to sites close to the origin of the 2008 and 2010 Ochromonas algal blooms, resulting in 10 deep station sites in total (**Table 2-1**). Water samples were collected monthly from May to October, weekly from April to June, and twice in the winter. Water sampling in Sugar Lake and Mable Lake was conducted at spring and fall overturn only.

At each deep station site (**Figure 2-1**), a multi-parameter logging data sonde was used to collect a vertical profile to 60 m depth, or bottom. Parameters recorded electronically included dissolved oxygen, temperature, pH, specific conductivity and turbidity. Water transparency was measured with a standard 20 cm diameter Secchi Disk without a viewing chamber. Composite epilimnetic and hypolimnetic water samples were collected with a van Dorn or Kemmerer bottle from three epilimnetic and three hypolimnetic depths, as determined from the thermal profiles. The full range of parameters collected was as follows:

- Water temperature and dissolved oxygen profiles
- pH, specific conductivity and turbidity profiles and composite samples
- Secchi depth
- General water chemistry (chloride, total organic carbon, sulphate, etc.)
- Macronutrients (i.e., soluble reactive phosphorus, total dissolved phosphorus, total phosphorus, nitrates, nitrites, ammonia, total organic and total nitrogen)
- Chlorophyll *a*
- Phytoplankton abundance, biomass and taxonomy
- Zooplankton biomass (settled volume and taxonomy)

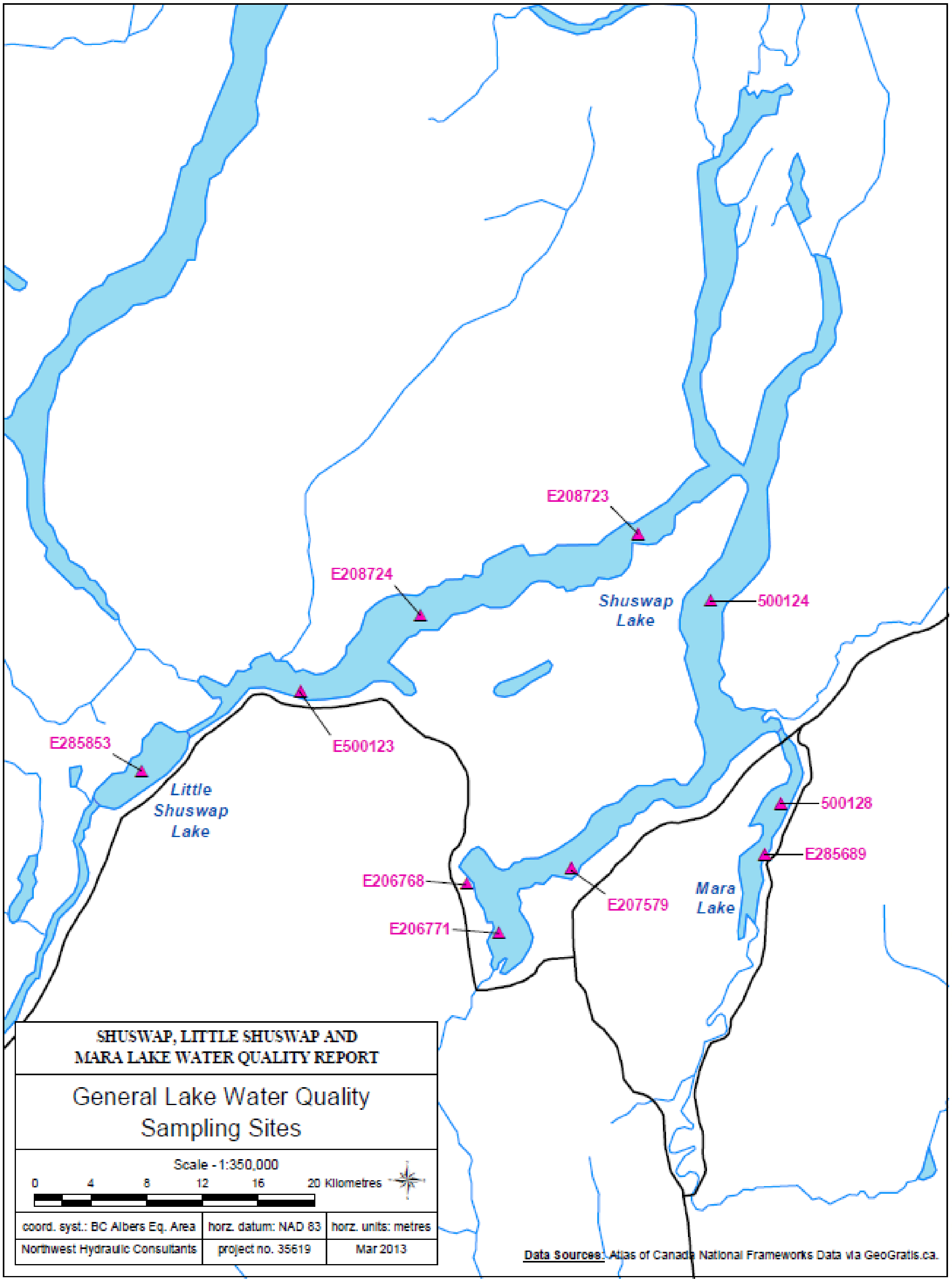
Samples were placed on ice in coolers and shipped to Maxxam Analytics, Fraser Environmental and Lidija Vidmanic, PhD for water chemistry, phytoplankton and zooplankton analysis within 24 hours.

Important parameters for deep water stations are discussed below by examining individual measurement sets.

Table 2-1 Deep station monitoring site locations

Station Number	Station Name	Station ID	Latitude	Longitude	Year(s) sampled
Deep Station 1	Little Shuswap Lake Deep	E285853	50.84944444	-119.6480556	2011
Deep Station 2	Mara Lake opposite Fosett	500128	50.79027778	-119.0044444	2011
Deep Station 3	South Mara off King-Baker Creek	E285689	50.75972222	-119.0255556	2011
Deep Station 4	Shuswap Lake off Sandy Point TB#5	E206771	50.72694444	-119.3016667	2011, 2005-2008
Deep Station 5	Shuswap Lake opposite Marble Point	500124	50.92138889	-119.0555556	2011, 2008-2010
Deep Station 6	Shuswap Lake west of Sorrento	500123	50.8900000	-119.4800000	2011, 2003-2008
Deep Station 7	Shuswap Lake TB#2 (Fraser's Beach)	E206768	50.7600000	-119.3300000	2005-2008
Deep Station 8	Shuswap Lake off Canoe Wharf	E207579	50.81527778	-119.0697222	2005-2008
Deep Station 9	Shuswap Lake off Armstrong Point	E208723	50.9675	-119.1227778	2002-2007
Deep Station 10	Shuswap Lake off McBride Point	E208724	50.93	-119.3513889	2002-2007

Figure 2-1 Map of ten SLIPP deep station sampling sites in Shuswap, Little Shuswap and Mara Lakes



2.1 Temperature and Dissolved Oxygen

Temperature is a measurement of heat stored in water. Surface water temperatures have an annual pattern and range from 0°C in midwinter at the surface and may approach 25°C in surface waters in August. Natural sources of heat include: solar radiation, transfer from air, condensation of water vapor at the water surface, sediments, precipitation, inflow from tributaries, surface runoff and groundwater. Temperature is the primary influencing factor on water density and consequently the thermal stratification pattern of water in Shuswap Lake.

Temperature is important as it affects the solubility of many chemical compounds and can therefore influence the effect of pollutants on aquatic life. Increased temperatures elevate the metabolic oxygen demand, which in conjunction with reduced oxygen solubility, impacts many species by affecting growth rates and survival.

There are a number of criteria to judge the effects of water temperature. For instance the CCME Canadian Drinking Water Guidelines specify a maximum of 15°C for drinking water supplies. There are also a number of criteria for temperature for fisheries, particularly for salmonids since they are generally sensitive to increases in water temperature.

The temperature profiles shown in **Figure 2-2**, **Figure 2-3** and **Figure 2-4** provide information on how the lake waters are stratified. In winter and early spring the lake generally has little thermal stratification and the temperature and dissolved oxygen are similar at all depths. In the winter the lake is mixed top to bottom by the energy of the wind and the temperature through the water column would be 1 to 5°C, depending on weather conditions, but typically about 2°C mid winter. Similarly, dissolved oxygen would be near full saturation for the temperature (12 to 14 mg/L).

In the spring, the increasing sunlight energy and air temperatures cause the surface waters to warm and as they warm the density decreases and the warmer water forms a layer at the surface of the lake. In a conventional temperature profile there is a distinct mixed surface layer (epilimnion) and a rapid temperature transition (the thermocline) with increasing depth and then deep cold water (the hypolimnion) in the lower depths of the lake, which does not mix with the upper layer and has no contact with the atmosphere.

In Shuswap Lake the surface waters begin to warm in April and by May there is a distinct thermal gradient with surface waters warming to 10 to 17°C depending on the sampling station. By June, surface water temperatures are 18 to 20°C, increase through July and peak in August between 18°C and near 25°C at the Sandy Point station. After August the lake begins to cool and lose its heat and the thermal stratification that has developed and the surface cools to 4 to 5°C. It then mixes completely in December, and the lake waters circulate top to bottom throughout the winter except in periods of extreme cold when the surface waters cool to less than 4°C and a period of winter stratification can occur.

Stockner and Shortreed (1991) suggested the term “warm dimictic” for this type of stratification. In technical terms dimictic describes a lake that has two thermal stratification periods each year (one in the summer and one in the winter). Nidle and Shortreed (1996) describe the lake as being either dimictic or monomictic depending on the severity of winter cold.

The vertical stratification in 2011 was not what might be expected in a conventional lake with stratification into a typical epilimnion, thermocline and hypolimnion. Rather the temperature profiles show a gradual decrease in temperature with depth down to the hypolimnion upper boundary and no distinct epilimnion or thermocline at any of the stations. The lake is mixed in thin stratified layers down to about 20 m at the Sorrento and Sandy Point stations and to about 30 m at the Marble Point station.

Dissolved oxygen profile data shows lower DO in surface waters (expected as warmer water holds less oxygen) but considerable variation with depth. Most stations have slight decreases in DO with depth (Shuswap Lake west of Sorrento [500124], **Figure 2-2**) with some profiles having more decreases (Sandy Point, **Figure 2-3** – with some strange fluctuations like a decrease in DO in the mixed layer in August) and a noticeable decrease in DO in the bottom water at the Marble Point station in August which is the only profile with Sandy Point that shows significant deep water DO depletion.

In general, DO as an indicator of good water quality shows little evidence of oxygen deficits that might be a sign of over enrichment with nutrients or a limitation to aquatic life diversity or productivity.

Figure 2-2 **2011 oxygen and temperature profiles at Shuswap Lake West of Sorrento deep station sampling site (500123) in Shuswap Lake**

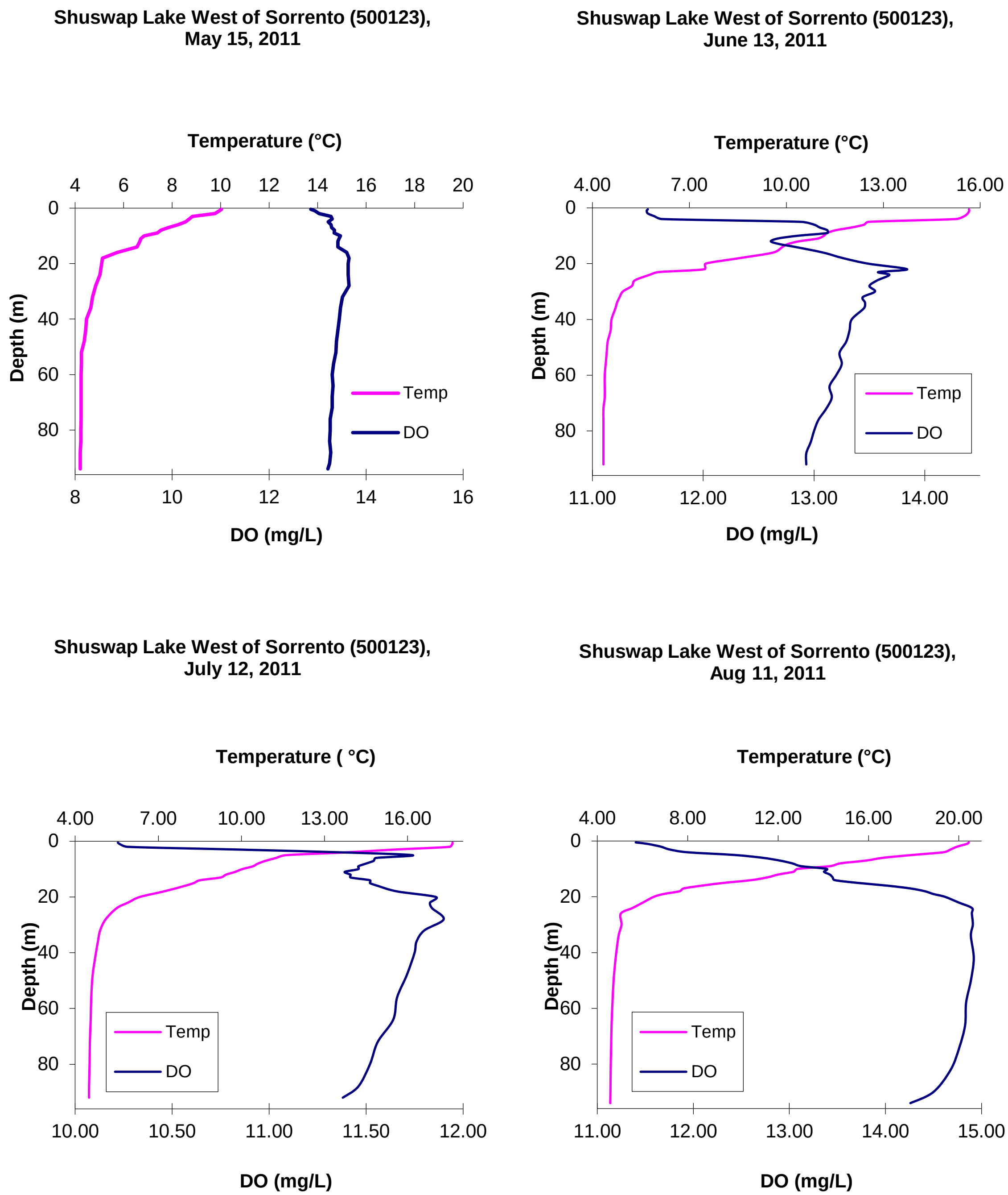


Figure 2-3 2011 oxygen and temperature profiles off Sandy Point TB#5 deep station sampling site (E206771) in Shuswap Lake

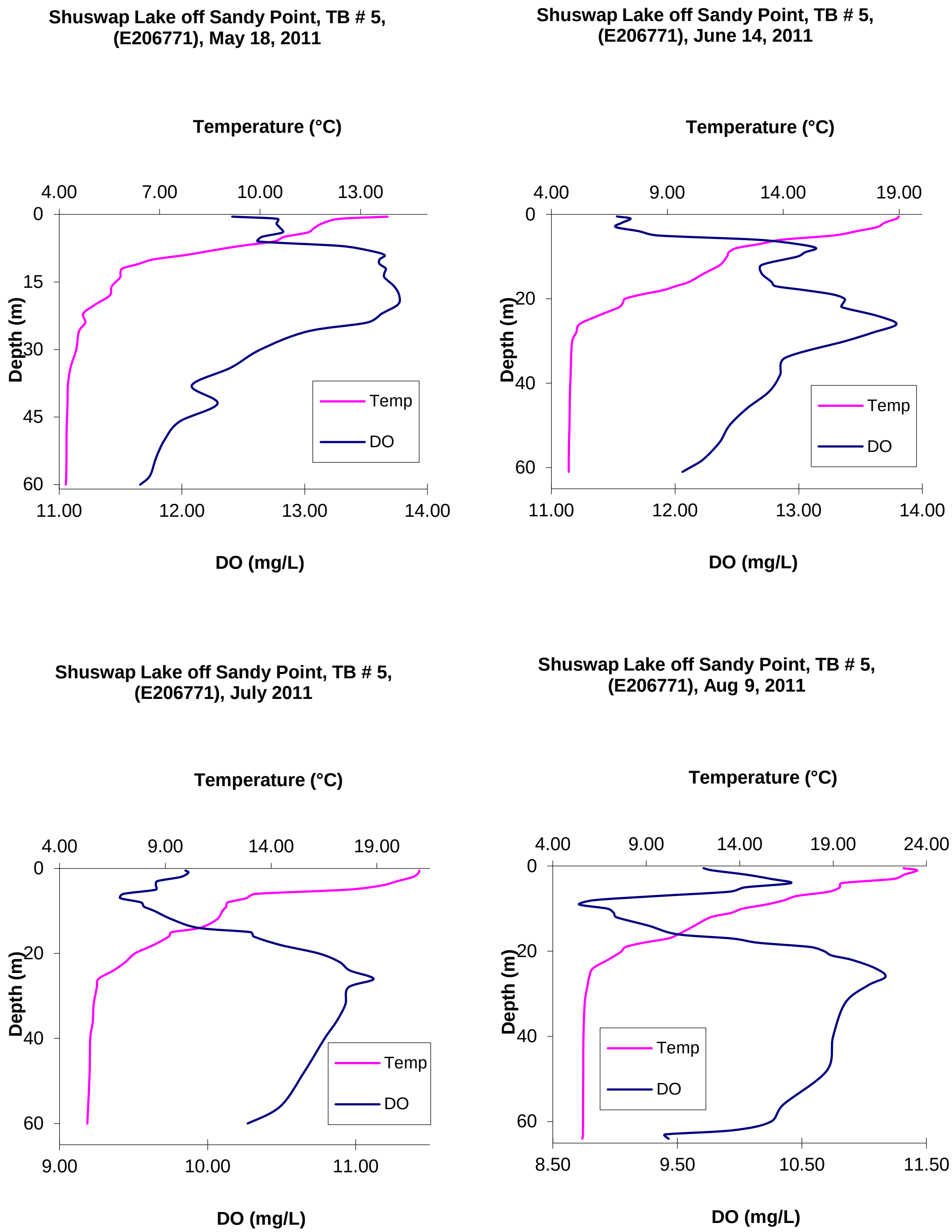
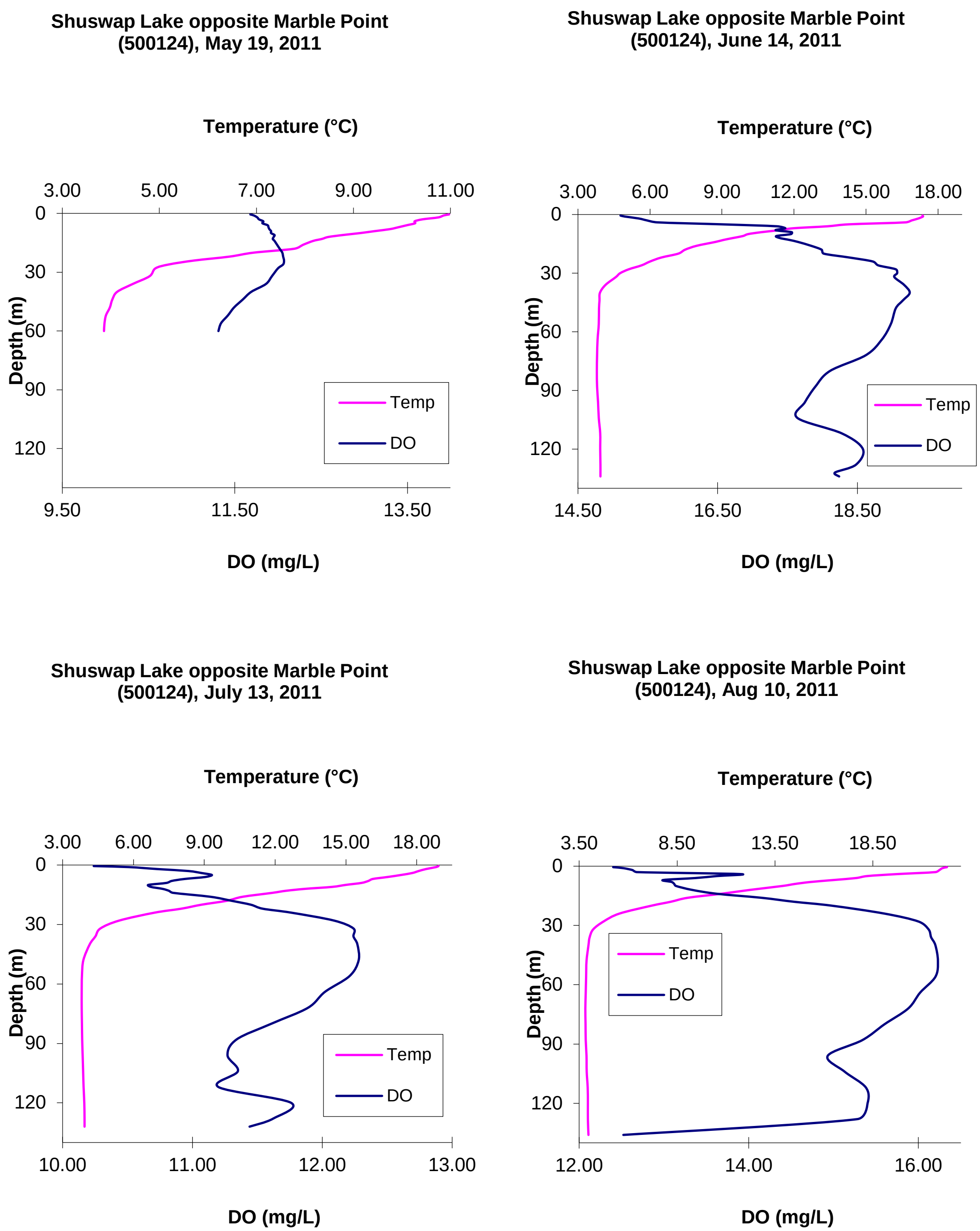


Figure 2-4 2011 oxygen and temperature profiles at opposite Marble Point deep station sampling site (500124) in Shuswap Lake



The temperature profiles shown in **Figure 2-5**, **Figure 2-6** and **Figure 2-7** provide information on what the thermal regimes of Mara and Little Shuswap.. As with Shuswap, in winter and early spring the lake generally has little thermal stratification and the temperature and dissolved oxygen are similar at all depths. In the winter the lake is mixed top to bottom by the energy of the wind and the temperature through the water column would be 1 to 5°C depending on weather conditions but typically about 4°C. Similarly dissolved oxygen would be near full saturation for the temperature (12 to 14 mg/L). Mara and Little Shuswap Lakes have smaller surface areas and less depth and both of these factors affect the temperatures and the thermal stratification.

In both Mara and Little Shuswap Lakes, the surface waters begin to warm in April and there is a distinct thermal gradient with surface waters warming to 13°C in Mara Lake, but only to about 10°C in Little Shuswap Lake. This is likely due to the cooler inflow waters from the larger, deeper Shuswap Lake. By June surface water temperatures are 14 to 16°C, increase through July and peak in August between 22°C and 24°C in Mara Lake. Little Shuswap Lake reaches only about 18°C in the surface water in August 2011. After August the lakes begin to cool and lose heat and the thermal stratification that has developed and the surface cools to 4 to 5°C. It then mixes completely in October or November and the lake waters circulate top to bottom throughout the winter. In technical terms Mara and Little Shuswap Lakes are usually like Shuswap Lake in that they show a monomictic thermal stratification pattern.

The vertical stratification in 2011 in Mara Lake (**Figure 2-6**) was similar to Shuswap Lake in that the profiles were not what might be expected in a conventional lake with stratification into a typical epilimnion, thermocline and hypolimnion. Rather the temperature profiles show a gradual decrease in temperature with depth down to the hypolimnion upper boundary and no distinct epilimnion or thermocline at either of the stations. The lake is mixed in layers down to about 30 m at both Mara Lake stations in the summer period. Little Shuswap Lake in the summer does show the more typical textbook type of thermal stratification with an epilimnion from the surface down to 16 to 18 m, a distinct thermocline down to 30 m, a sharp temperature break at the top of the hypolimnion and cold (4 to 5°C) water from that depth to the bottom (**Figure 2-7** for July and August data).

Mara Lake dissolved oxygen profile data shows a slight depression in DO in surface waters (expected as warmer water holds less oxygen) but considerable variation with depth depending on the time of year. The station opposite Fosett shows a decrease in DO with depth, but a very large increase in DO between 15 and 45 m in June. This may be due to algal photosynthesis but seems very deep in the water column for this to occur. The maximum concentrations are over 16 mg/L which would be above the DO saturation level of the water or caused to measurement or sampling issues. The DO in deep water in July and August is also notable but the concentrations are more reasonable. A similar deep water DO maximum at the Kingbaker Creek station (**Figure 2-6**) for June shows the same pattern as the Fosett station although the concentration of DO is lowered to 14.5 mg/L. All the Mara Lake stations have notable decreases in DO with depths near the bottom, likely an indication of the more biologically productive nature of Mara Lake.

In Little Shuswap Lake **(Figure 2-7**) there is less evidence for any DO depletion and the DO profiles, although variable, are typical of ana oligotrophic system with a low level of primary productivity.

In general, DO as an indicator of water quality shows little evidence that oxygen deficits might be a sign of over-enrichment with nutrients or a limitation to aquatic life diversity or productivity in Little Shuswap Lake; however, some of the data shows that Mara Lake may be receiving a higher loading of nutrients than Shuswap or Little Shuswap Lakes.

Figure 2-5 2011 oxygen and temperature profiles opposite Fosett deep station sampling site (500128) in Mara Lake

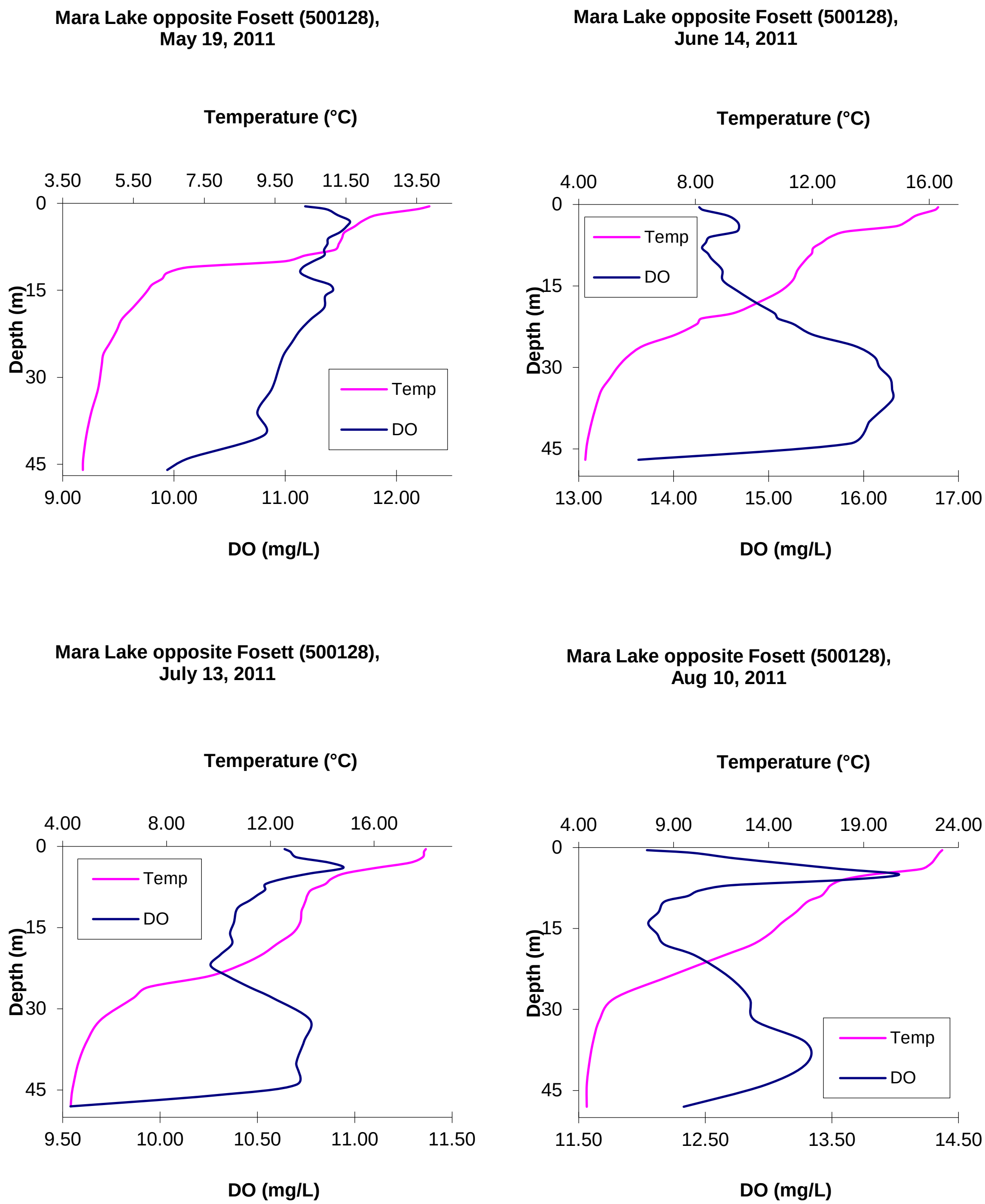


Figure 2-6 2011 oxygen and temperature profiles at South Mara off King-Baker Creek deep station sampling site (E285689) in Mara Lake

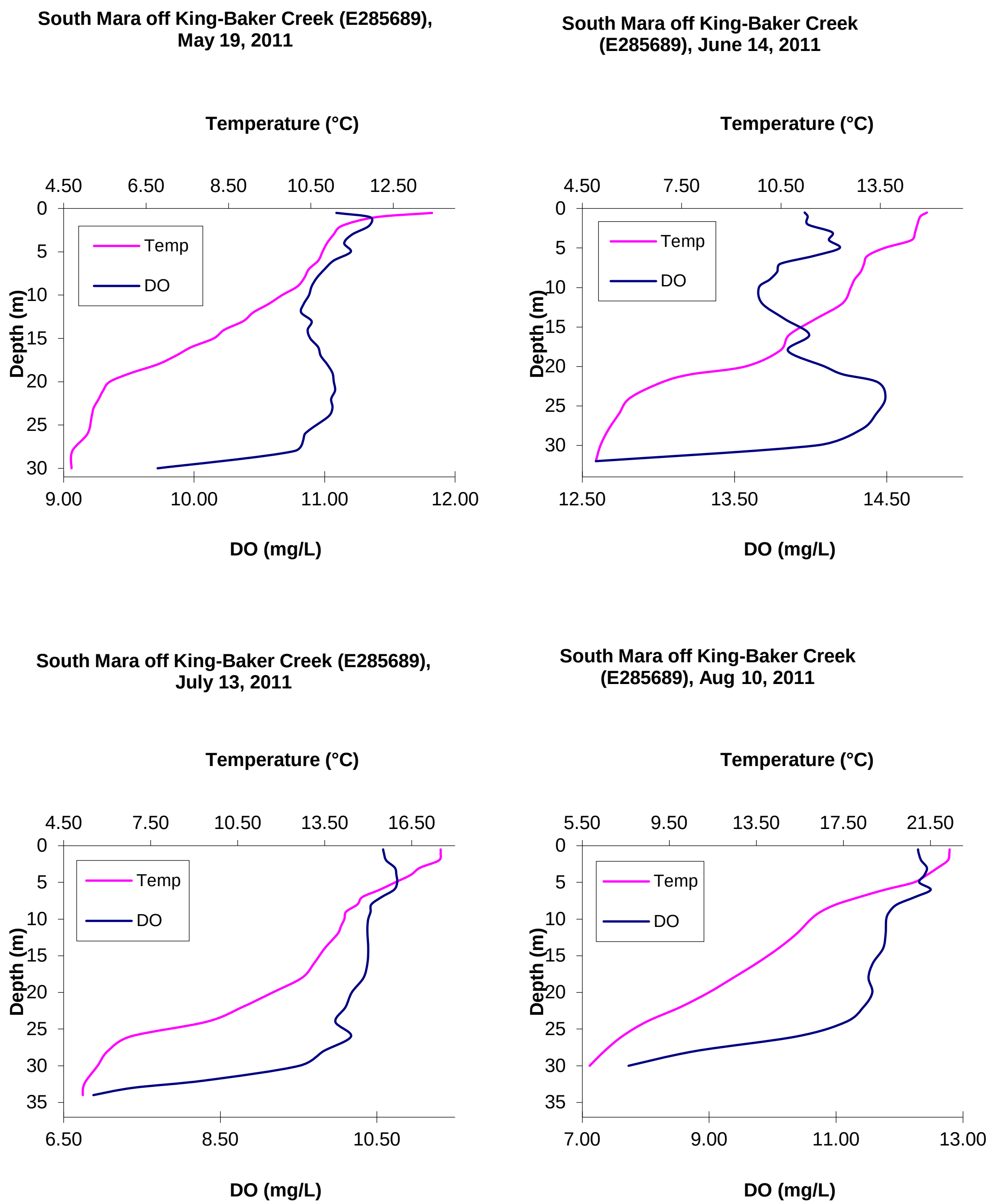
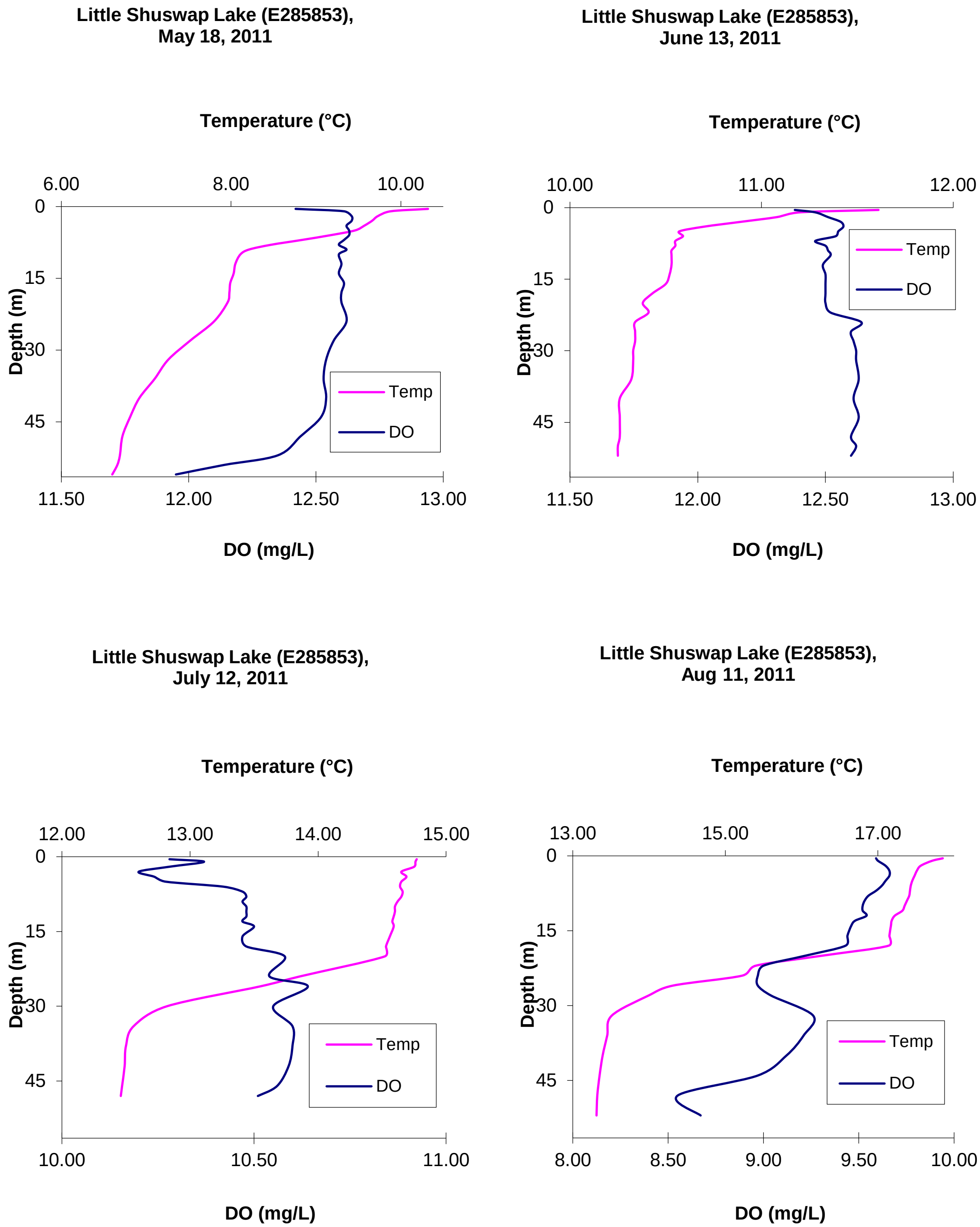


Figure 2-7 2011 oxygen and temperature profiles at Little Shuswap Lake deep station sampling site (E285853) in Little Shuswap Lake



2.2 Phosphorus

Three fractions of phosphorus (P) were sampled and analysed in the deep water sampling program. Phosphorus is considered a key element in fresh water as it is an essential nutrient and is often the most limiting nutrient to phytoplankton growth in fresh water with nitrogen another important nutrient element that may also algal growth.

Natural sources of P within the watershed includes that derived from minerals soils and bedrock; decay of organic litter, leaves and algae and import into the system as marine-derived P on a cycli basis from sockeye salmon spawner escapments.

2.2.1 Soluble Reactive Phosphorus

Soluble Reactive Phosphorus (SRP, also called orthophosphorus) is a measure of the inorganic oxidized form of soluble phosphorus. It is generally reported in µg/L or mg/L and in BC lakes and rivers is generally found only in very low concentrations (<5 µg/L or <0.005 mg/L) and typically below analytical detection limits (<1 µg/L). This form of phosphorus is the most readily available for uptake during photosynthesis (bioavailable) and quickly taken up by algae.

Anthropogenic sources of SRP (and other forms of phosphorus) are sewage treatment plant effluents, septic sewage disposal systems, agriculture, urban developments, and land disturbance.

Figure 2-8 below shows the results from the deep water stations in Mara and Little Shuswap Lakes and Shuswap itself for 2011 (upper panel) and the sites in Shuswap Lake (lower panel over the sampling period 2008-2011) for SRP. What is apparent from the SRP data scatter plots is that a large majority of SRP samples from these locations are at 2 µg/L or less with only a few samples (in September and December 2011 for 2011 data) at concentrations that might be considered of concern.

The Salmon Arm sites appear to show higher concentrations than other sites. The combined Shuswap Lake stations figure for the longer period of record (2008-2011) appear to show some year to year variation – more high concentrations of SRP in 2008 and 2011 and almost all the concentrations in 2009 and 2010 below detection limits. The inter-annual variation may be related to hydrology or weather.

2.2.2 Total Dissolved Phosphorus

Total Dissolved Phosphorus (TDP) is defined as the fraction of phosphorus that will pass through a 0.45 micron filter. It would consist of SRP and any dissolved organic P and any very small size particulate P. It generally has a high proportion of bioavailable P.

Figure 2-9 displays a similar pattern for Total Dissolved Phosphorus. The upper panel for 2011 shows the combined scatter plot for all stations. It is difficult to discern if a trend over the calendar year is present but many of the high values are from the Shuswap Sandy Point station.

For the longer term data set (2002-2011) it is difficult to see any pattern; the sites collected in any individual year seem too different so it is difficult to make an objective comparison. However, the TDP concentrations do not show any particular reason for concern or any areas that have consistently higher TDP concentrations.

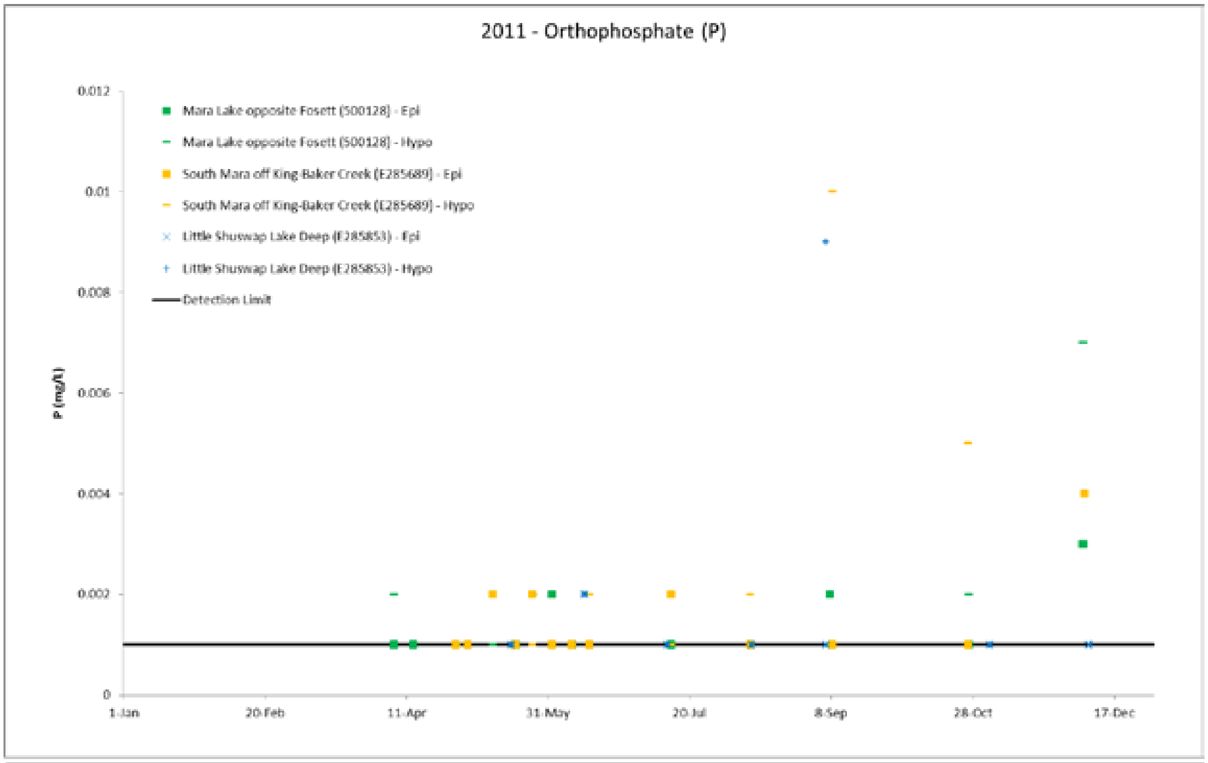
2.2.3 Total Phosphorus

Total Phosphorus (TP) is a measure of both inorganic and organic forms of phosphorus and the dissolved or particulate forms. The relative proportion of bioavailable P as a fraction of TP is highly variable. Water with a high concentration of suspended solids (turbid stream water) often has only a low percentage of bioavailable P. A general guideline regarding phosphorus and lake productivity is that concentrations of <10 µg/L phosphorus in a lake is considered to be indicative of unproductive lake systems (oligotrophic), 10 to 25 µg/L P will be found in lakes considered to be moderately productive (mesotrophic), and >25 µg/L P will be found in lakes considered highly productive (eutrophic).

Criteria for TP (generally measured at spring overturn) for drinking water sources is for a maximum of 10 µg/L; for protection of aquatic life in lakes the range of 5 to 15 µg/L is used as a guideline and for recreational lakes a maximum of 10 µg/L TP is proposed.

Figure 2-10 shows similar data for total phosphorus. The upper panel for 2011 with almost all the data below the 10 µg /L guideline. One value for Mara Lake seems inexplicably high and may simply be an outlier. Several of the high values of TP are for the Shuswap Sandy Point station (red squares and triangles). The longer term data set (2002 to 2011) indicates no obvious trend. However, year to year comparisons are difficult to evaluate since different stations were sampled in different years. Again, the majority of values above the 10 µg/L TP guideline are from the Shuswap Sandy Point station.

Figure 2-8 Soluble reactive phosphorus (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes (Detection Limit= 0.001 mg/L)



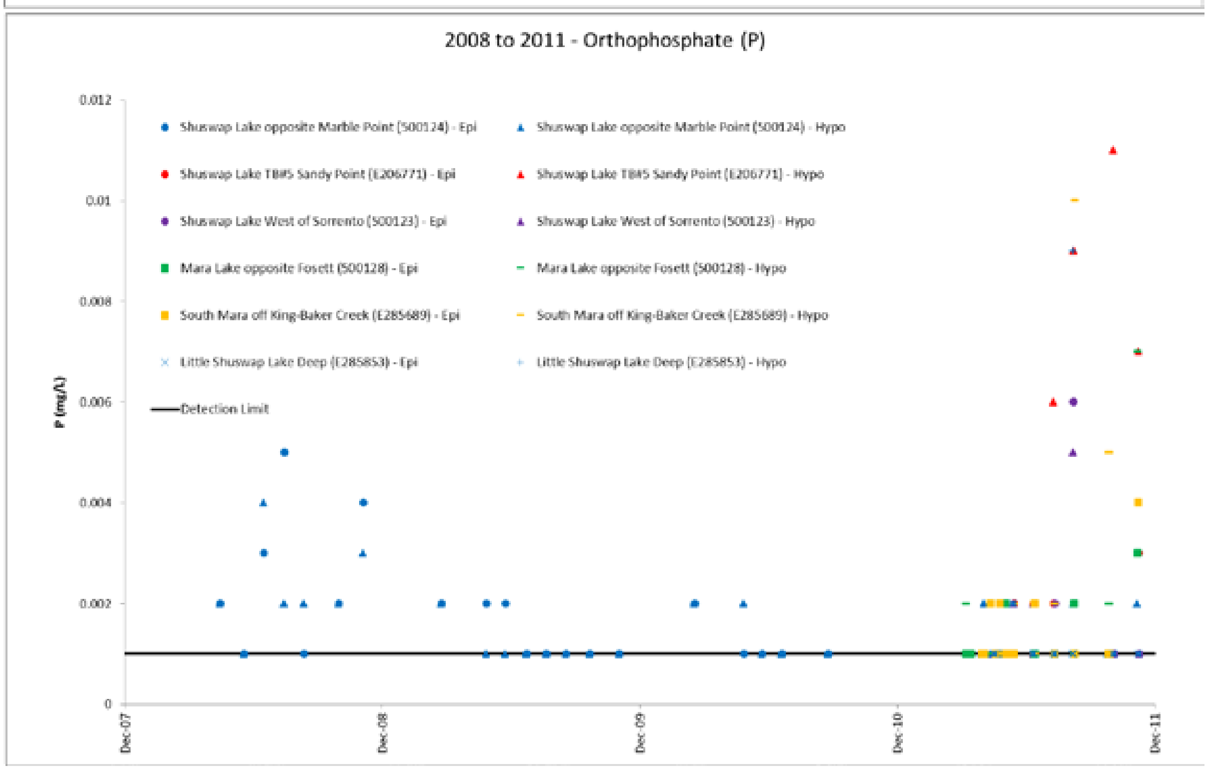
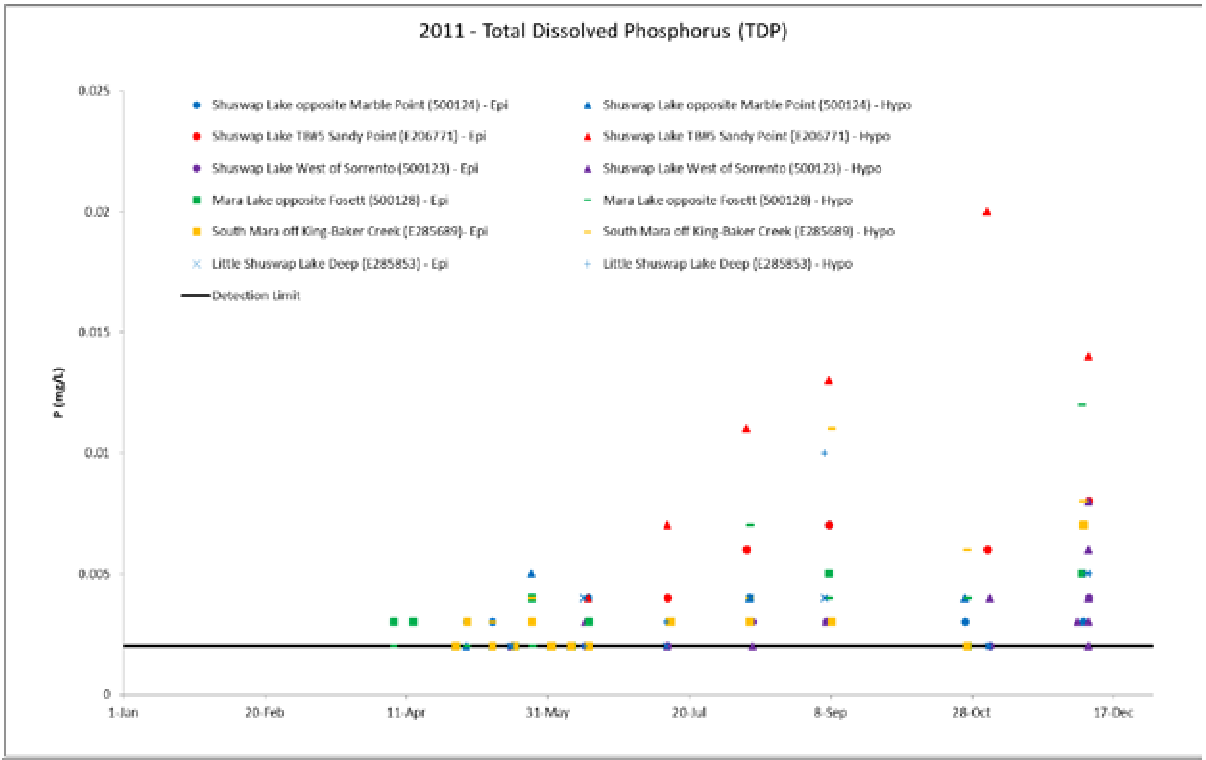


Figure 2-9 Soluble dissolved phosphorus (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes (Detection Limit= 0.002 mg/L)



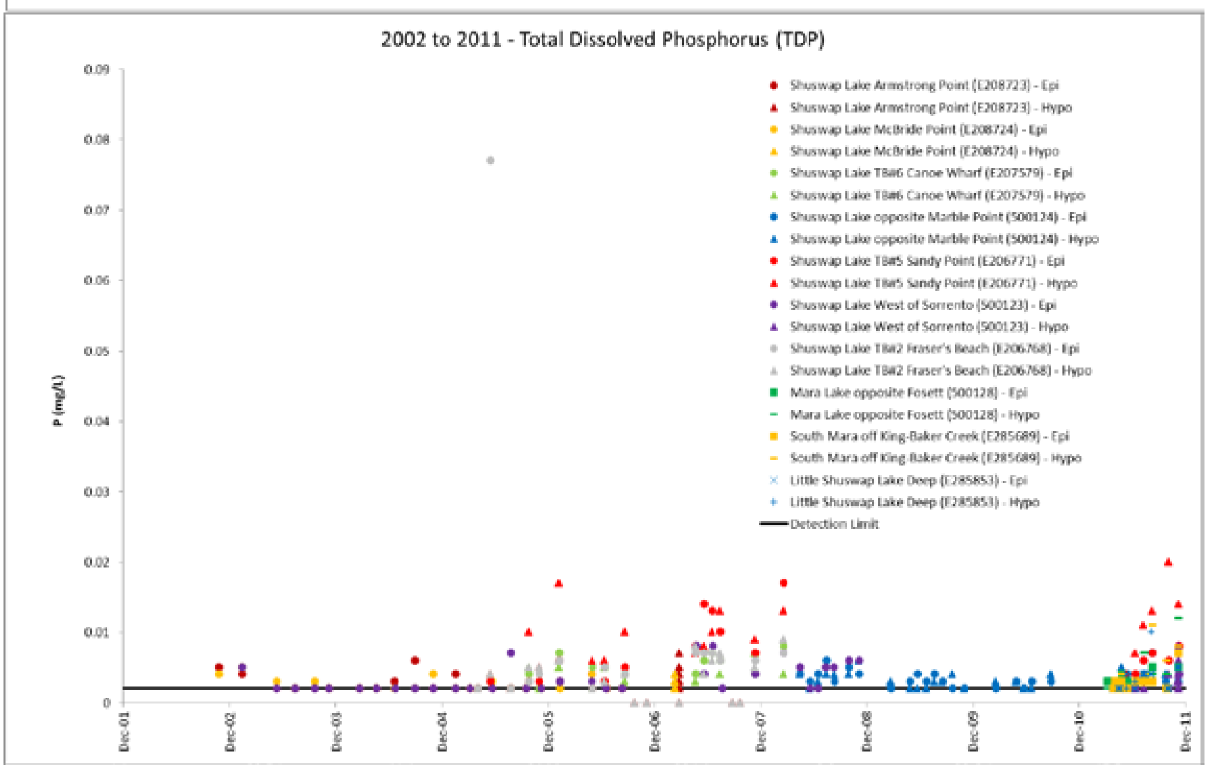
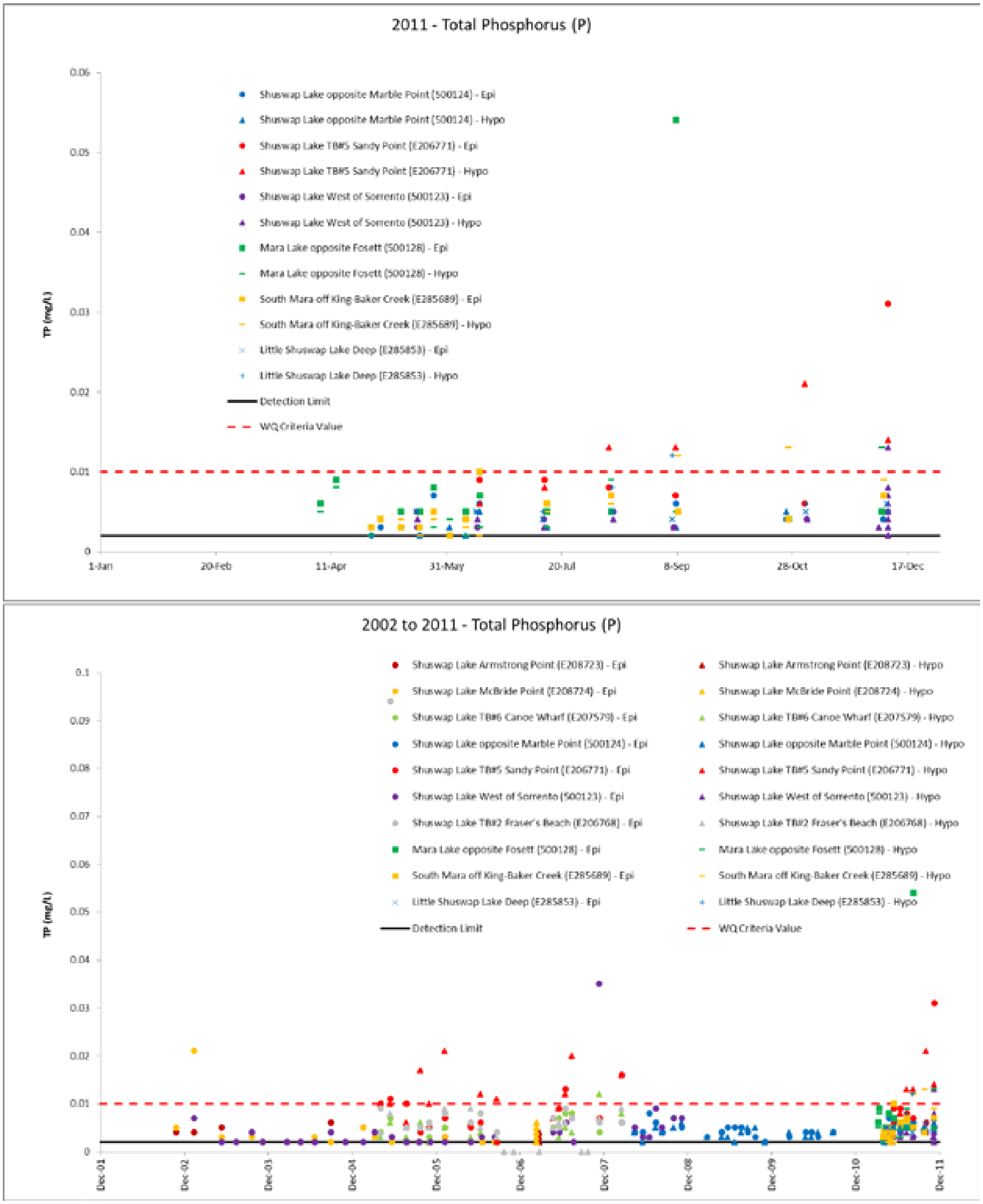


Figure 2-10 Total phosphorus (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes (Detection Limit= 0.002 mg/L; BC Water Quality Criterion= 0.01 mg/L)



2.3 Nitrogen

Nitrogen is present in fresh water in several forms and the nitrogen cycle, and the transformations between the nitrogen forms is a complex process. Nitrates and Nitrites form organic compounds that are key aquatic nutrients.

2.3.1 Ammonia Nitrogen

Ammonia (NH_3 and NH_4+) is a measure of the most reduced inorganic form of nitrogen in water and includes dissolved ammonia (NH_3) and the ammonium ion (NH_4+). Nitrogen is an essential plant nutrient and although ammonia is only a small component of the nitrogen cycle, it is important as it is biologically directly available to algae and plants. Natural undisturbed waters typically have ammonia concentrations less than 0.1 mg/L. Excessive concentrations of ammonia and other nitrogen compounds may contribute to eutrophication of water bodies. This results in prolific algal growths that have deleterious impacts on other aquatic life, drinking water supplies, and recreation.

Ammonia at high concentrations is toxic to aquatic life – especially un-ionized (NH_3) as the relative proportion can vary with pH and temperature. Anthropogenic sources for ammonia as well as other nitrogen fractions are sewage treatment plant effluents, septic sewage treatment systems, agriculture, urban developments, land disturbance, recreation, industrial effluents and mining (blasting residuals).

2.3.2 Nitrate and Nitrite Nitrogen

Nitrate (NO_3-) is the measurement of the most oxidized and stable form of inorganic nitrogen in fresh water. Nitrate is the principle form of combined nitrogen found in natural waters. It results from the complete oxidation of nitrogen compounds. It is generally reported in µg/L or mg/L. Without anthropogenic inputs, most surface waters have less than 0.3 mg/L of nitrate. Nitrate is a primary form of biologically available nitrogen used by algae and plants as a nutrient for growth. Excessive amounts of nitrogen may result in phytoplankton or macrophyte proliferations.

Nitrite (NO_2-) is a measure of a form of nitrogen that occurs as an intermediate in the nitrogen cycle. It is an unstable form that is either rapidly oxidized to nitrate (nitrification) or reduced to nitrogen gas (de-nitrification). This form of nitrogen can also be used as a source of nutrients for plants. It is normally present in only minute quantities in surface waters (<0.001 mg/L). Nitrite is normally reported with nitrate.

Dissolved Inorganic Nitrogen (DIN) is the sum of ammonia, nitrate and nitrite. It is a calculated value from analytical results.

2.3.3 Total Organic Nitrogen

Total Organic Nitrogen (TON) is a measure of that portion of nitrogen that is organically bound. Organic nitrogen includes all organic compounds such as proteins, polypeptides, amino acids, and urea. Dissolved organic nitrogen can often constitute over 50% of the total soluble nitrogen in fresh water. Organic nitrogen is not immediately available for biological activity. Therefore, it does not contribute to furthering plant proliferation until decomposition to the inorganic forms of nitrogen occurs – generally by bacterial metabolism , However, it can taken up and directly used by the chrysophyte *Ochromonas*, the algae causing the massive 2008 and 2010 algal blooms. Kjeldahl nitrogen is a measure of both the ammonia and the organic forms of nitrogen.

2.3.4 Total Nitrogen

Total Nitrogen is a measure of all forms of nitrogen (organic and inorganic). Nitrogen is an essential plant element and is often the limiting nutrient in marine waters.

Figure 2-11 (Ammonia), **Figure 2-12** (Nitrate-Nitrite), **Figure 2-13** (Total Organic Nitrogen) and **Figure 2-14** (Total Nitrogen) show results of sample analysis for 2011 monitoring (upper panel) and 2002-2011 longer term data (lower panel). Some patterns are discernible in the 2011 data. For instance, in Figure 2-9, some sites like the deep water (hypo) sites for Mara Lake Fosett and for Shuswap Sandy Point; the nitrate-nitrite concentrations are consistently higher than many other sites – and especially other surface water sites.

This pattern may also hold for other nitrogen fractions but it is difficult to establish this without some further graphing or statistical analysis. The scatter plots over the longer term data sets (2002-2011 – the lower panel) are difficult to interpret because sampling stations change from year to year. It is not clear whether there are trends or some sites have consistently higher concentrations. Some of this analysis is shown in the tables that follow the figures.

Figure 2-11 Ammonia (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes (Detection Limit= 0.005 mg/L)

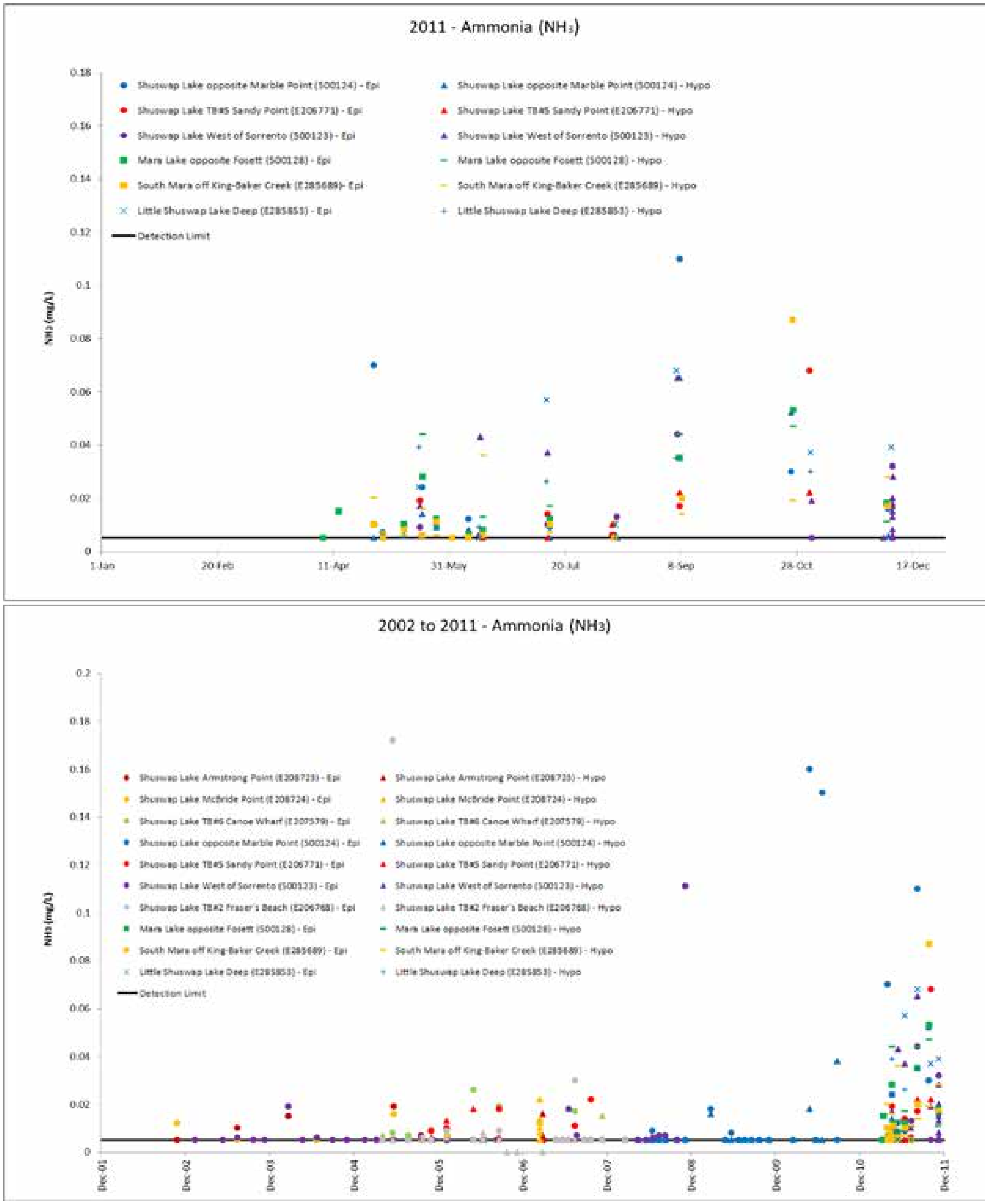


Figure 2-12 Nitrate and nitrite (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes (Detection Limit= 0.002 mg/L)

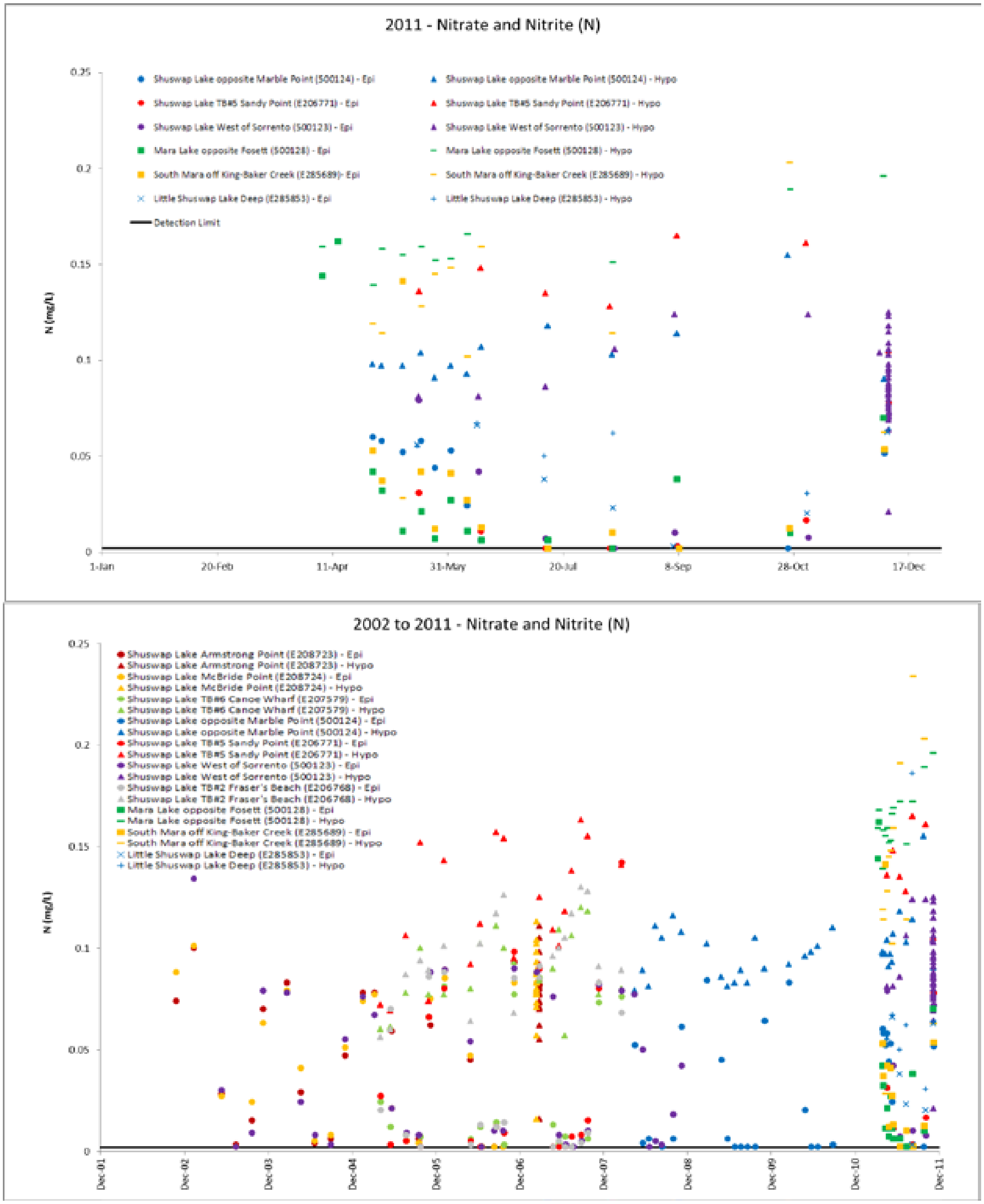
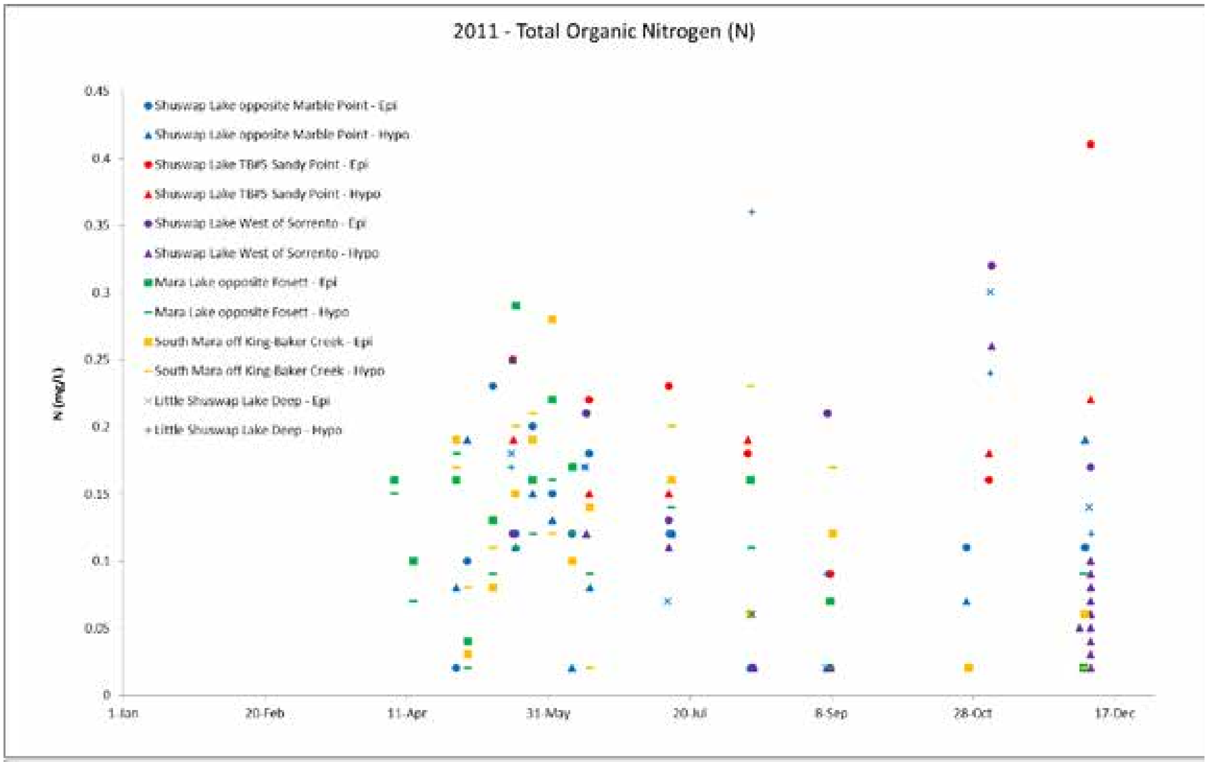


Figure 2-13 Total organic nitrogen (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes



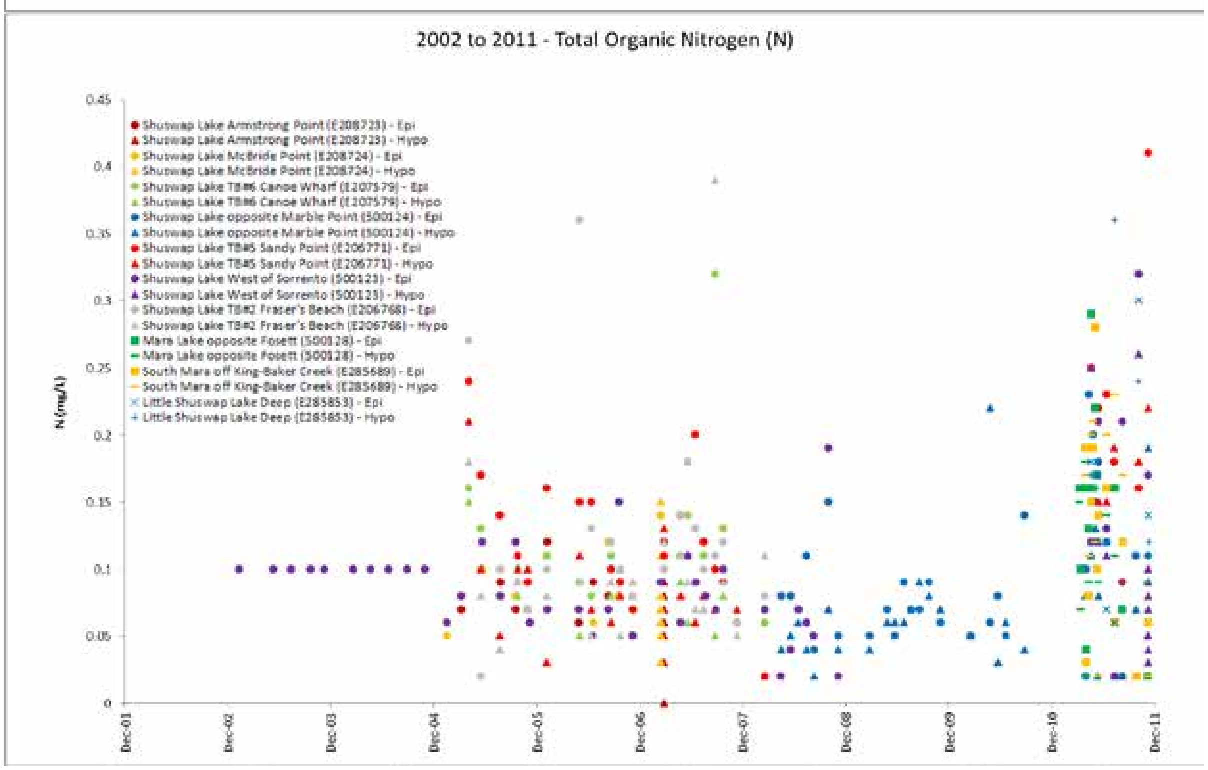
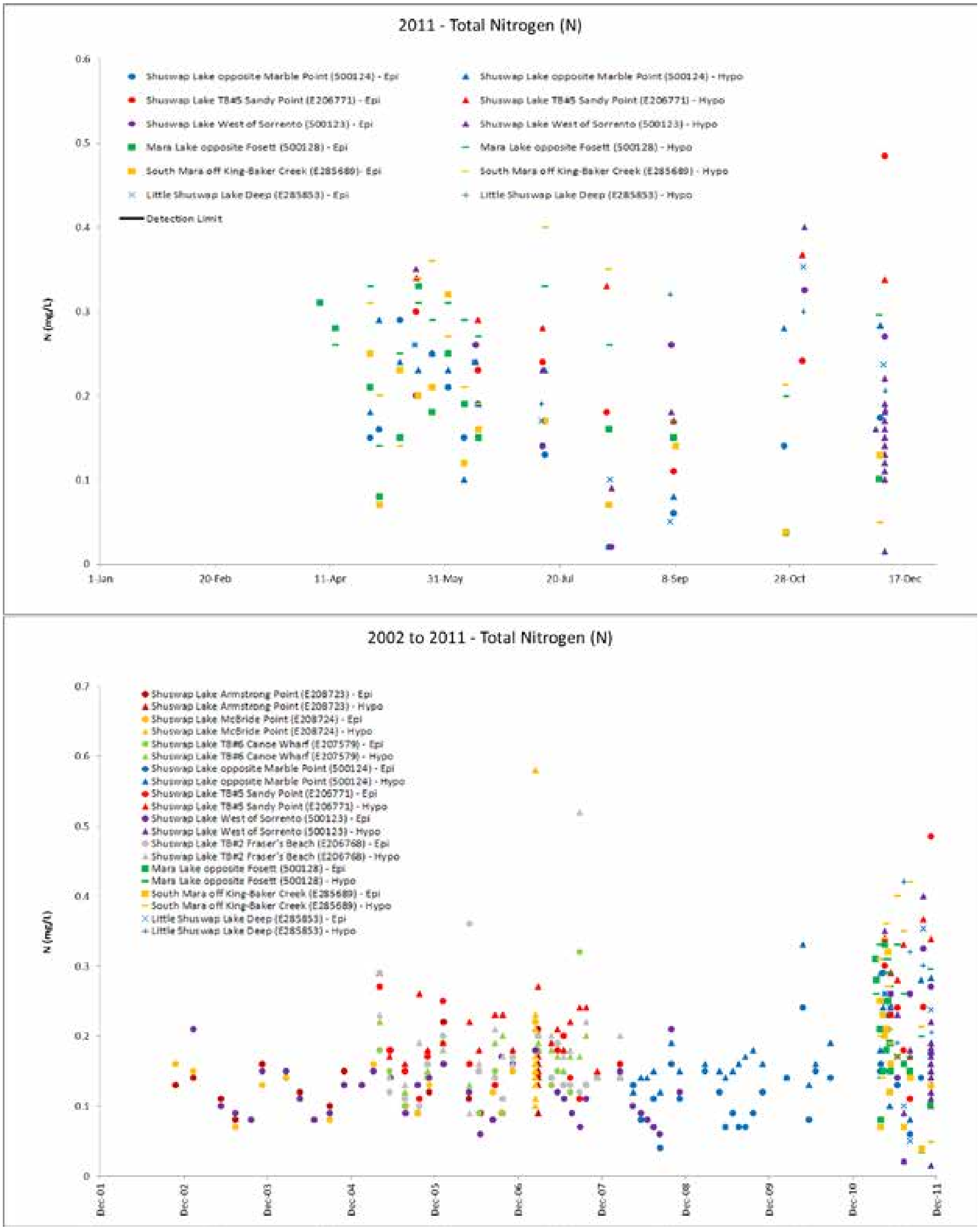


Figure 2-14 Total nitrogen (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes



2.4 Total Organic Carbon

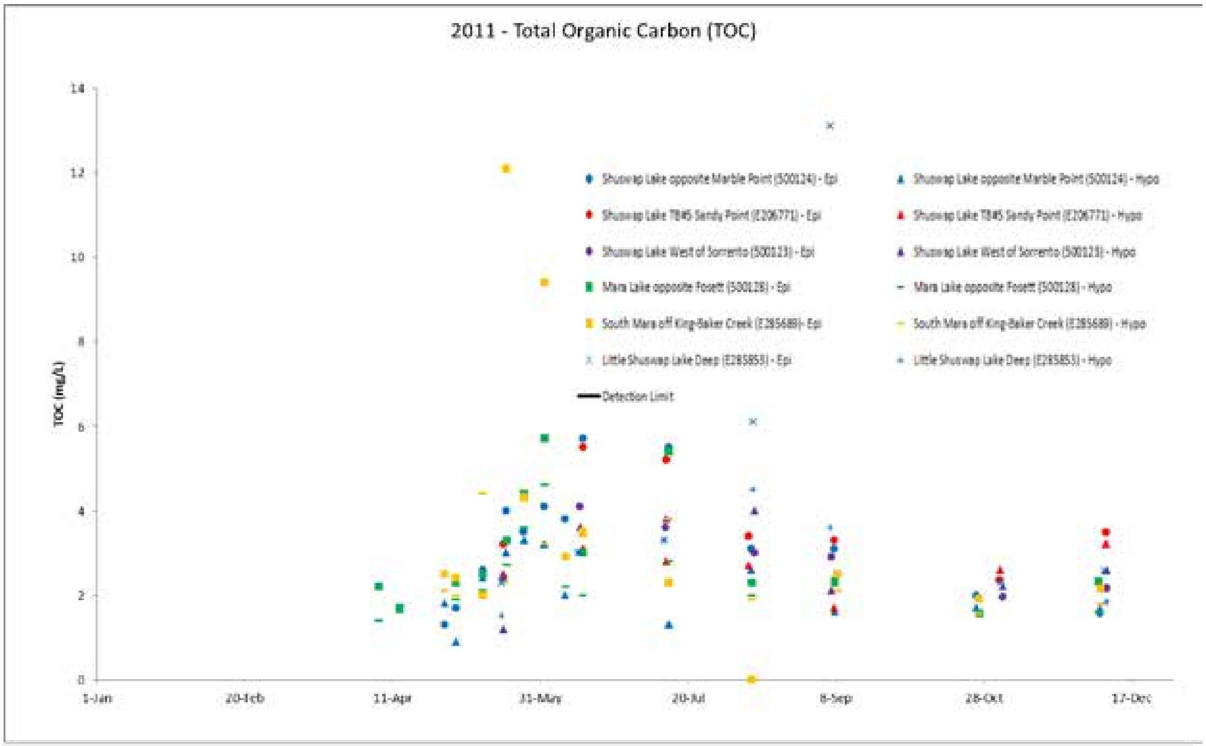
Total Organic Carbon (TOC) is a measure of the dissolved and particulate organic carbon in water. The bulk of organic carbon in water is composed of humic substances and partly degraded terrestrial plant materials. Some organic carbon (like humic substances) is resistant to microbial degradation but other (like algal cells) provides excellent substrate for fungi and bacteria, and carbon is a nutrient required for biological processes and the recycling of materials in the aquatic environment.

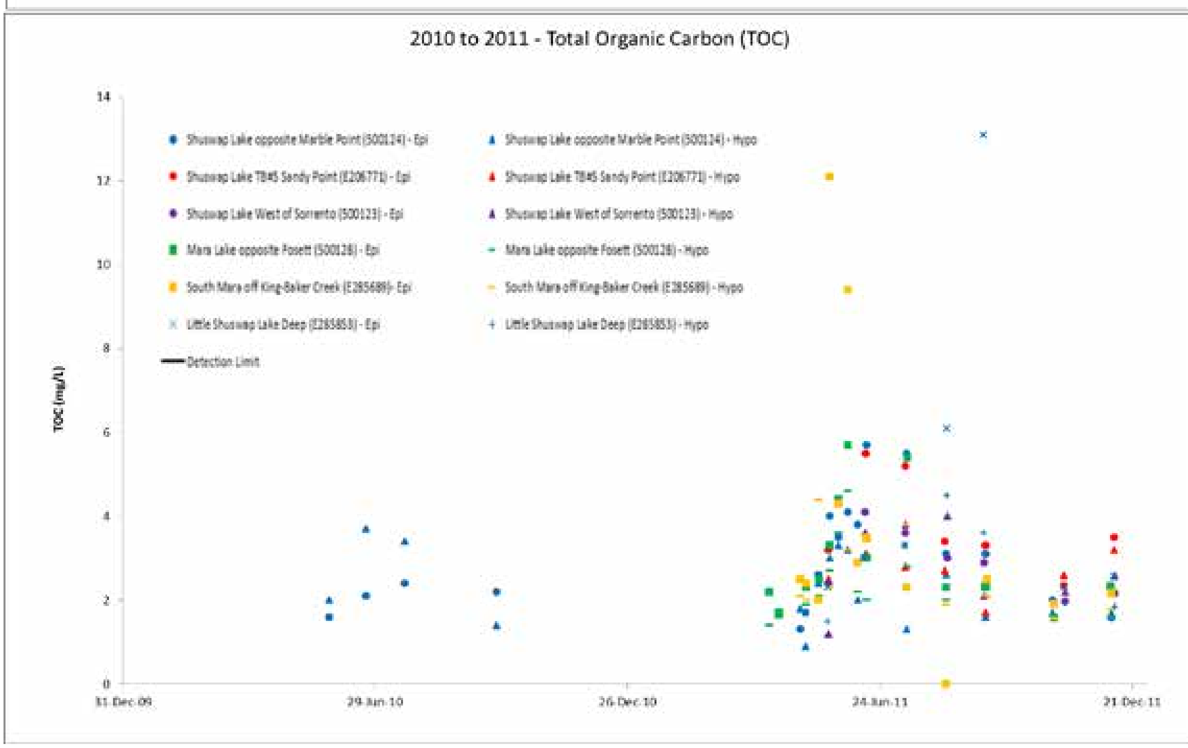
TOC is reported as mg/L and its range in natural waters may vary from 1 to 30 mg/L. Some regulatory agencies have suggested guidelines for TOC in raw drinking water subject to chlorination to prevent trihalomethanes (and other disinfection by-products) forming. The TOC guideline for drinking water supplies with chlorination is 4 mg/L (BCMOE). There are also aquatic life and wildlife guidelines for TOC and DOC, all four guidelines are: 30-day median ± 20% of the median background concentration.

The results for TOC concentrations (**Figure 2-15**) show that the concentrations for all stations is in the range 1 to 6 mg/L and varies throughout the year at each sampling site and between sites during the 2011 sampling season. Some notably high concentrations are seen in Mara Lake in spring, but concentrations in later parts of the year are in the same range in Mara as in other lakes.

There are overall higher concentrations in spring – perhaps as a result of inputs from spring runoff. In terms of comparison between sites, it would appear that TOC may be higher in Mara Lake sites and in the Salmon Arm of Shuswap Lake (Sandy Point) than other sites. Little long term information is available as TOC was only analysed in 2010 and 2011.

Figure 2-15 Total organic carbon (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes





2.5 pH

pH is the measurement of the hydrogen-ion concentration in the water. A pH below 7 is acidic (the lower the number, the more acidic the water, with a decrease of one full unit representing an increase in acidity of ten times) and a pH above 7 (to a maximum of 14) is basic (the higher the number, the more basic the water). Natural fresh waters have a pH range from 4.0 to 10.0, although most lakes in BC have a pH of 7.0 or greater. Coastal streams commonly have pH values of 5.5 to 6.5.

High pH values tend to facilitate the solubilization of ammonia, heavy metals and salts. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Lethal effects of pH on aquatic life occur below pH 4.5 and above pH 9.5. CCME Drinking Water Guidelines (CCME) specify a pH for drinking water of 6.5 to 8.5. Aquatic life guidelines are generally 6.5 to 9.0 unless background levels are otherwise and unique fauna and flora exist (i.e., boggy areas with pH below 6.5 and marl lakes with pH above 9.0).

The pH data shown in **Figure 2-16** appear to show an annual pattern with higher pH in spring and slightly less alkaline pH in summer and fall. This would be expected as higher phytoplankton productivity in spring would result in higher pH. The limited sampling in 2007-08-09 makes the long term trends difficult to evaluate in **Figure 2-16** (lower panel).

Figure 2-16 pH at deep stations in Shuswap, Little Shuswap and Mara Lakes

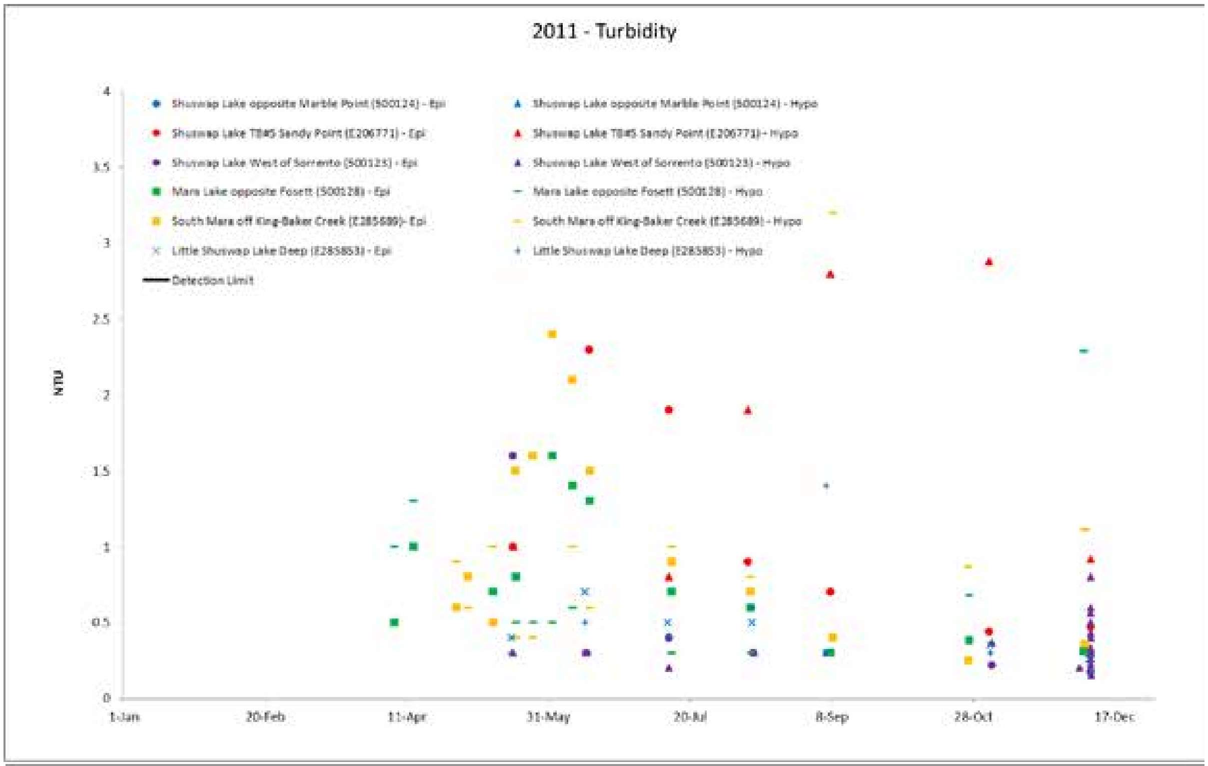
2.6 Turbidity

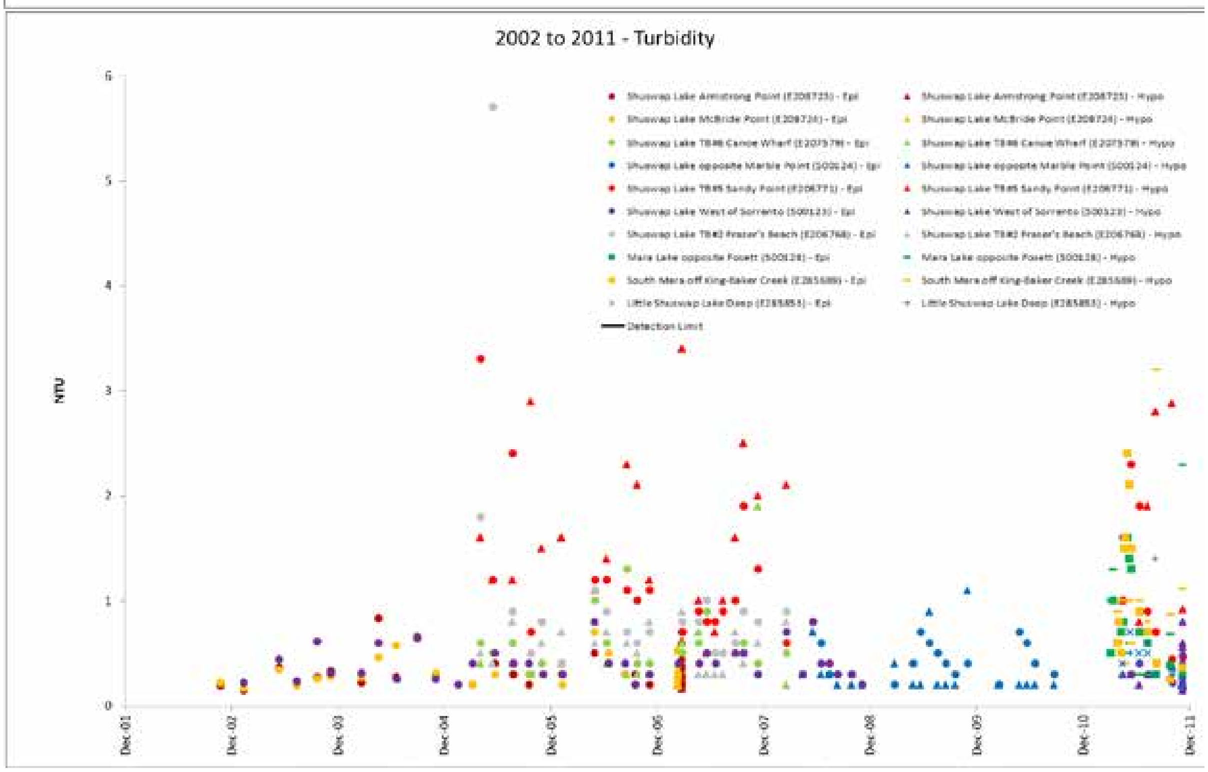
Turbidity is a measurement of the suspended particulate matter in a water body that interferes with the passage of light through the water. Materials that contribute to turbidity are silt, clay, organic material, or micro-organisms. Turbidity values are generally reported in Nephelometric Turbidity Units (NTU). Pure distilled water would have non-detectable turbidity (0 NTU).

The extinction depth (for lakes), measured with a Secchi Disk, is an alternative means of expressing turbidity. High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow. High turbidity reduces light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress fish productivity. Turbidity interferes with the disinfection of drinking water and is aesthetically unpleasant. The criteria for drinking water (CDWG) at the point of consumption is 1 NTU maximum (for health) and 5 NTU maximum (for aesthetics). There are also turbidity guidelines for protection of aquatic life.

The turbidity data in **Figure 2-17** shows generally higher turbidity (lower water clarity) in spring than in summer and fall – again that may be due to spring phytoplankton blooms but this needs to be compared to chlorophyll *a* data to verify if this is the reason. For both the 2011 data and the longer term data trend, the general pattern seems to show higher concentrations in Mara Lake and in Salmon Arm than other sites but more analysis is required to verify this. There appear to be differences between sites but the differentiation in this type of scatter plot is difficult to discern.

Figure 2-17 Turbidity (NTU) at deep stations in Shuswap, Little Shuswap and Mara Lakes





2.7 Other Water Quality Parameters

The following three water quality parameters were also collected and used as part of the ensemble of data to assess the water quality of Shuswap, Mara, and Little Shuswap Lakes and the data presented in F**igure 2-18**, **Figure 2-19** and **Figure 2-20**.

2.7.1.1 Dissolved Chloride

Of the halides, the anion chloride appears in the highest concentrations in natural fresh water systems. It is reported as mg/L dissolved chloride. The average chloride concentration in natural fresh waters is 1 to 10 mg/L. Halide concentrations are generally greater in lakes that are in proximity to marine regions. Some anthropogenic sources are municipal water supply disinfection, sewage treatment plant effluents, groundwater sewage disposal systems, urban developments, industrial effluents, and road slats.

The data shown in **Figure 2-18** for 2011 (upper panel) again seems to show higher chloride concentrations in Mara Lake and in Salmon Arm than other sites. It is difficult to interpret any trends with time in the long term data (lower panel) because of changes in sampling frequency and different sites being sampled in different years.

2.7.1.2 Specific Conductivity

Specific Conductivity is the measurement of the ability of water to conduct an electric current - the greater the content of minerals or ions in the water (principally the major cations calcium, magnesium and potassium and the anions carbonate, bicarbonate, chloride and sulphate) the more current the water can conduct. Ions are positively or negatively charged dissolved metals and other dissolved materials.

Conductivity is reported in the unit of microsiemens per centimeter (µS/cm). Natural waters are found to vary between 50 and 1500 µS/cm. Coastal lakes and streams in BC often have specific conductivity values of <100 µS/cm, while interior lakes and streams range up to 500 µS/cm and higher in dry climates. Specific conductivity may be used to estimate the total ion concentration of the water and is often used as an alternative measure of dissolved solids. Correlations between conductivity and dissolved solids for a specific body of water are often undertaken as a way to estimate dissolved solids in the field.

Some anthropogenic sources are mining, roads (de-icing salts) and industrial and municipal effluents. Specific conductivity can be used as an indicator of general land disturbance (i.e., roads, logging, land disturbance). Due to its natural variability, there are few guidelines for this parameter – it is useful as an indicator of localized inputs and of long-term trends. Sample data for specific conductivity is shown in **Figure 2-19**, and shows many of the sites have a distinct dissolved ion concentration. The lowest conductivity is in Little Shuswap Lake with the Shuswap site at Sorrento the next highest and the Mara Lake and Shuswap Marble Point sites intermediate and the Salmon Arm site at Sandy Point with the highest values.

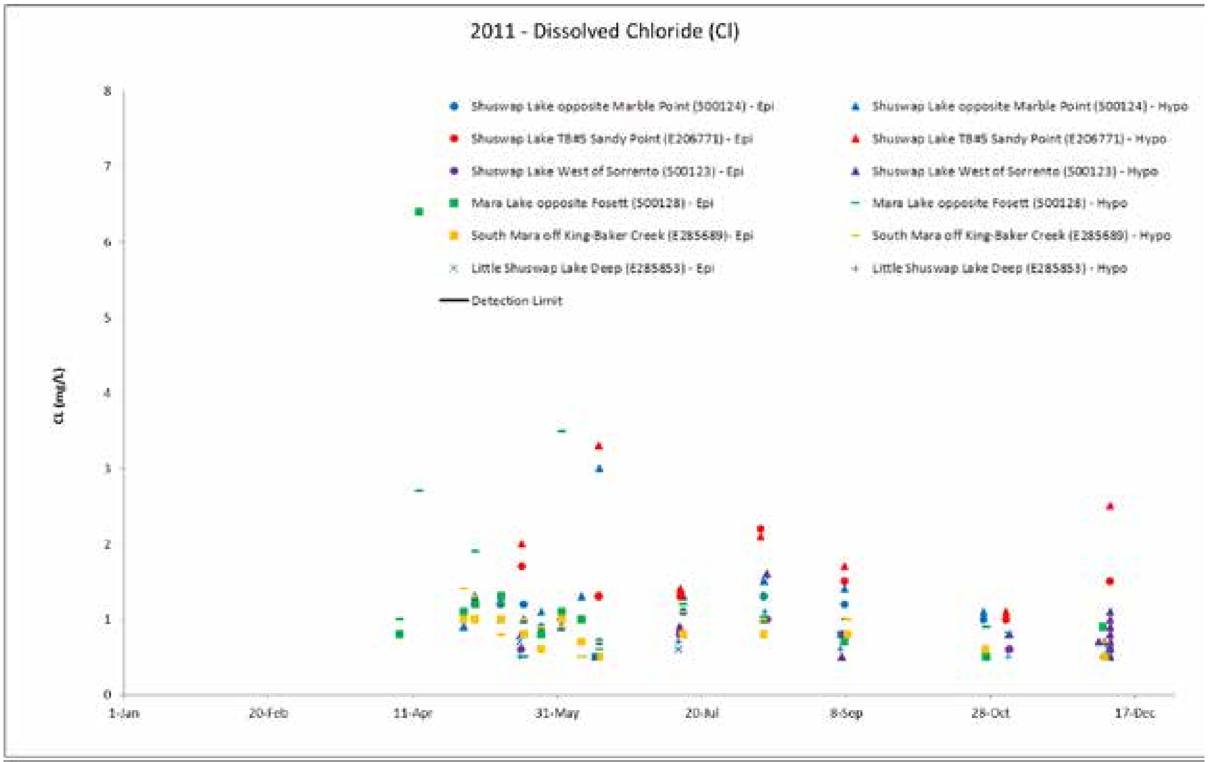
Specific conductivity is the most distinct water quality parameter and could be used as an identifier for the different lakes or lake basins.

2.7.1.3 Sulphates

Sulphate is one of the anionic mineral ions (the oxidized form of sulphur) that are found dissolved in fresh water. Sulphate levels in Canadian lakes typically range from 3 to 30 mg/L. Sulphur originates naturally from sulphide minerals in the soil, atmospheric sulphur dioxide and biological processes. Anthropogenic sources are fertilizers and industrial processes like pulp mills and mining and smelting.

Results for the sampling data for sulphate are shown in **Figure 2-20**. Again both for the 2011 data and the longer term monitoring results, sites from Mara Lake and Salmon Arm (Sandy Point) seem to show the highest concentrations – reflecting the higher biological productivity and higher loading of nutrients and contaminants to these water bodies.

Figure 2-18 Dissolved chloride (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes



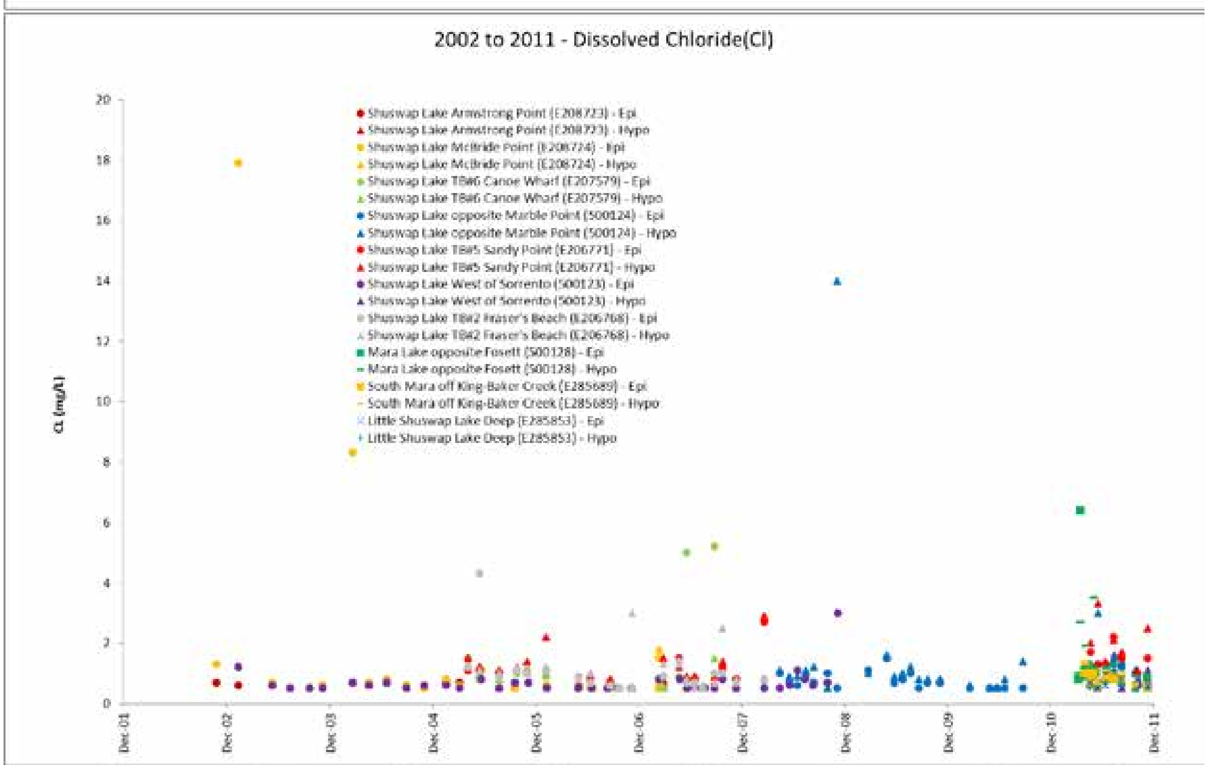


Figure 2-19 Specific conductivity (µS/cm) at deep stations in Shuswap, Little Shuswap and Mara Lake

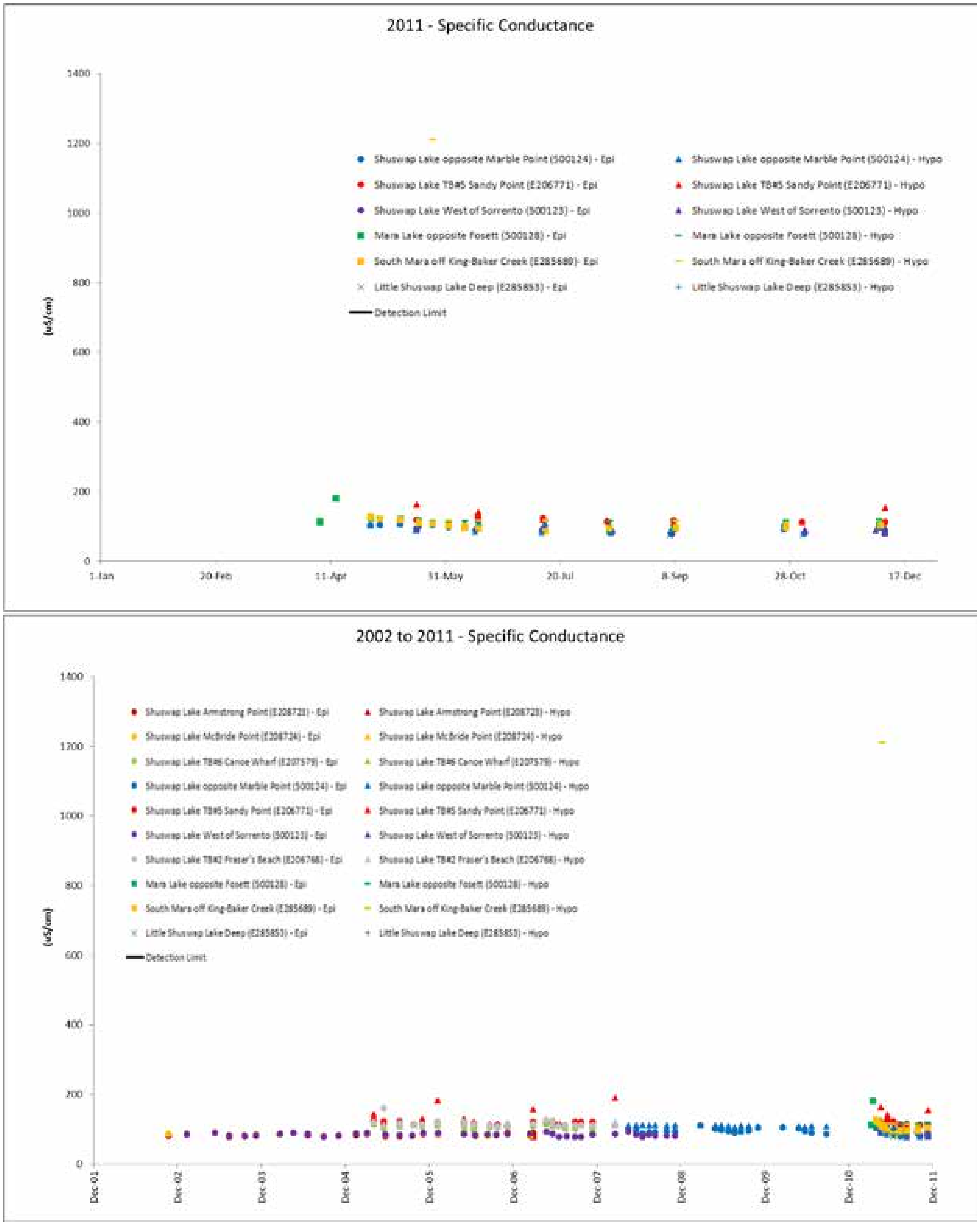
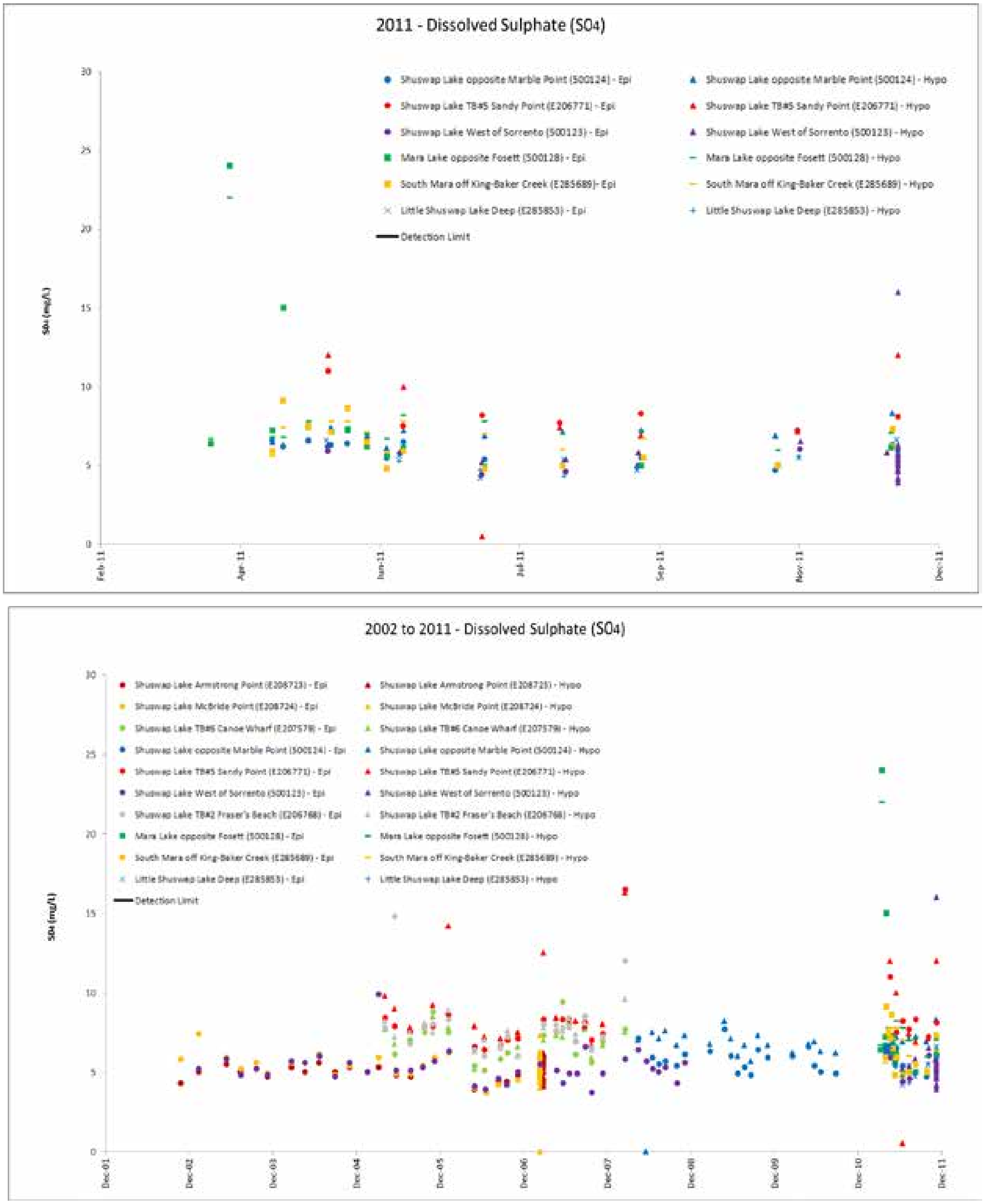


Figure 2-20 Sulphate (mg/L) at deep stations in Shuswap, Little Shuswap and Mara Lakes



2.8 Primary Productivity

Table 2-2 is a compilation of comparative data for six key deep water sites in the study sampled in 2011 for four indicator parameters. The sites are listed in what might be considered upstream to downstream sequence. For ammonia nitrogen it is interesting to see that the concentrations increase from Mara Lake and Salmon Arm (annual average about 15 µg/L) to slightly higher at the Marble Point site and higher again at the main arm site west of Sorrento and highest of all average concentration in Little Shuswap Lake at 28.5 µg/L. The pattern for nitrate seems to be opposite with concentrations trending lower with distance "downstream".

Table 2-2 Water Quality in Shuswap and Mara Lakes, British Columbia: Deep Stations 2011

Station	Sample Number	Ammonia-N	Nitrate-N	Total-P	Chlorophyll *a*
South Mara off King-Baker Creek E285689	26	14.5 (5-36)	84 (2-234)	4.9 (2-13) (7.6% exc.)	3.1 (0.9-9.2) (75% exc.)
Mara Lake opposite Fosett 500128	26	15.7 (5-53)	101 (2-196)	6.6 (2-54) (6.6% exc.)	4.1 (1.3-11.3) (77% exc.)
Shuswap Lake off Sandy Point TB#5 E206771	14	15.7 (5-68)	90.6 (2-165)	11.0 (4-31) (35% exc.)	2.9 (1.9-4.3) (60% exc.)
Shuswap Lake opposite Marble Point 500124	26	19 (5-110)	68 (2-114)	3.9 (2-7) (0% exc.)	2.3 (0.8-4.0) (25% exc.)
Shuswap Lake west of Sorrento 500123	14	23.7 (5-65)	63.7 (2-124)	3.7 (3-5) (0% exc.)	1.8 (0.5-3.0) (16.6% exc.)
Little Shuswap Lake Deep E285853	14	28.5 (5-57)	55.8 (23-186)	5.7 (4-12) (7% exc.)	(1.0-3.7)

All values in µg/L. Arithmetic means with range of values given in brackets. Total-P WQ criteria set at 10 µg/L and expressed as % of values that exceed. Chlorophyll *a* WQ criteria set at 2.5 µg/L and expressed as % of values that exceed. ND = not determined.

For phosphorus and for chlorophyll *a* (the pigment used to measure algal biomass) the data are compared to guidelines to determine the relative percentage of time that these guidelines are exceeded at these stations. For total phosphorus, the number of samples that exceeded the criteria was relatively low (7 to 8%) (as was the case for Little Shuswap Lake total phosphorus (TP) samples.

The contrast comes with the Salmon Arm sampling site (Sandy Point) where 35% of the TP samples exceeded the guideline of 10 µg/L but the two other Shuswap Lake sites never had any TP sample results above the 10 µg/L guideline/criteria. For chlorophyll *a*, the pattern is similar with the Salmon Arm sampling site (Sandy Point) and the Mara Lake sites exceeding the guideline of 2.5 µg/L from 60 to 75% of the time but the two other Shuswap Lake sites only had sample results above the guideline 16% of the time in 2011.

Table 2-3 is a compilation of nutrient and chlorophyll data comparing the 2011 data to three previous years at the Sandy Point site in Salmon Arm. Taken at face value, both the ammonia and nitrate appear to show increases over time but since the sample size differs in each year and the timing of samples may differ as well, the trend may or may not be true. That pattern also seems to be possible with total phosphorus concentration, but again with the same uncertainty. The pattern of exceedance for both TP and Chl *a* do not appear to show a trend toward either TP or algal biomass becoming more of a problem; however, the time scale examined here is very short (2005 to 2011).

Trend cycles are likely correlated with the cyclic escapement of sockeye salmon runs to the Shuswap system, and warrants consideration on dominant and sub-dominant years and by overall escapement magnitude. Both 2011 and 2007 were years after the dominant runs with 2011 considered a historic record escapement.

Table 2-3 Water Quality in Shuswap Lake at Shuswap Lake off Sandy Point TB#5 -Deep Station (E206771) during 2005-2011

Year	Sample Number	Ammonia-N	Nitrate-N	Total-P	Chlorophyll *a*
2005	10	5.5 (5-9)	57.6 (2-152)	9.3 (4-17) (20% exc.)	3.2 (1.7-6.4) (60% exc.)
2006	8-12	10 (5-18)	79.9 (2-157)	8.7 (2-21) (37.5% exc.)	1.9 (1-4.1) (33% exc.)
2007	6-10	6.4 (5-22)	76.9 (2-163)	11.0 (7-20) (20% exc.)	3.9 (0.9-10.6) 57% exc.)
2011	14	15.7 (5-68)	90.6 (2-165)	11.0 (4-31) (35% exc.)	2.9 (1.9-4.3) (60% exc.)

All values in µg/L. Arithmetic means with range of values given in brackets. Total-P WQ criteria set at 10 µg/L and expressed as % of values that exceed. Chlorophyll a WQ criteria set at 2.5 µg/L and expressed as % of values that exceed. ND = not determined.

The station summary for Shuswap at Marble Point for 2011 and three preceding years is given in **Table 2-4** so a preliminary evaluation of trends (and inter-annual variability) might be examined. No trends seem apparent.

Table 2-4 Water Quality in Shuswap Lake at Shuswap Lake opposite Marble Point -Deep Station (500124) during 2008-2011

Year	Sample Number	Ammonia-N	Nitrate-N	Total-P	Chlorophyll *a*
2008	14	5.28 (5-9)	58.9 (2-116)	4.8 (2-8) (0% exc.)	1.9 (0.7-4.8) (28.5% exc.)
2009	16	6.7 (5-18)	25.8 (2-105)	3.6 (2-5) (0% exc.)	1.2 (0.5-2.6) (12.5% exc.)
2010	10	36.6 (5-160)	60.7 (2-110)	3.6 (3-4) (0% exc.)	3.7 (0.7-4.7) (40% exc.)
2011	26	19 (5-110)	68 (2-114)	3.9 (2-7) (0% exc.)	2.3 (0.8-4.0) (25% exc.)

All values in µg/L. Arithmetic means with range of values given in brackets. Total-P WQ criteria set at 10 µg/L and expressed as % of values that exceed. Chlorophyll *a* WQ criteria set at 2.5 µg/L and expressed as % of values that exceed. ND = not determined.

The station summary for the Sorrento deep station in Table 2-5 has a longer sample result record and so provides the best evaluation of potential trends in the key nutrient and algal biomass data. For ammonia, the results for 2008 and 2011 are notably higher than the 2003 to 2007 data set. It is not clear however if this is indicative of any recent increase in ammonia at this site. No obvious increase over time is evident in the nitrate data or the total phosphorus data.

The differences between years are likely due to differences in hydrology (and subsequent loading amounts and timing of nutrient inputs) into the lakes and possibly other factors as well. Defining year to year variability is a valuable piece of information, and further analyses based on estimation of total loading and marine-derived sources from sockeye escapements is critical. The chlorophyll *a* data shows higher algal biomass in 2007 that corresponds with relatively high TP that year at this station.

Table 2-5 Water Quality in Shuswap Lake west of Sorrento-Deep Station (500123) during 2003-2011

Year	Sample number	Ammonia-N	Nitrate-N	Total-P	Chlorophyll a
2003	10 (chl. 5)	5.1 (5-6)	73.3 (2-134)	3.6 (2-7) (0% exc.)	0.8 (0.5-1.2) (0% exc.)
2004	10 (chl. 5)	8.8 (5-19)	40.7 (3-83)	2.3 (2-4) (0% exc.)	1.2 (0.8-2.1) (0% exc.)
2005	12 (chl.6)	5.7 (5-13)	58.4 (9-106)	2.6 (2-5) (0% exc.)	0.8 (0.5-1.4) (0% exc.)
2006	12 (chl.6)	5 (5-5)	58.9 (2-89)	2.6 (2-4) (0% exc.)	1.0 (0.6-2.0) (0% exc.)
2007	16 (chl.8)	6.4 (5-18)	56.6 (2-123)	7.8 (2-35) (11% exc.)	2.3 (0.9-6) (25% exc.)
2008	17 (chl.8)	12.5 (5-111)	65.3 (2-125)	4.9 (2-13) (6% exc.)	1.3 (0.7-2.2) (0% exc.)
2011	14 (chl.6)	23.7 (5-65)	63.7 (2-124)	3.7 (3-5) (0% exc.)	1.8 (0.5-3.0) (16.6% exc.)

All values in µg/L. Arithmetic means with range of values given in brackets. Total-P WQ criteria set at 10 µg/L and expressed as % of values that exceed. Chlorophyll *a* WQ criteria set at 2.5 µg/L and expressed as % of values that exceed. ND = not determined.

3 Near Shore Water Quality - Littoral Monitoring

Near shore littoral sites that showed indications of septic seepage (based on previous fluorometer measurements) and locations identified by SLIPP partners as sites of interest to users or as sites receiving point or non-point discharges (e.g. downstream of storm sewers) were sampled at up to 20 sites. Attached algae were monitored using similar selection criteria, but also included sites of concern by residents and SLIPP partners, at up to 20 sites (10 visual sites, 10 analysed sites).

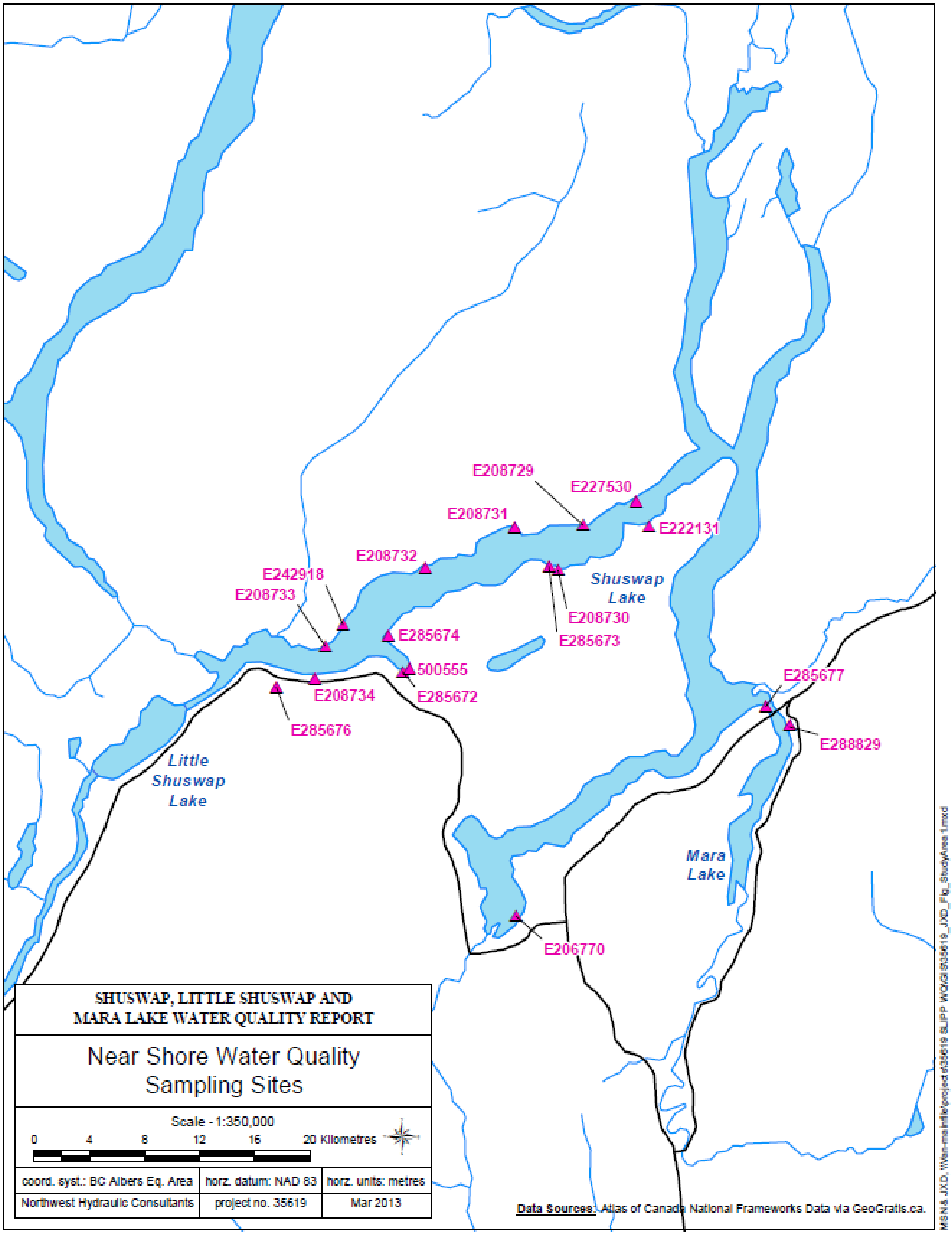
There are a wide range near shore sites: 1) Raw drinking water taken from systems with intakes up to 60m deep, except at Crescent Bay (10 or 15 m); 2) Algal growth at 22 sites with 3 m depths, 5 m offshore and plates 1m subsurface; and near shore grab samples collected at surface in 1 m depths, usually within 5 m of shore.

Secchi depth measurements were collected at selected sites of concern and those for which volunteers were available on a weekly or bi-weekly basis, hence were flexible. Near shore water samples were partly collected at raw water taps at intakes ranging from shallow to deep. Other near shore samples were taken at surface level within 50 m from the shore. later, littoral sites were specified to be 100 m off shore (**Table 3-1** and **Figure 3-1**).

Table 3-1 Near shore water quality monitoring station locations

Station Number	Station Name	EMS #	Latitude	Longitude	Year(s) sampled
Near Shore station 1	Shuswap Lake TB#4 - Salmon Arm at Christmas Island	E206770	50.714167	119.278889	2011, 2003-2007
Near Shore station 2	Cedar Heights - 2271 Blind Bay Rd.	E285672	50.879444	119.371389	2011-2012
Near Shore station 3	Eagle Bay Estates-4300 Eagle Bay Rd.	E285673	50.938889	119.210833	2011-2012
Near Shore station 4	McArther Reedman - 3399 MC Bride Point Rd.	E285674	50.903611	119.3825	2011-2012
Near Shore station 5	Sorrento Water System - 1286 TCH	E285676	50.877222	119.5025	2011-2012
Near Shore station 6	Crescent Bay - Old Sicamous Rd	E285677	50.834444	119.001944	2011-2012
Near Shore station 7	Shuswap Lake at Anglemont	E208729	50.9633	119.1711	2003-2007
Near Shore station 8	Shuswap Lake at Eagle Bay	E208730	50.9358	119.2014	2003-2008
Near Shore station 9	Shuswap Lake at Magna Bay	E208731	50.9662	119.242	2003-2007
Near Shore station 10	Shuswap Lake at Celista	E208732	50.9456	119.3379	2003-2007
Near Shore station 11	Shuswap Lake at Scotch Creek	E208733	50.901	119.4486	2003-2007
Near Shore station 12	Shuswap Lake at Sorrento	E208734	50.8805	119.4623	2003-2008
Near Shore station 13	Shuswap Lake at Wild Rose Bay	E222131	50.9582	119.1044	2003-2008
Near Shore station 14	Shuswap Lake at Horseshoe Bay	E227530	50.9756	119.1149	2003-2007
Near Shore station 15	Shuswap Lake East of Park	E242918	50.9138	119.428	2002-2007
Near Shore station 16	Shuswap Lake Blind Bay South-East	E500555	50.8811	119.3644	2003-2008

Figure 3-1 Map of SLIPP near shore sampling sites in Shuswap, Little Shuswap and Mara Lakes



Water samples were collected monthly from June 2011 to February 2012 or tailored to the specific uses or discharges. Attached algae were sampled using artificial substrates, starting in May and then every six weeks until October. Periphyton plates were retrieved after three, six and nine weeks of installation, and a visual evaluation was conducted every three weeks. Chl- a was collected at 14 stations and Periphyton samples collected from all sites at the end of season.

Secchi depth was measured weekly if possible, otherwise bi-weekly from May to October. Groundwater sampling was conducted 1-2 times/year and analyzed for the parameters detailed below. Drinking water sampling was conducted from once per year up to weekly sampling, depending on the parameter, by collecting water from 4 drinking water sample stations and analysing for the parameters detailed below. Samples were collected monthly from 5 sites. Beach sampling was conducted weekly during beach season. The full range of parameters collected were as follows:

1. Littoral grab sampling:
    a. General water chemistry (chloride, specific conductivity, turbidity, TOC, pH)
    b. Nutrients (SRP, TDP, TP, NO3+NO2, NH3, TON, TN, DOC)
    c. Fecal indicators (coliform bacteria)
    d. Indicators of septic leakage (dissolved sulphate)
2. Attached algae:
    a. Formal Visual comparison – using a New Zealand Method
    b. Chlorophyll *a* concentrations
    c. Some accumulated periphyton species composition
3. Secchi Disk:
    a. Secchi Depth
4. Groundwater sampling:
    a. Water level
    b. General chemistry (bromide, chloride, fluoride, sulfate, specific conductivity, turbidity, TOC, pH, total alkalinity, hardness)
    c. Nutrients (Ammonia-N, TKN, nitrate, nitrite, organic-N, orthophosphate-P, TP)
    d. Dissolved metals
    e. Fecal indicators (fecal coliform, total coliform, *Escherichia coli (E. coli)*)
5. Drinking Water Sampling:
    a. Fecal indicators (coliform bacteria)
    b. General Chemistry (chloride, specific conductivity, turbidity, TOC, pH)
    c. Dissolved metals
    d. Organic compounds as needed
6. Beach Sampling:
    a. Fecal indicators (coliform bacteria)

3.1 Phosphorus

Three fractions of phosphorus (P) were sampled and analysed in this program. Phosphorus is considered a key element in fresh water as it is an essential nutrient and often the most limiting nutrient to plant growth in fresh water ecosystems. In nearshore areas, excess phosphorus may be related to algal blooms, attached algal and macrophyte growth.

3.1.1 Soluble Reactive Phosphorus

Figure 3-2 shows soluble reactive phosphorus (mg/L) at near shore stations in Shuswap and Mara Lakes (Detection Limit = 0.001 mg/L). The results show that SRP was only occasionally found at the near-shore sites sampled – three occasions at the Christmas Island site and once each at Crescent Bay and Eagle Bay Estates sites. The concentrations were only slightly above detection limits and did not show any strong evidence for shore-based phosphorus inputs into the lake.

3.1.2 Total Dissolved Phosphorus

Figure 3-3 shows total dissolved phosphorus (mg/L) at near shore stations in Shuswap and Mara Lakes (Detection Limit = 0.002 mg/L). The results shown for TDP also indicated that concentrations above detection limits were only occasionally found at the near-shore sites sampled – the highest values at the Christmas Island site and a few other samples close to the detection limit and similar to the deep water concentrations found near these sites. The concentrations, for the most part, were only slightly above detection limits and did not show any strong evidence for shore based phosphorus inputs into the lake, if TDP is used as an indicator.

3.1.3 Total Phosphorus

Figure 3-4 shows total phosphorus (mg/L) at near shore stations in Shuswap and Mara Lakes (Detection Limit= 0.002 mg/L; BC Water Quality Criteria= 0.01 mg/L). The results show that TP above the guideline concentration of 10 µg/L was only found at one of the near-shore sites sampled – on four occasions at the Christmas Island site. The other TP concentrations were typical of lake TP concentrations and only slightly above detection limits and did not show any strong evidence for shore based phosphorus inputs into the lake.

Figure 3-2 Near Shore Soluble Reactive Phosphorus

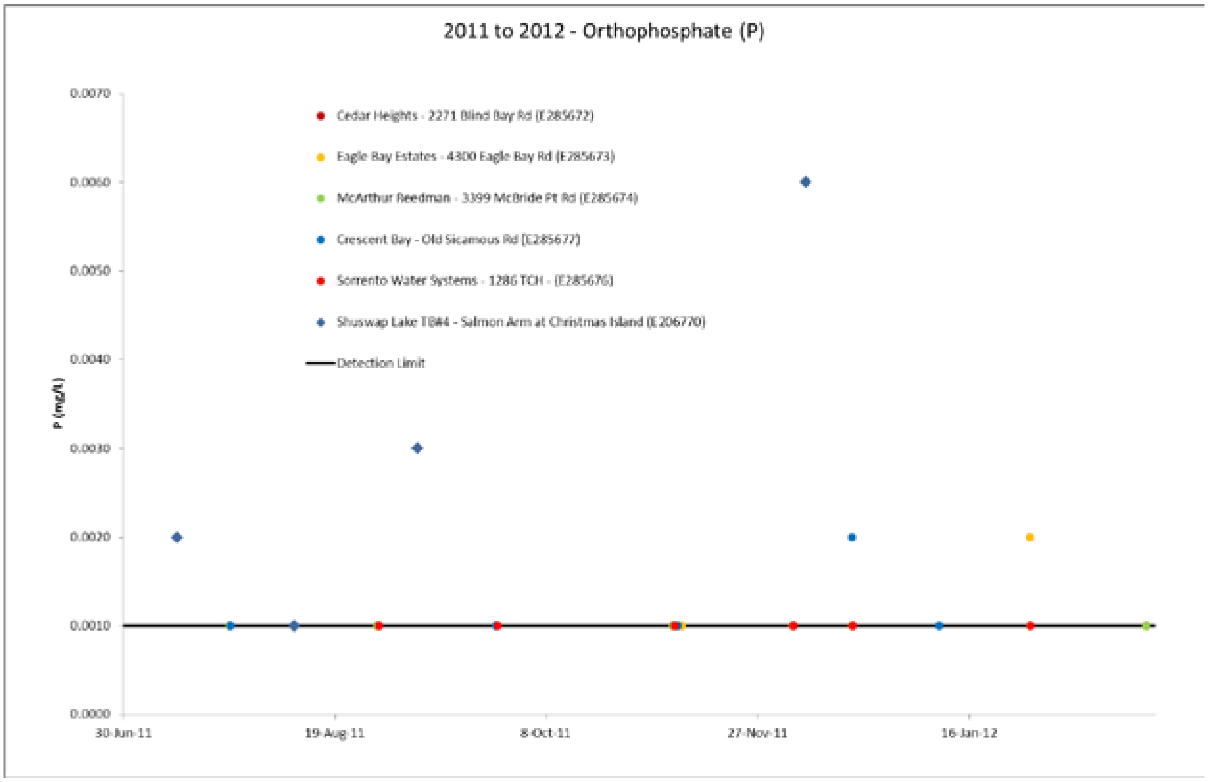


Figure 3-3: Total Dissolved Phosphorus

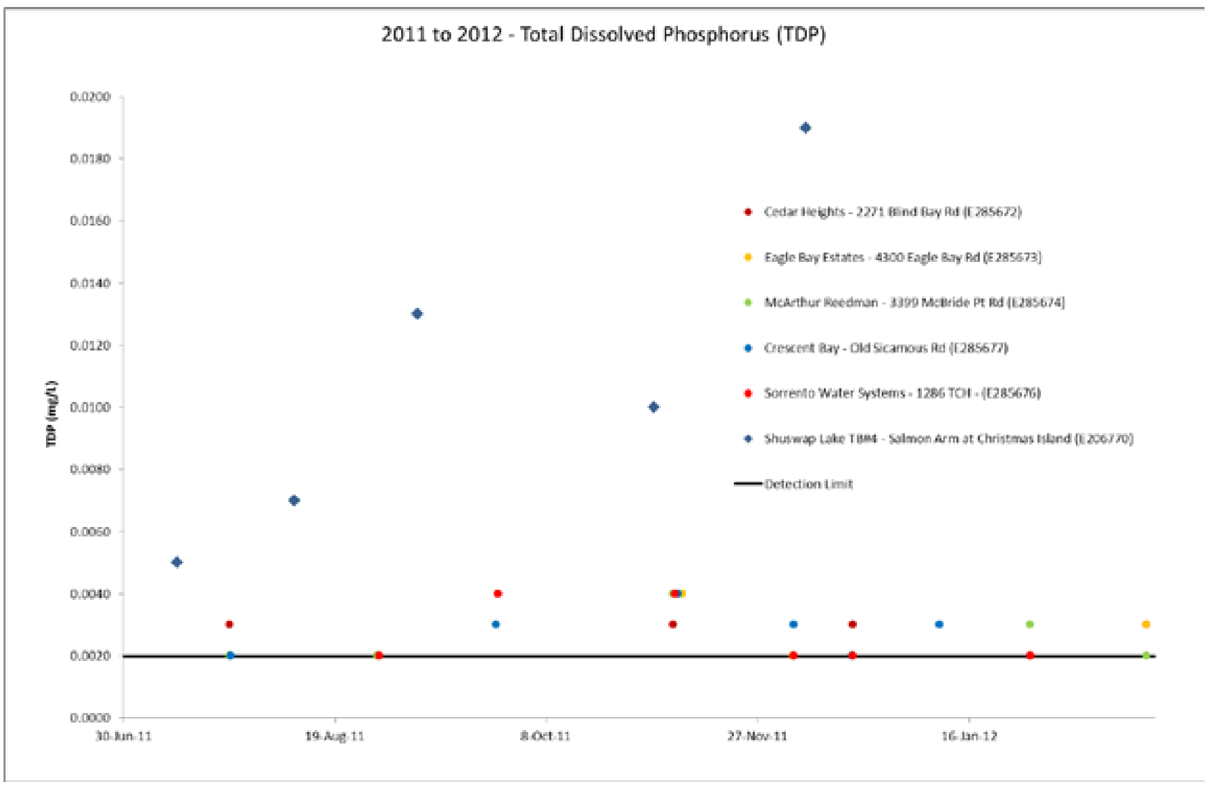
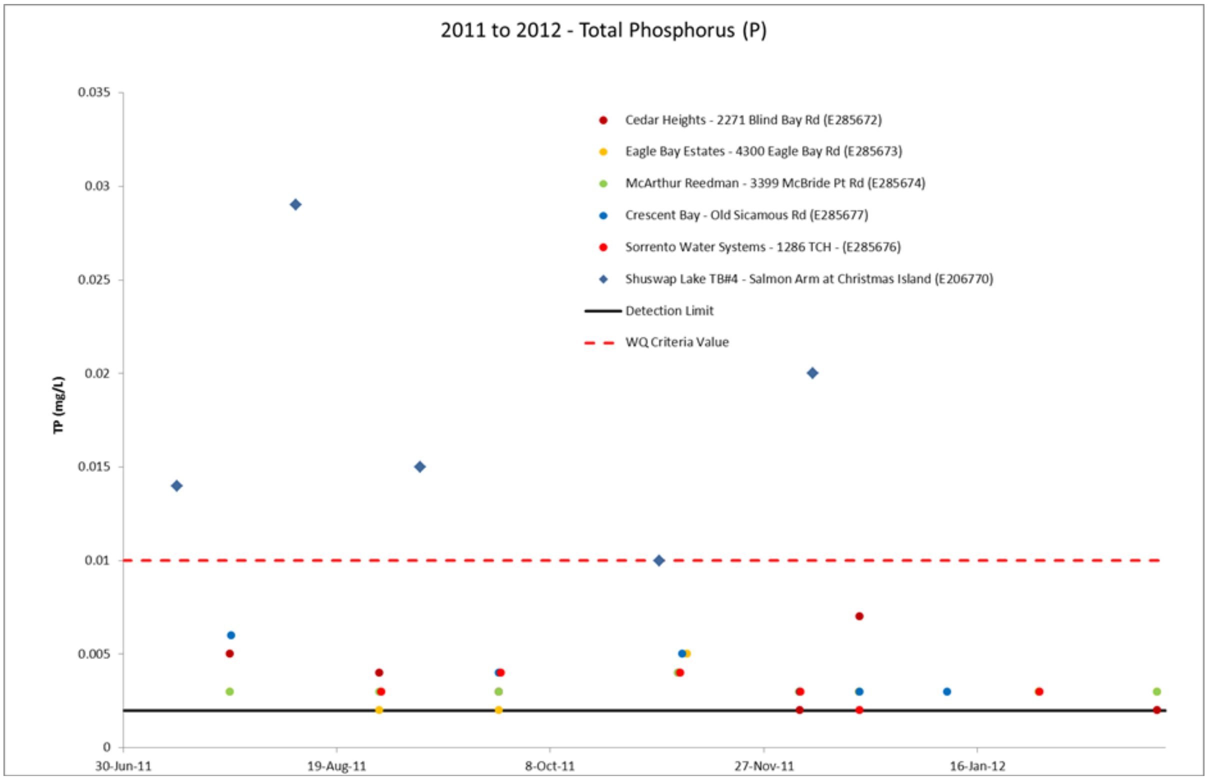


Figure 3-4 Total Phosphorus



3.2 Nitrogen

Nitrogen is present in fresh water in several forms and the nitrogen cycle, and the transformations between the nitrogen forms is a complex process. Nitrates and Nitrites form organic compounds that are key aquatic nutrients. Detailed descriptions are provided in Section **2.3.**

3.2.1 Ammonia Nitrogen

Figure 3-5 shows ammonia nitrogen (mg/L) at near shore stations in Shuswap and Mara Lakes (Detection Limit= 0.005 mg/L), and show that the shallow sampling stations at the locations of interest indicate concentrations well above what is seen in deep water sites. Again using the Sorrento deep water sampling site as a point of reference, the average concentration of ammonia for the year 2011 was 24 µg/L. The average 2011 concentrations for Sandy Point in Salmon Arm, which is a much more enriched site, is an average of 16 µg/L.

For the sites shown, it would appear that the majority would be above these levels. At least four samples have concentrations above 80 µg/L and should receive attention as potential sources of nitrogen to the lake (two from Cedar Heights, one from Crescent Bay and one from Eagle Bay). Rex et al. (2010) indicate that ammonia concentrations can significantly increase for short periods due to decaying salmon; The site West of Sorrento had large amounts of salmon carcasses decaying in the shoreline sediment. Ammonia is also typical indicator of sewage discharge. The fact that these sites are well offshore (100 m) and subject to dilution, there is the potential for concentrations at the shoreline to be much higher.

3.2.2 Nitrate and Nitrite Nitrogen

Figure 3-6 shows nitrate and nitrite nitrogen (mg/L) at near shore stations in Shuswap and Mara Lakes (Detection Limit= 0.002 mg/L). In contrast to the phosphorus sampling, which showed few results that would bring attention to potential shallow water contamination, the results for nitrate plus nitrite indicate potential variation.

The data for the deep water stations in the main body of the lake (using the Sorrento station as an example) has an average concentration of 64 µg/L as a point of reference. The average 2011 concentrations for the Sandy Point sampling station in Salmon Arm, which is a much more enriched site, is an average of 91 µg/L. In this data set, many of the reported values are above these values (although some are below). Concentrations of nitrate for example at the Crescent Bay sampling site at about 170 µg/L are fairly strong evidence of nitrate input at that location. Similarly there are elevated (above deep water site concentrations) nitrate levels at several other locations – Sorrento Water Systems, Crescent Bay and Eagle Bay Estates.

The monitoring results for nitrate would provide some evidence that nitrogen is a better indicator than phosphorus for potential sites that might be contributing nutrients to the lake system. Nitrate and ammonia are known to travel through soils very efficiently as a component of ground water flow – in contrast to phosphorus which tends to bind to soil particles much more readily and not be transmitted from the soil into surface water. The presence of salmon carcasses is also an issue and sampling during non-dominant escapements should be compared with dominant years, and correlated to observed carcass densities during sampling.

3.2.3 Total Organic Nitrogen

Figure 3-7 shows total organic nitrogen (mg/L) at near shore stations in Shuswap and Mara Lakes. The data recoded from these shallow water sites indicate the concentrations are within the range that was reported for the deep water sites. From **Figure 2-13**, the range of TON seems to be quite wide – at an informal glance the range of most values is 30-300 µg/L and most of the values shown here for the shallow sites fall within that range. Based on the data, TON appears to be a less useful indicator of potential nitrogen contributions than ammonia and combined nitrate forms.

3.2.4 Total Nitrogen

Figure 3-8 shows total nitrogen (mg/L) at near shore stations in Shuswap and Mara Lakes. The data shown shows that for shallow water sites, the concentrations are within the range that was reported for the deep water sites. From **Figure 2-14**, the range of TN at deep water sites seems to be quite wide – at an informal glance the range of most values is 100-400 µg/L, and most of the values shown here for the shallow sites fall within that range with many below it. As with TON, TN may not be as strong an indicator of potential contamination as ammonia and nitrate.

Figure 3-5 Ammonia Nitrogen

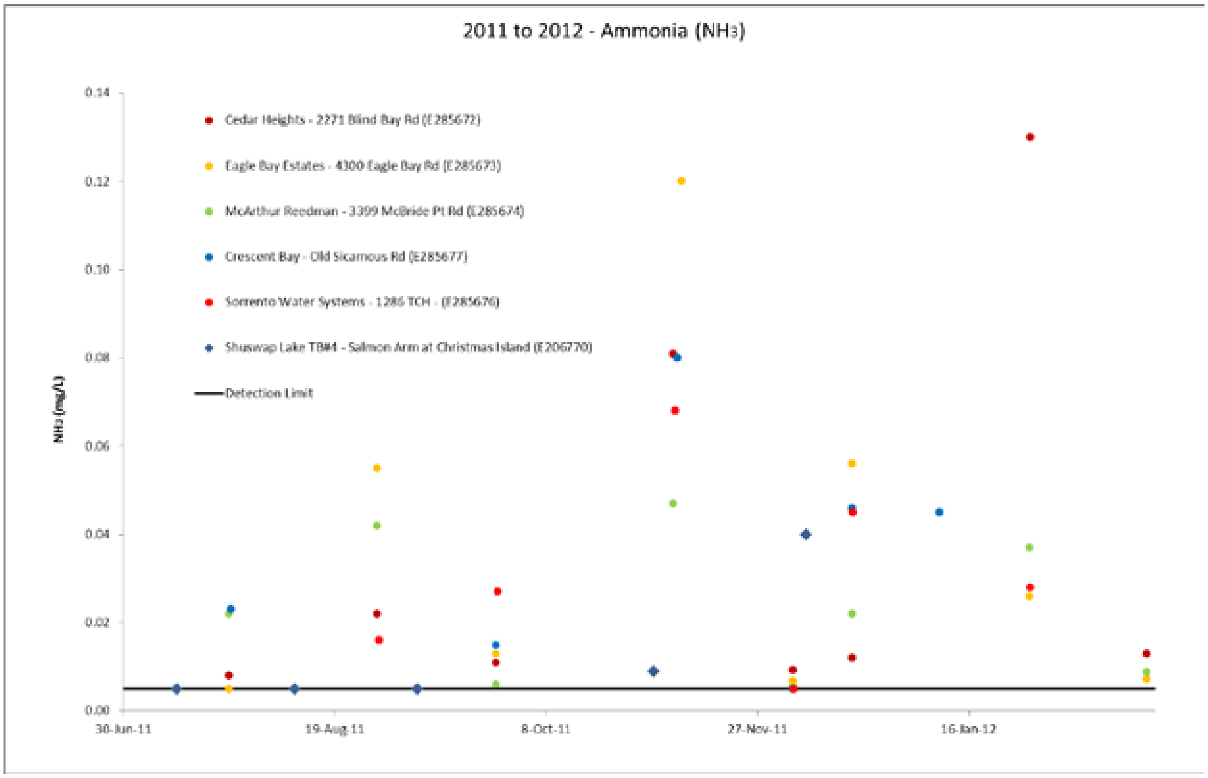


Figure 3-6 Nitrate and Nitrite Nitrogen

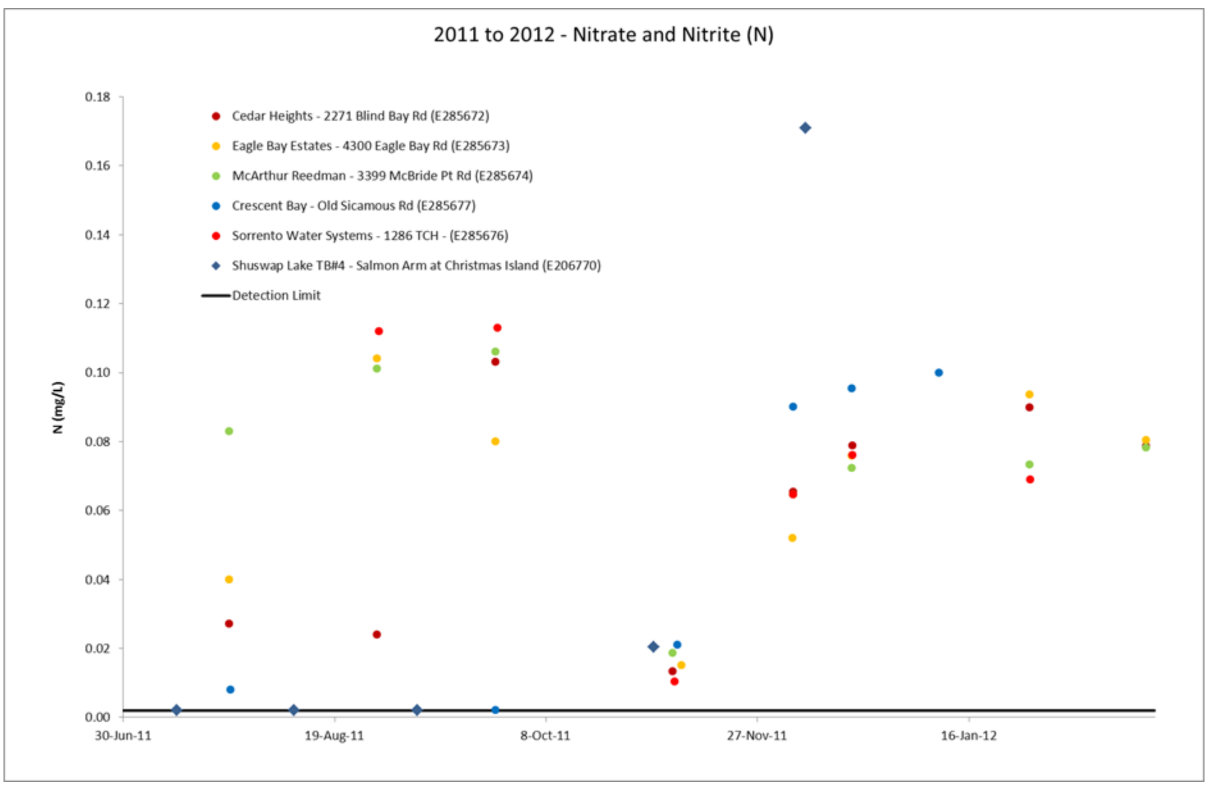


Figure 3-7 Total Organic Nitrogen

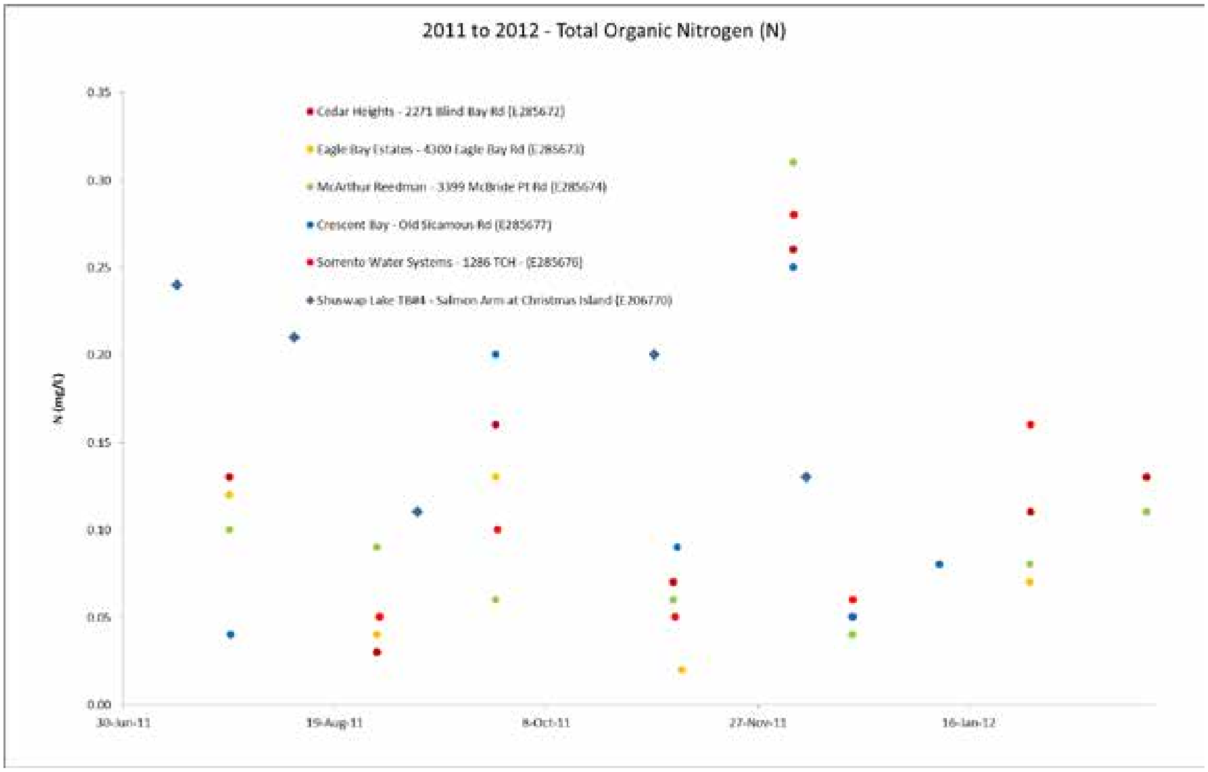
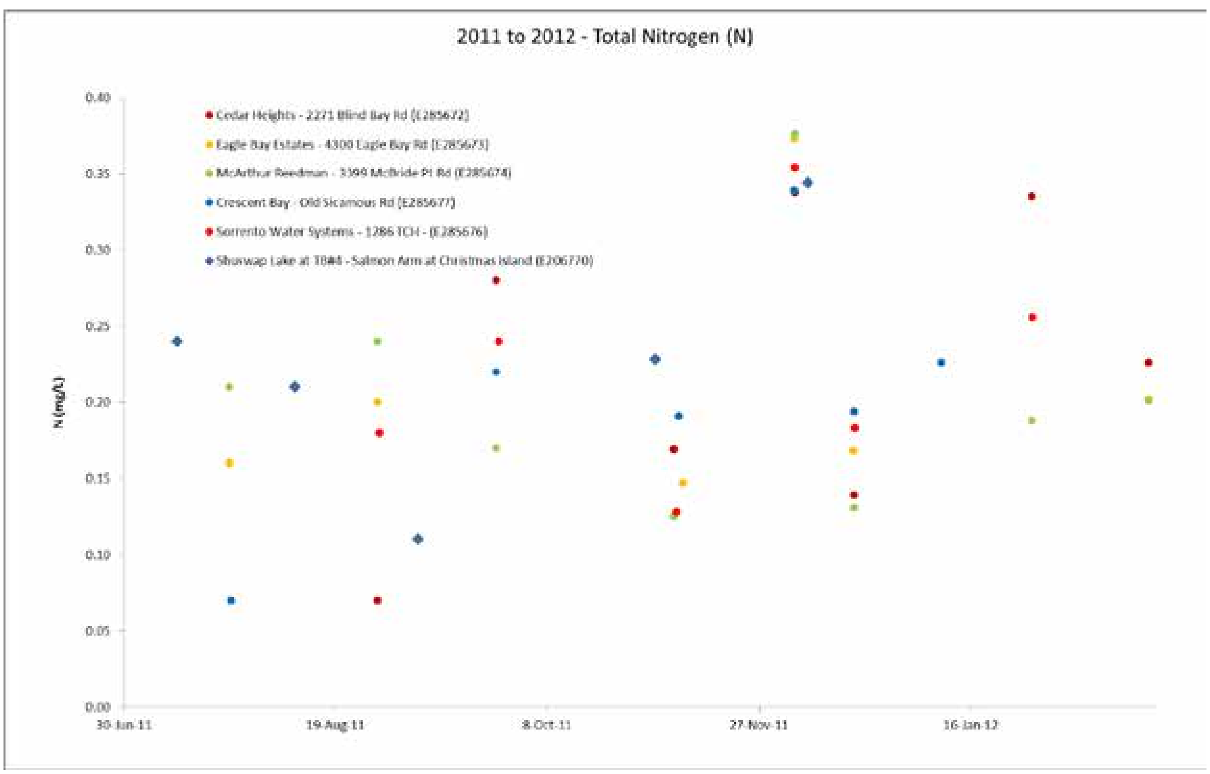


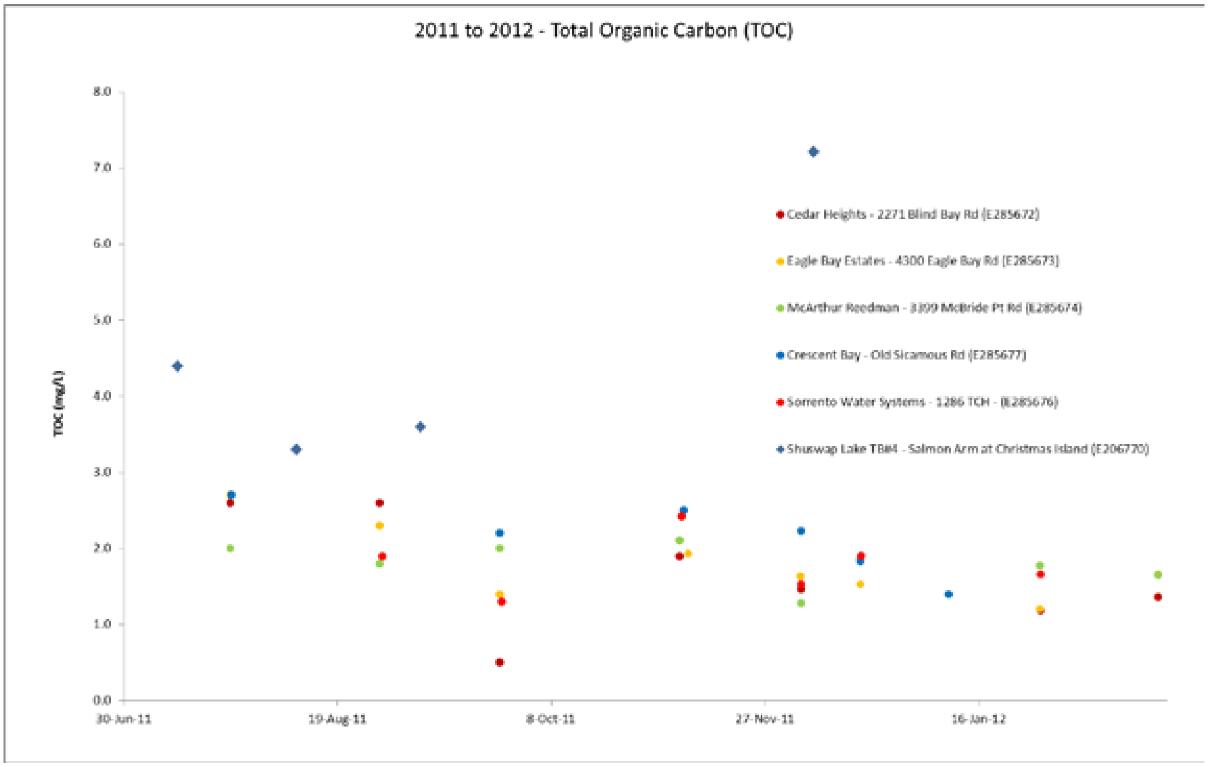
Figure 3-8 Total Nitrogen



3.3 Total Organic Carbon

Figure 3-9 shows total organic carbon (mg/L) at near shore stations in Shuswap and Mara Lakes. The data for TOC show an apparent concentration trend from June 2011 to February 2012 (with one possible outlier value). The reason for this decrease over time is not clear. The TOC data for the deep stations (**Figure 2-15**) shows a similar decrease, although perhaps not as distinct. The concentration range shown here for the shallow sites is similar to the deep water sites.

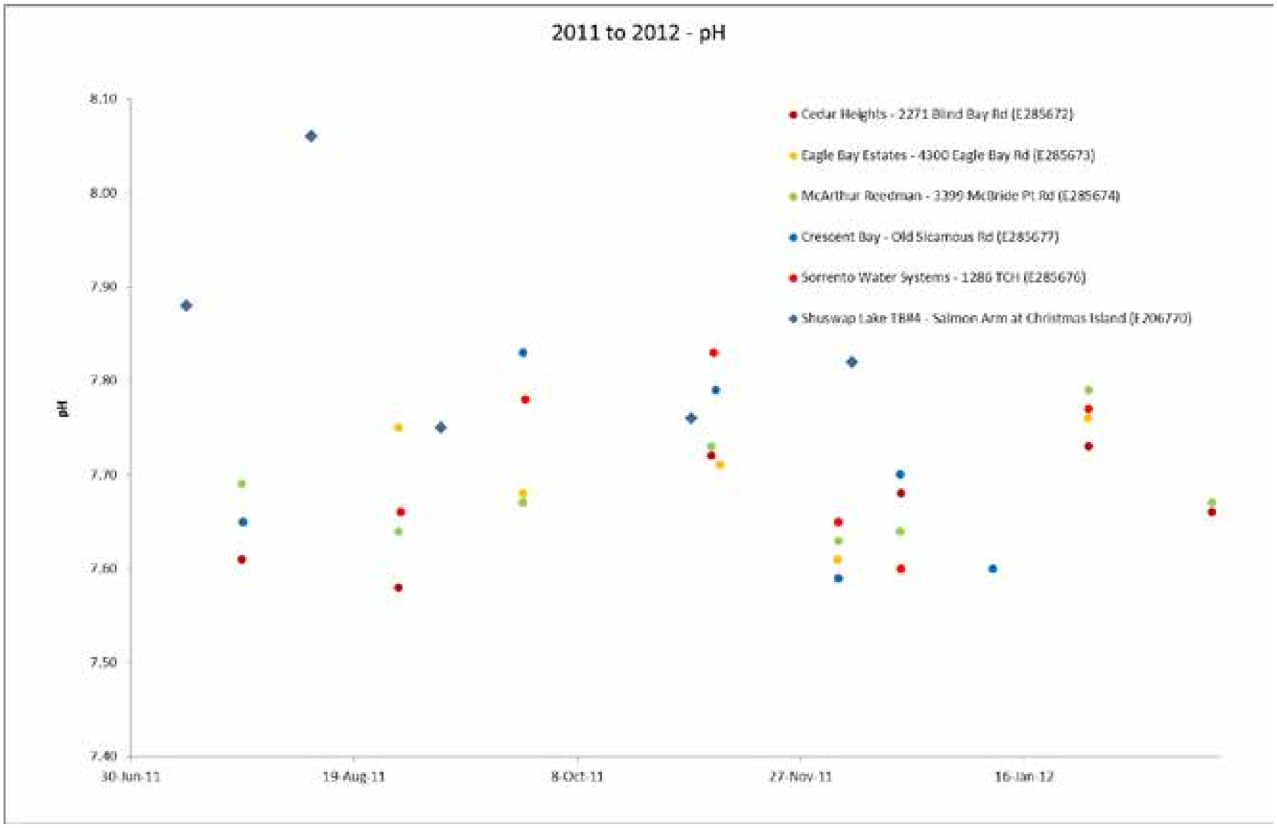
Figure 3-9 Total Organic Carbon



3.4 pH

Figure 3-10 shows pH at near shore stations in Shuswap and Mara Lakes. In the absence of a rigorous statistical analysis, an informal comparison of the near shore pH data shown here and the pH data for the deep water stations (**Figure 2-16**), appears to show little difference. Since the lake water is well buffered, this is not unexpected as it would require a significant input or change to result in a shift in the pH of the water. pH would not be expected to be a strong indicator for watershed disturbance on lake water quality.

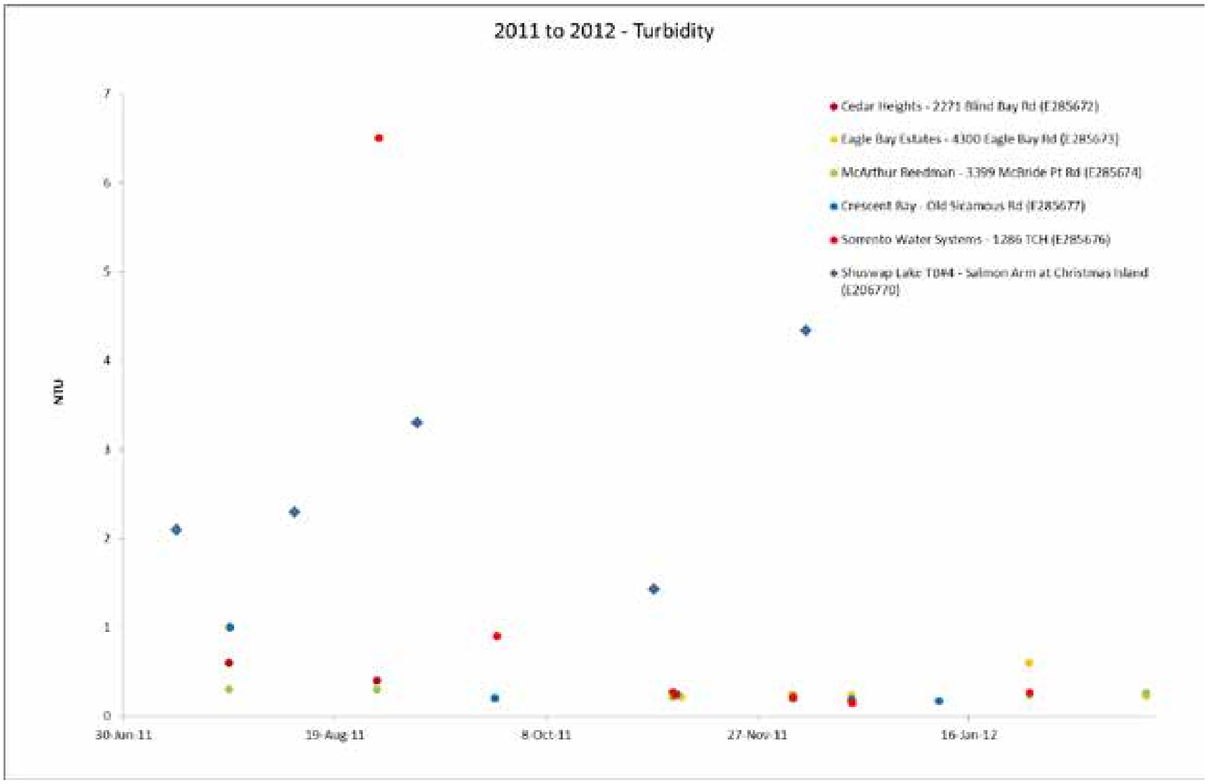
Figure 3-10 pH



3.5 Turbidity

Figure 3-11 shows turbidity (NTU) at near shore stations in Shuswap and Mara Lakes. The values for turbidity reported here can be compared to the data from the deep water stations shown in **Figure 2-17**. The 2011 data for deep stations are all below 3 NTU and most below 2 NTU so it is difficult to see a major difference with the exception of the three very high values in **Figure 3-11**(Sorrento Water Systems and two samples from Christmas Island). Secchi depth data might be used to corroborate the turbidity data and provide better information on whether there is poorer water clarity in these near shore sites of particular interest.

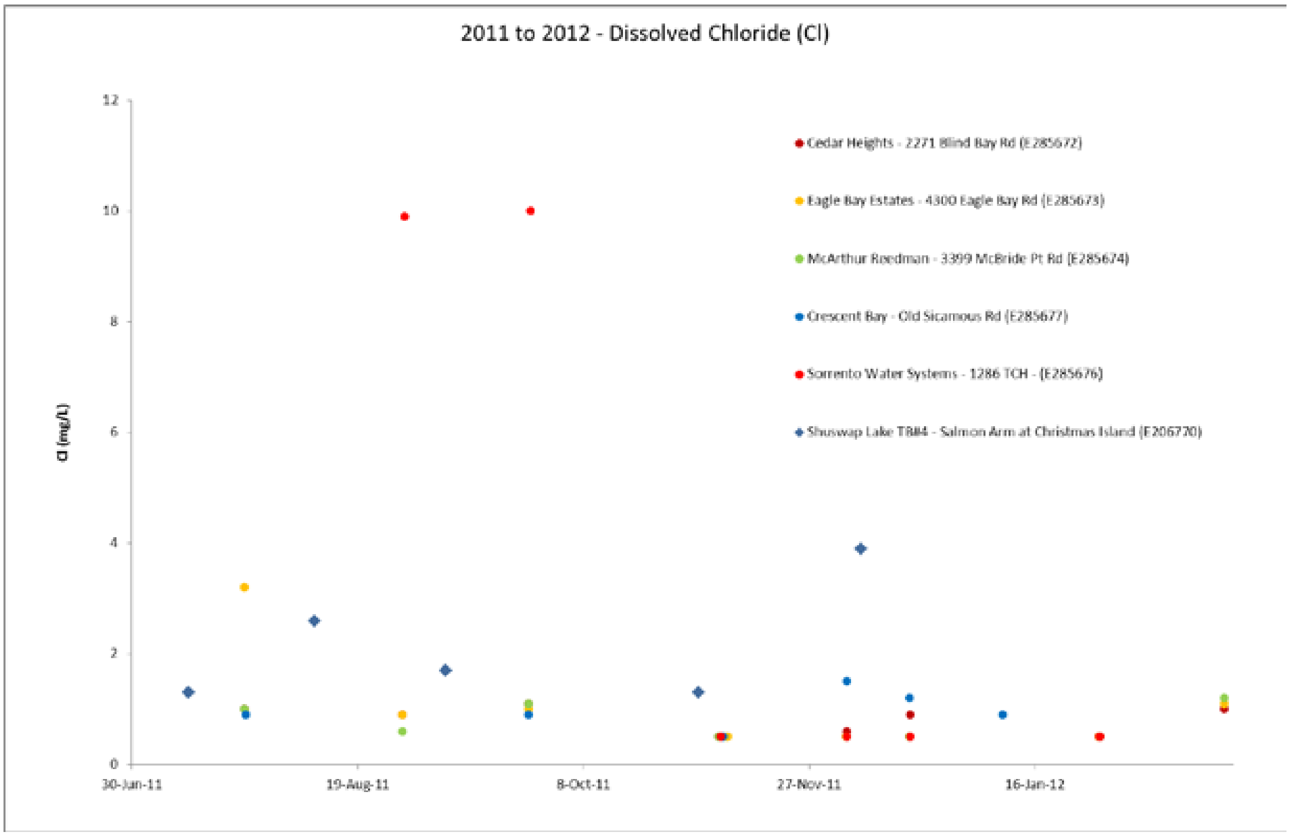
Figure 3-11 Turbidity



3.6 Dissolved Chloride

Figure 3-12 shows dissolved chloride (mg/L) at near shore stations in Shuswap and Mara Lakes. Chloride has been used as an indicator of sewage contamination particularly so the data shown here are particularly interesting. Again using the deep water sampling sites as the basis of comparison, **Figure 2-18** for 2011 shows a range of about 0.5 to 3.0 mg/L and for most of the near shore stations, the data are in this range. Again there are notable high values at the Sorrento water Systems site and at the Christmas Island site that are likely significant.

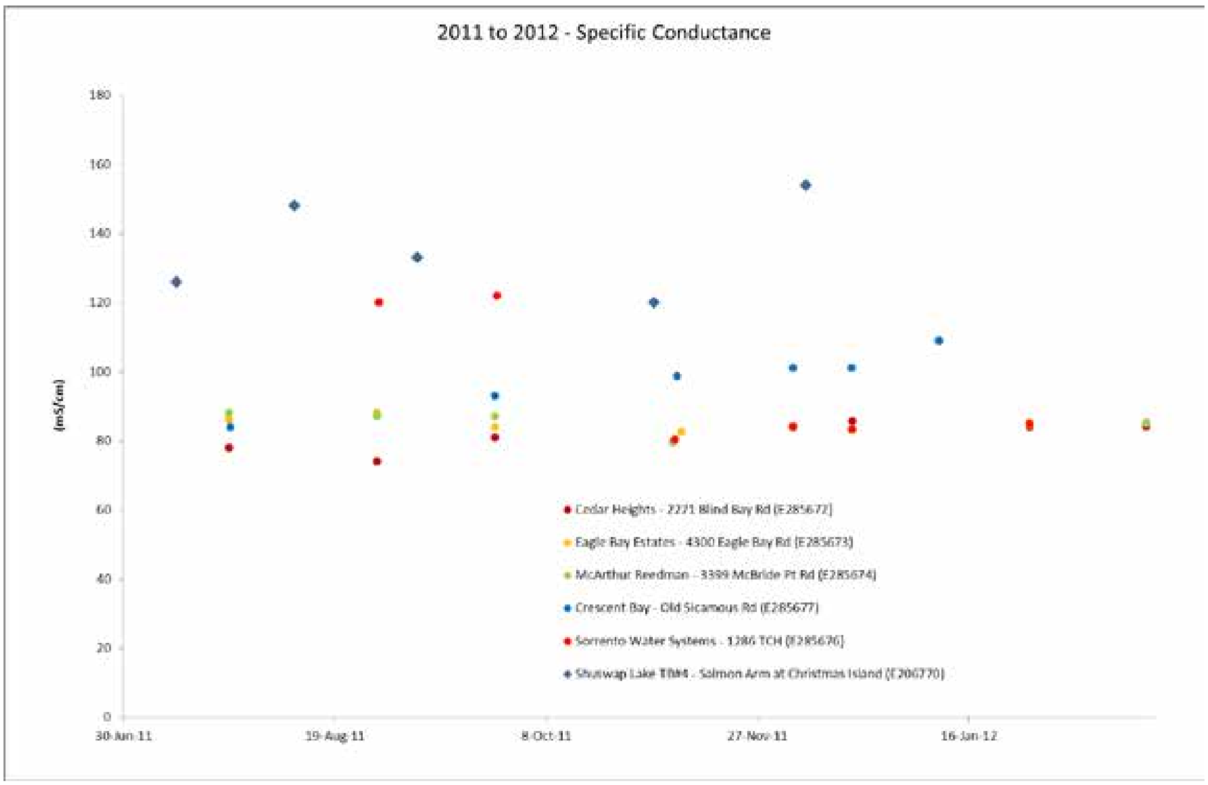
Figure 3-12 Dissolved Chloride



3.7 Specific Conductivity

Figure 3-13 shows specific conductivity (µs/cm) at near shore stations in Shuswap and Mara Lakes. Specific conductivity is a measurement that has the potential as use for a tracer of nutrient or contaminant inflows to the lake. A conductivity meter is often used in conjunction with fluorometry to locate inflows at the lakeshore. The data above appears to show unusually high specific conductivity at two sites: Sorrento Water systems and Christmas Island in comparison to the values reported for the deep sites (**Figure 2-19**). For other sites it may be possible to determine if there are potential problems by comparing the data between the near shore and deep stations.

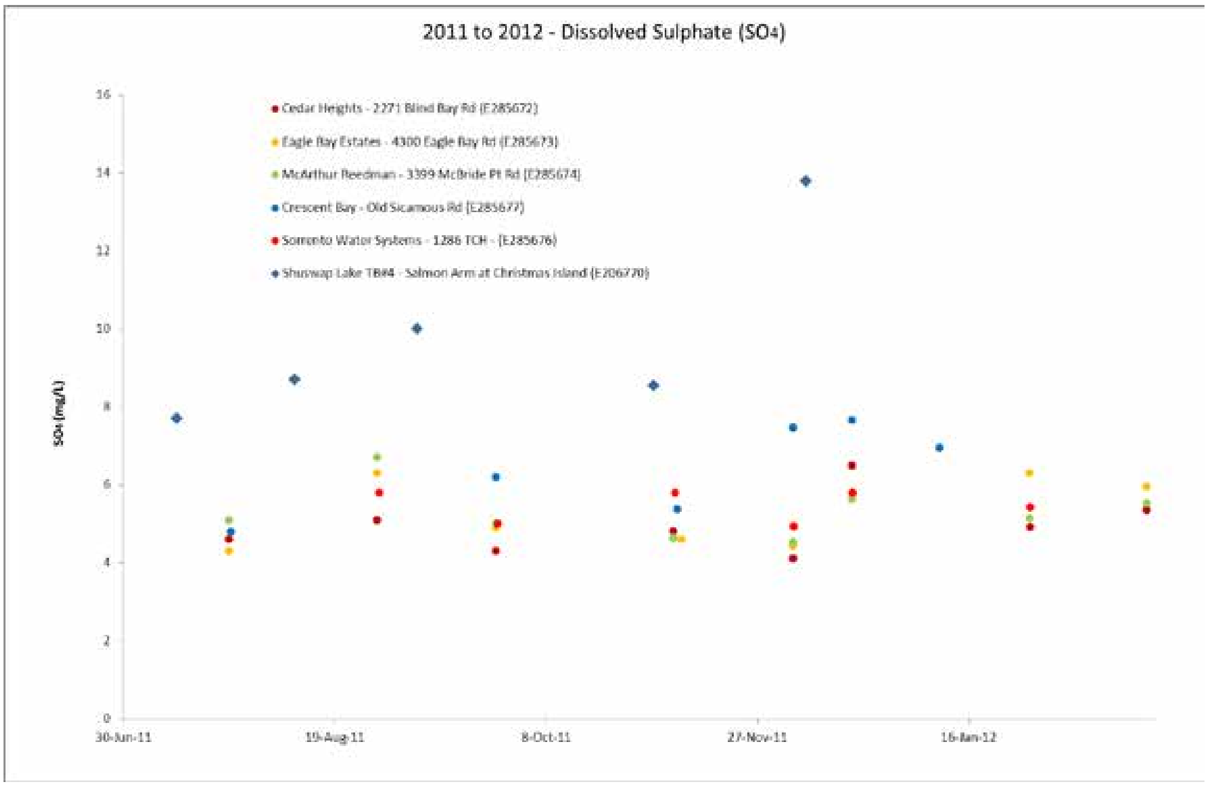
Figure 3-13 Specific Conductivity



3.8 Dissolved Sulphate

Figure 3-14 shows dissolved sulphate (mg/L) at near shore stations in Shuswap and Mara Lakes. Sulphate is also used as an indicator of watershed disturbance or nutrient input – especially from fertilizers or sewage. The deep water station data from **Figure 2-20** for 2011 showed a range of concentrations, the highest being at Sandy Point in the Salmon Arm of Shuswap Lake where the open water concentrations ranged from about 8 to 12 mg/L. The highest concentrations reported here for the near shore stations are also from the Salmon Arm (Christmas Island). However the overlapping ranges do not show that the concentrations from the near shore stations are notably different from the deep water stations. From the deep station data, each lake or arm of the lake seems to have a signature concentration for sulphate and so a site by site comparison might be necessary to identify any problem locations using sulphate as an indicator.

Figure 3-14 Dissolved Sulphate



3.9 Coliform monitoring

A major public concern on the Shuswap area is the safety of the water as a supply for drinking water and for recreation. Fecal coliform bacteria are the standard indicator used in evaluation of water for individual water intakes and for supplies by water utilities. Water utilities provide disinfection and sometimes treatment to domestic water before it is distributed to households. Many private water intakes do not have disinfection of the raw water drawn from the lake.

Fecal coliform bacteria are an indicator of potential sewage contamination in water. Fecal coliforms are present in the fecal material of all warm blooded animals and are generally not harmful in themselves but are used as an indicator of potential protozoan, bacterial and viral pathogens that may also originate from sewage contamination. There was no 2011 fecal coliform data available to include with this report; all data were retained by the Interior Health Authority (IHA).

3.10 Chlorophyll *a* and periphyton accrual monitoring

The concept behind this aspect of the monitoring is to provide quantitative data for assessing how much attached algae (periphyton) is growing in some areas – especially those areas where nutrients are suspected to cause excessive periphyton growth. Periphyton growth is not only aesthetically undesirable but can be a source for problems with salmon spawning areas (oxygen depletion, gravel cementation) but cause ecological changes like shifts in benthic invertebrate communities and subsequent changes in fisheries production or distribution.

The data shown below in **Figure 3-15** and **Figure 3-16** provides a comparative evaluation of sites in Mara Lake (upper panel) and Shuswap Lake main arm. Tiles were placed at each site as substrates for periphyton to grow on and sections of the tiles were samples every three weeks from August through October at Mara Lake and every four weeks in Shuswap Lake. The biomass of algae that was growing on the tiles is measured as the photosynthetic pigment chlorophyll *a*.

The results indicate that some sites have larger periphyton standing crop / biomass than others. Presumably the biomass is a reflection of the supply of nutrients to that site – given all other factors that might affect the periphyton accumulation are similar (light availability, grazing by invertebrates, turbulence by wave action etc.). Missing lines are result of lost data and the slope of the line between sampling dates is an indication of relative accumulation rates of periphyton that should be related to growth rates (and nutrient supply).

Figure 3-17 shows the groups of algae that are present in the periphyton community. This is useful information as it provides insight into the ecological role of the periphyton and to the nature of the nutrients that are feeding the community. Certain groups of algae like diatoms (orders *Pennales* or *Centrales*) or green algae (*Zygnematales*, *Ulothricales*, *Oedogoniales*, *Chlorococcales*) are much more desirable ecologically as they provide better food quality to aquatic invertebrates and better trophic efficiency than other groups like cyanobacteria (also known as blue-green algae – *Oscillatoriales*, *Nostocales*, *Chroococcales*).

The results show that of the three dominant orders of algae shown in the bar graph, two are cyanobacteria and the third is diatoms. Cyanobacteria are undesirable for a number of reasons, and conditions at this site seem to favour their presence.

Figure 3-15 2011 chlorophyll *a* accrual (mg/m^2) on algae tiles on Mara Lake

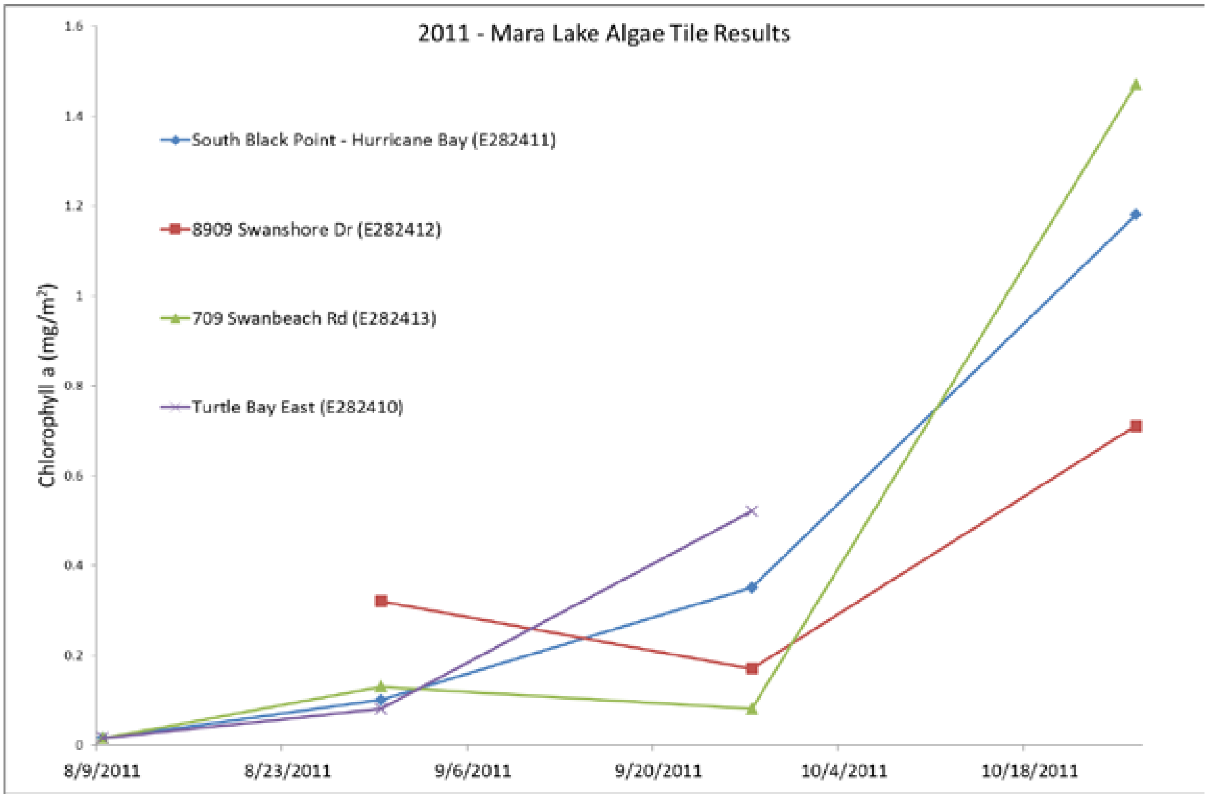


Figure 3-16 2011 periphyton accrual monitoring (cells/cm^2) on Shuswap Lake

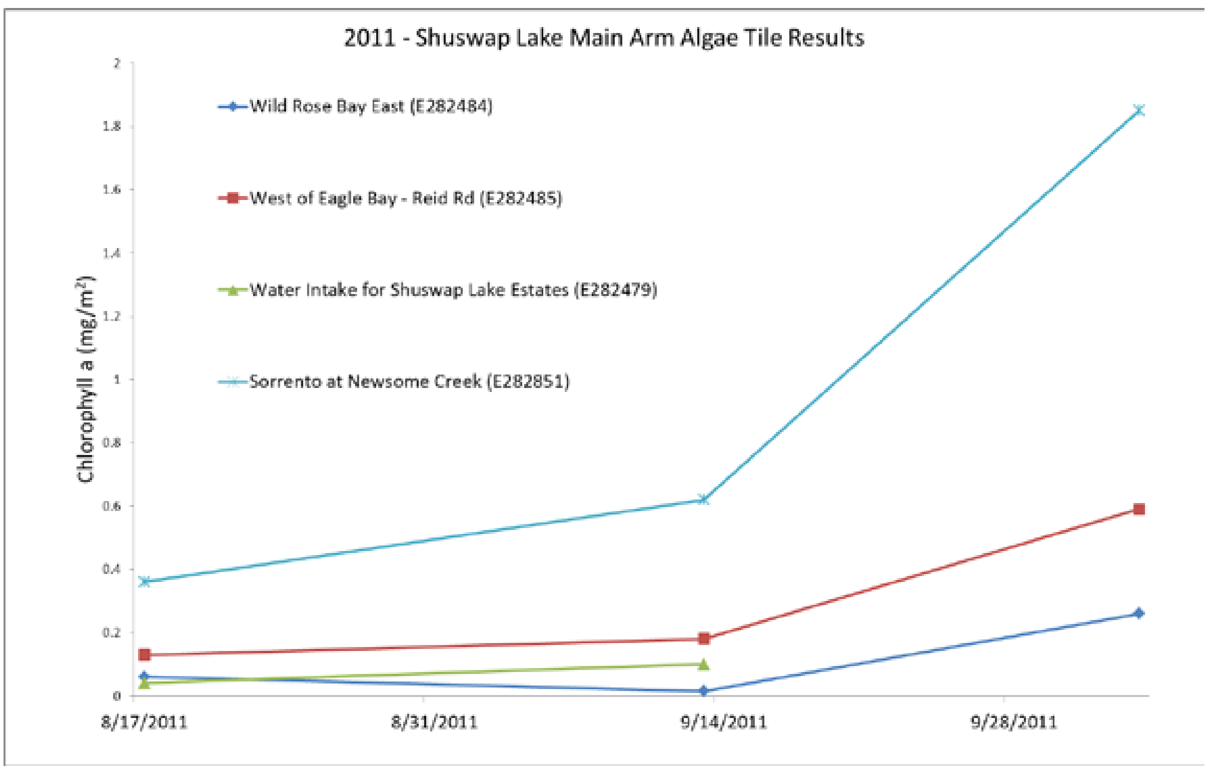
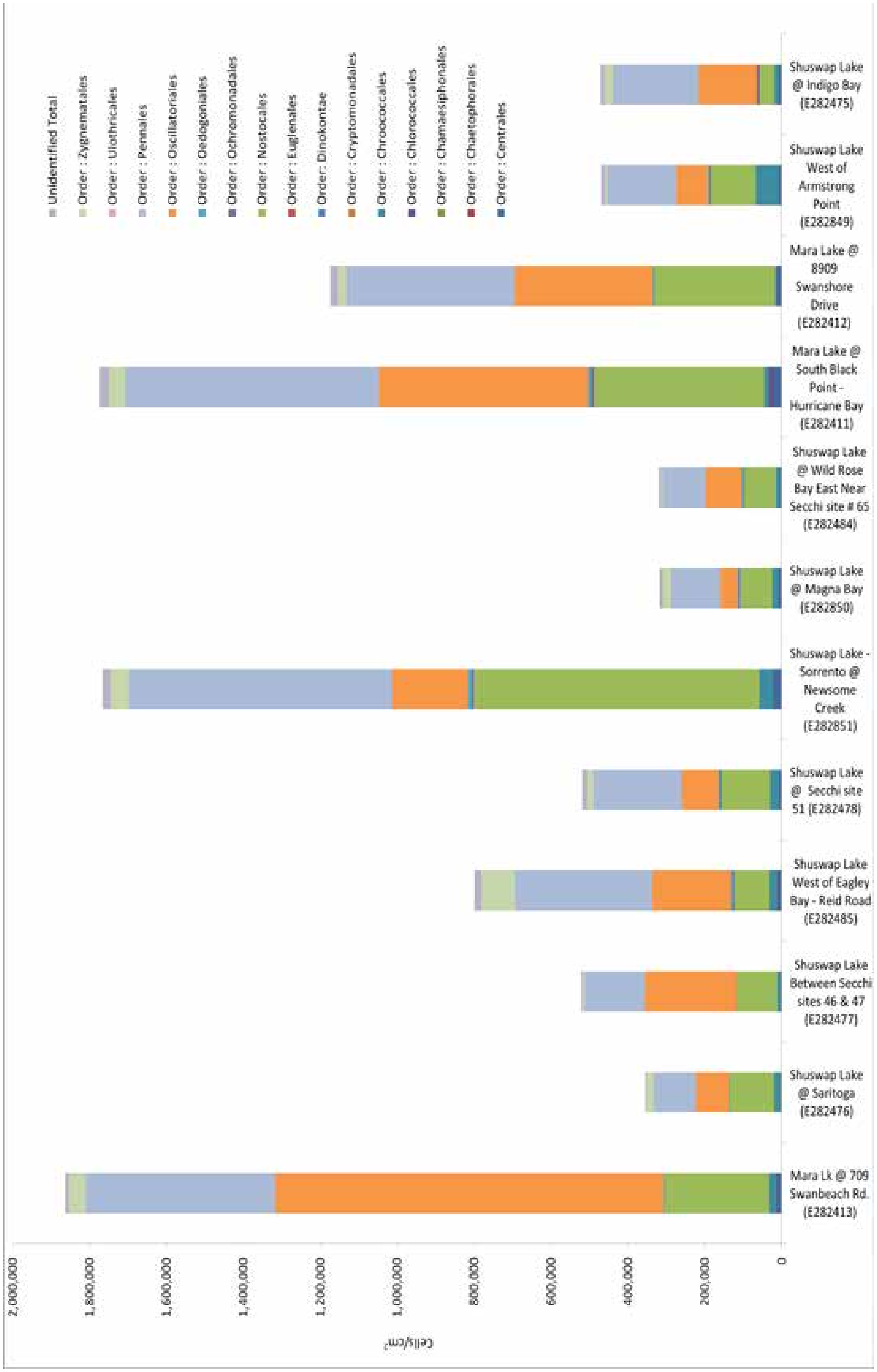


Figure 3-17 Algal groups on Shuswap and Mara Lakes



3.10.1 Specific Activity Monitoring

Table 3-2 below provides an overview of the data collected for the near shore stations as well as for sites that were sampled to evaluate the water quality adjacent to the City of Salmon Arm Waste Water Treatment Plant – all sites in the Salmon Arm of Shuswap Lake. The order list shows a gradient of sorts away from the STP discharge. At the discharge site, the frequency of *E. coli* exceeding the 10 MPN threshold is high at 50% and is less at the edge of the Initial Dilution Zone and there are no exceedances at the other three sites. Similarly for the phosphorus guideline where the STP site has 100% exceedances, the IDZ site and the Christmas Island data for both 2011 and the 2003-07 data sets show more than 70% of samples exceed the P guideline.

The total nitrogen data has a similar pattern with highest values near the plant and notably lower values for Christmas Island and Crescent Bay. Ammonia is similar but the concentrations at Crescent Bay are relatively high as they are with nitrate. The very low nitrate at the STP is an anomaly – an unusual reversed ratio of nitrate to ammonia with ammonia being higher than nitrate.

Table 3-2 Water Quality in Shuswap Lake: Near Shore and WWTP Stations- Salmon Arm

Station	Year (No. Samples)	*E. coli*	Fecal Coliforms	Nitrate-N	Ammonia –N	Total-N	Total-P
Shuswap Lake at City of Salmon Arm STP Discharge(E263503)	2011 (4)	(50% exc.)	ND	11.2	78.2	342	33 (100% exc.)
Shuswap Lake 100m N IDZ (E263504)	2011 (8)	(33% exc.)	ND	109	56.5	380	40 (71% exc.)
Shuswap Lake TB#4 Salmon Arm at Christmas Island (E206770)	2011 (7)	(0% exc.)	ND	30.9	11.7	226	15.2 (71%exc.)
Shuswap Lake TB#4 Salmon Arm at Christmas Island (E206770)	2003-07 (20)	(0% exc.)	(0% exc.)	17.1	18.9	262	23 (73% exc.)
Crescent Bay - Old Sicamous Rd (E285677)	2011 (7)	ND	ND	50	35.5	201	4.4 (0% exc.)

Values as arithmetic means in µg/L. *E. coli* and Fecal coliforms expressed as % of values exceeding 10/100 mL. Total-P WQ criteria set at 10 µg/L and expressed as % of values that exceed. ND = not determined.

Summary data for the North Shore shallow water stations (**Table 3-3**) provides some information that might provide relative priorization as to where the most serious concerns are. The high number of samples exceeding the *E. coli* and Fecal Coliform guideline at the Horseshoe Bay site and the East of Park sites are notable and the high percentage of exceedances at the Scotch Creek site for phosphorus deserve extra attention. The nitrogen concentration values need to be compared to the nearest deep water site to evaluate whether the concentrations are significantly higher than the deep water sites – which serve as a control of sorts.

Table 3-3 Water Quality in Shuswap Lake: Near Shore Stations- North Shore (from East to West)

Station	Year (No. Samples)	*E. coli*	Fecal Coliforms	Nitrate-N	Ammonia –N	Total-N	Total-P
Shuswap Lake at Horseshoe Bay (E227530)	2003-07 (20)	(28% exc.)	(28% exc.)	28.8	5.8	104	3.3 (5% exc.)
Shuswap Lake at Anglemont (E208729)	2003-07 (21)	(4.7% exc.)	(4.7% exc.)	27.7	7.1	104.7	2.9 (0% exc.)
Shuswap Lake at Magna Bay (E208731)	2003-07 (21)	(0% exc.)	(4.7% exc.)	28.9	10.2	104	3.2 (5% exc.)
Shuswap Lake at Celista (E208732)	2003-07 (21)	(0% exc.)	(0% exc.)	28.6	6.8	99.7	2.6 (0% exc.)
Shuswap Lake East of Park (E242918)	2002-07 (21)	(14% exc.)	(14% exc.)	30.9	5.8	117	2.6 (0% exc.)
Shuswap Lake at Scotch Creek (E208733)	2003-07 (20)	(5% exc.)	(5%exc.)	25.6	5.6	97	4.6 (11% exc.)

Values as arithmetic means in µg/L. *E. coli* and Fecal coliforms expressed as % of values exceeding 10/100 mL. Total-P WQ criteria set at 10 µg/L and expressed as % of values that exceed. ND = not determined.

The summary data for the South Shore shallow water stations (**Table 3-4**) also provides some information that might provide relative priorization as to where the most serious concerns are. The higher number of samples exceeding the *E. coli* and Fecal Coliform guideline at the Wild Rose Bay and Sorrento near shore sites are notable. Surprisingly none of the sites show phosphorus guidelines were exceeded. As with the north shore sites, the nitrogen concentration values need to be compared to the nearest deep water site to evaluate whether the concentrations are significantly higher than the deep water sites – which serve as a notional control.

Table 3-4 Water Quality in Shuswap Lake: Near Shore Stations-South Shore (East to West)

Station	Year (No. Samples)	*E. coli*	Fecal Coliforms	Nitrate-N	Ammonia –N	Total-N	Total-P
Shuswap Lake at Wild Rose Bay (E222131)	2003-07 (26)	(7.6% exc.)	(3.8% exc.)	29	6.2	83	3.3 (0% exc.)
Shuswap Lake at Eagle Bay (E208730)	2003-08 (26)	(3.8% exc.)	(3.8% exc.)	25.7	9.6	94	2.8 (0% exc.)
Eagle Bay Estates-4300 Eagle Bay Rd (E285673)	2011 (9)	ND	ND	86.8	34.3	215	3 (0% exc.)
McArther Reedman - 3399 MC Bride Point Rd (E285674)	2011 (9)	ND	ND	94.8	22.5	214	3.1 (0% exc.)
Shuswap Lake Blind Bay South-East (E500555)	2003-08 (26)	(0% exc.)	(3.8% exc.)	30.5	5.9	99.6	4.8 (0% exc.)
Cedar heights - 2271 Blind Bay Rd. (E285672)	2011 (9)	ND	ND	73.5	46.1	222	3.6 (0% exc.)
Shuswap Lake at Sorrento (E208734)	2003-08 (26)	(11.5% exc.)	(11.5% exc.)	29	9.7	100	2.8 (0% exc.)
Sorrento Water System - 1286 TCH (E285676)	2011-12 (7)	ND	ND	77.4	31.1	233	3.1 (0% exc.)

Values as arithmetic means in µg/L. *E. coli* and Fecal coliforms expressed as % of values exceeding 10/100 mL. Total-P WQ criteria set at 10 µg/L and expressed as % of values that exceed. ND = not determined.

4 Near Shore Water Quality - WWTP and Point Source Monitoring

Monitoring of the discharge from the Salmon Arm WWTP was conducted at near field and far field sites, plus a control site. In Sicamous, groundwater wells around the infiltration basin were monitored. For Canoe Creek, a monitoring program is being developed.

For watercraft greywater discharge, a repeat of the 2009 MOE Greywater Study was conducted (i.e., 5 times weekly during high boating season plus 5 times weekly outside of boat season). This involved test sites at three beach sites that were highly frequented by boats: Nielson Beach, Hungry Cove, and Marble Point, in addition to three control beaches. Greywater samples were obtained from watercraft onboard collection tanks (6 tanks in 2011). The SLIPP samplers worked with the houseboat companies to determine tanked greywater volume for each tested tank as well as number people and days producing this amount. This was converted in loading estimates discharge information of potential discharges (or those under plans) from Environmental Protection Division, MOE.

Wastewater Treatment Plant (WWTP) discharge at Salmon Arm were monitored 6-8 times per year, and the Sicamous WWTP discharge was measured quarterly (**Table 4-1**).

Table 4-1 Near shore WWTP point source monitoring site locations.

Station Number	Station Name	EMS #	Latitude	Longitude
WWTP related deep sampling	Shuswap Lake at City of Salmon Arm STP Discharge	E263503	50.70555555	119.2922222
WWTP related shallow sampling	Shuswap Lake 100 m North Initial Dilution Zone	E263504	50.70972222	119.2908333

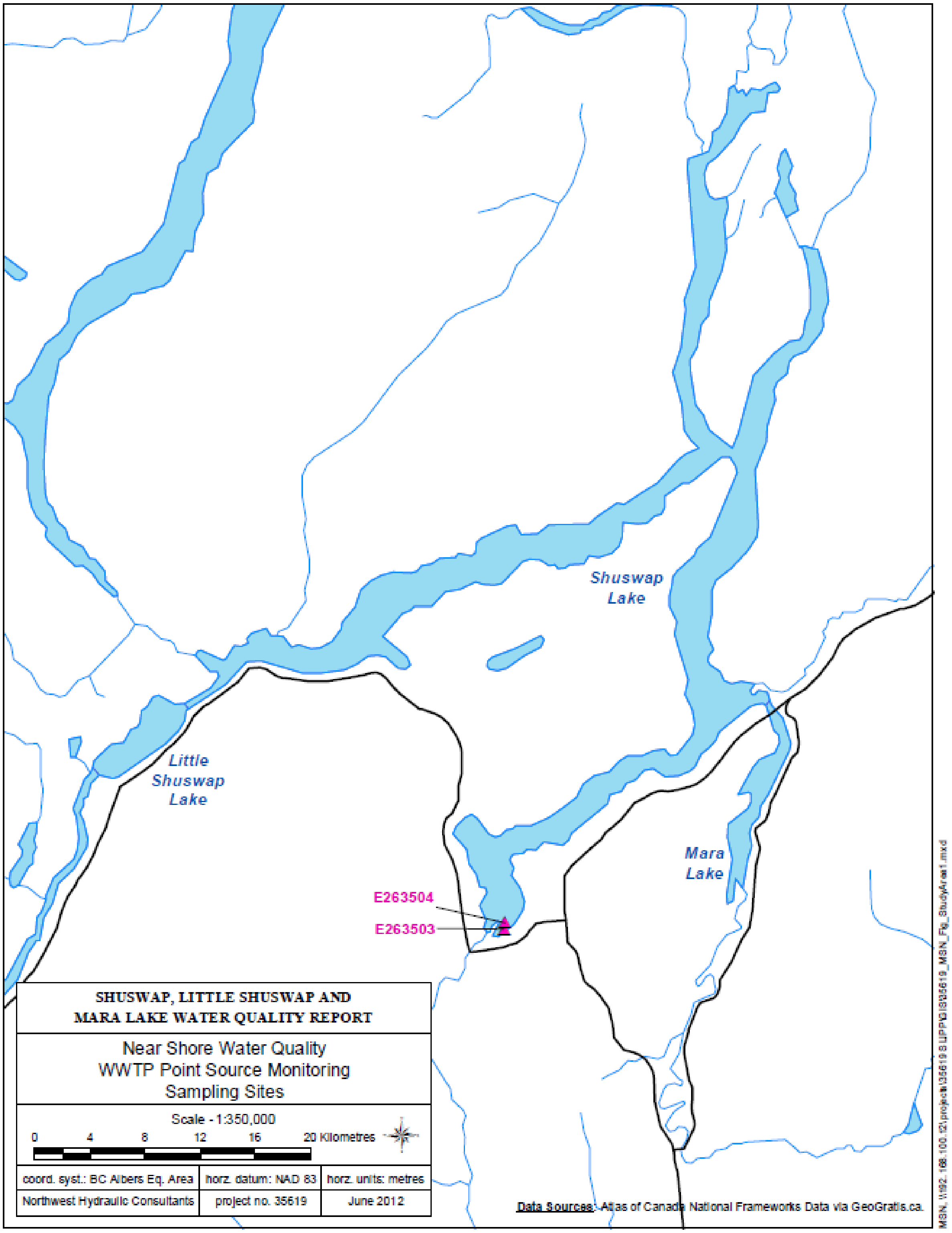
The full range of parameters collected were as follows:

1. Sewage Treatment Plant Discharges:
    a. Water temperature
    b. Nutrients
    c. Water clarity
    d. Water chemistry
2. Repeat of 2009 MoE Greywater Study:
    a. *E. coli*
    b. Fecal coliforms
    c. Greywater tracers (potential endocrine disruptors)
3. Greywater characterization:
    a. Nutrients
    b. Greywater tracers (potential endocrine disruptors)
    c. *E. coli*

d. Fecal coliforms

4. Loading information:
    a. Nutrients
    b. Contaminants that may exceed health or environmental thresholds

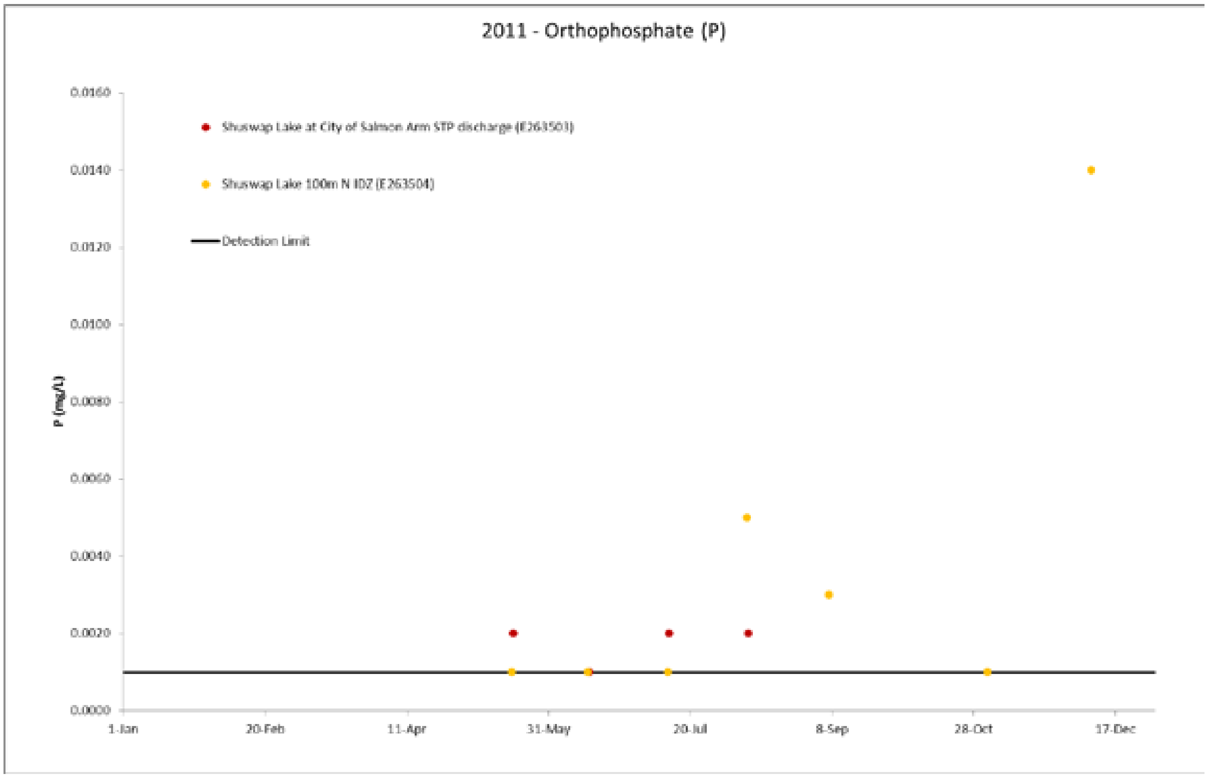
Figure 4-1 Map of SLIPP point source monitoring sites in Shuswap Lake



4.1 Soluble Reactive Phosphorus

Using the average concentration for SRP sampled at the Sandy Point site (epilimnion) during 2011 as a reference site, the differences between the two sites affected by the WWTP are clear (**Figure 4-2**). At Sandy Point the average SRP concentration was .002 mg/L (2 µg/L) and so these sites have similar concentrations.

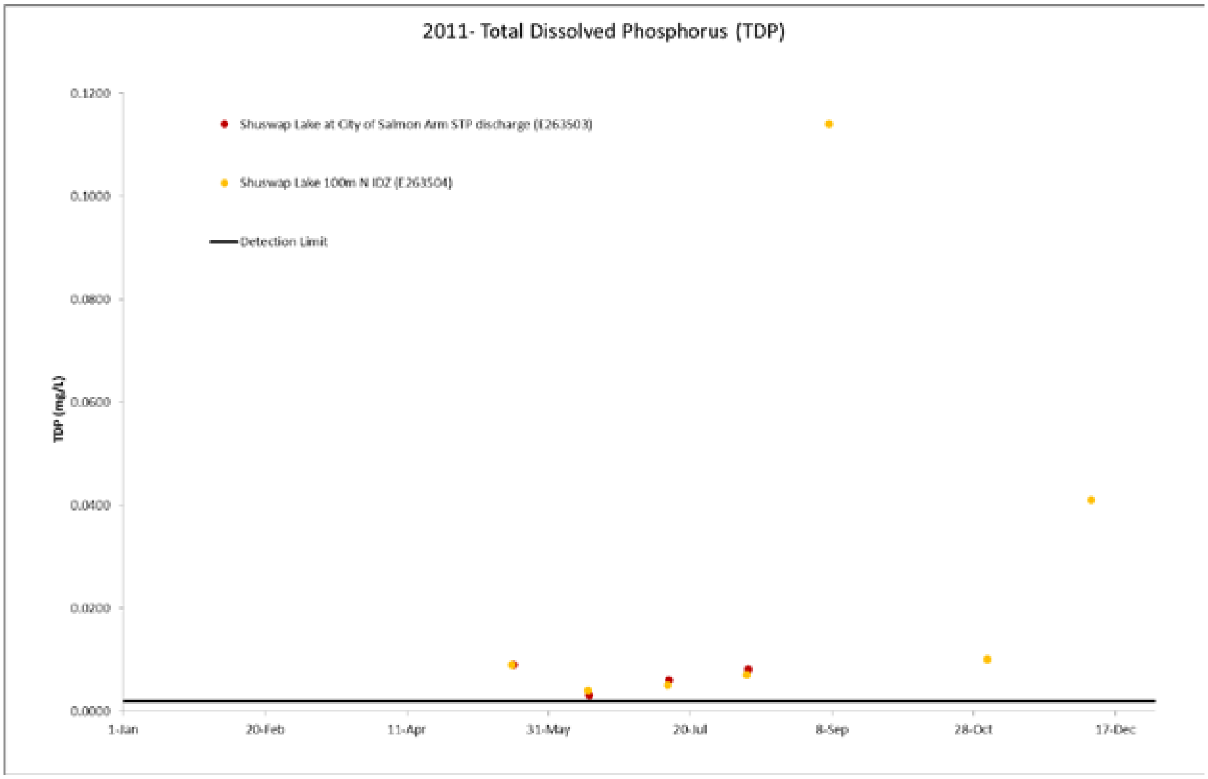
Figure 4-2 Soluble reactive phosphorus (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake (Detection Limit= 0.001 mg/L)



4.2 Total Dissolved Phosphorus

Using the average concentration for total dissolved phosphorus sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and these two sites affected by the WWTP is illustrated in **Figure 4-3**. At Sandy Point the average TDP concentration was about 6 µg/L and so these sites for some sampling dates have similar concentrations but September and December values are much higher.

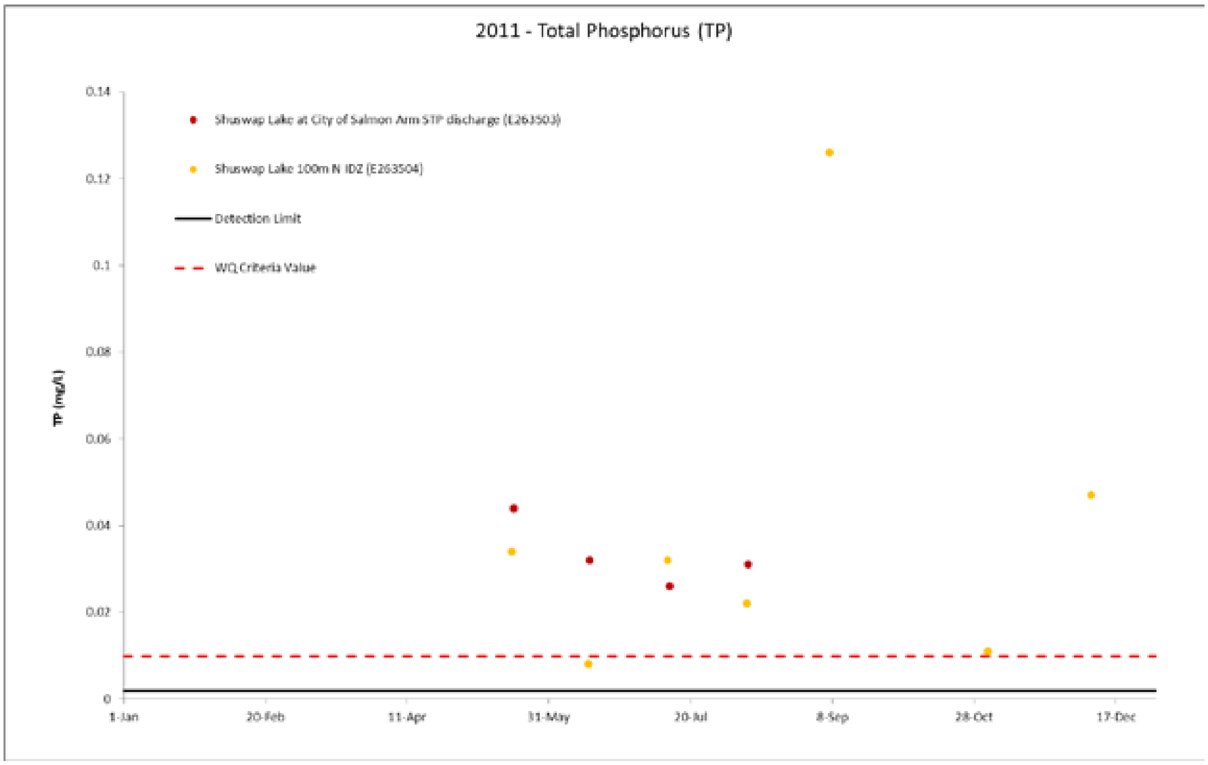
Figure 4-3 Total dissolved phosphorus (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake (Detection Limit= 0.002 mg/L)



4.3 Total Phosphorus

Using the average concentration for total phosphorus sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and these two sites affected by the WWTP is quite different (**Figure 4-4**). At Sandy Point the average TP concentration was about 11 µg/L and so these sites are much higher.

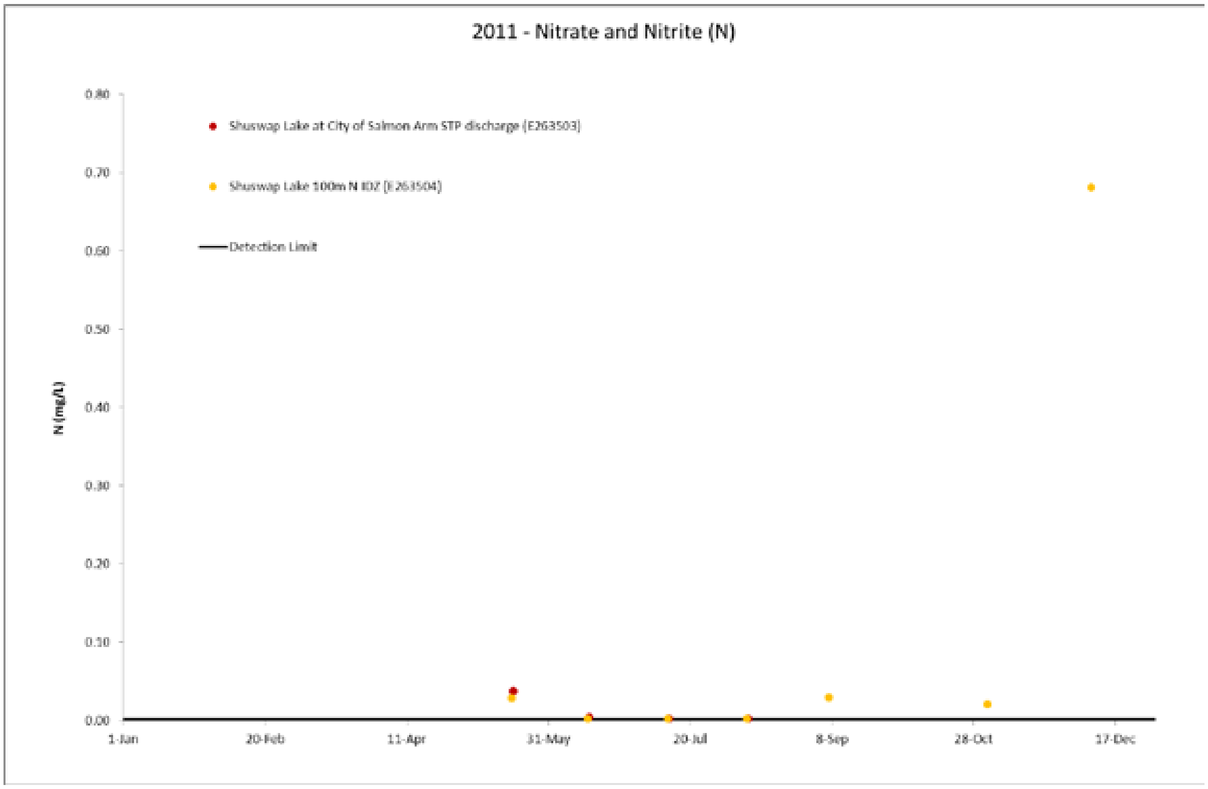
Figure 4-4 Total phosphorus (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake (Detection Limit= 0.002 mg/L; BC Water Quality Criteria= 0.01 mg/L)



4.4 Nitrate and Nitrite Nitrogen

Using the average concentration for nitrate sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and these two sites affected by the WWTP is quite different (**Figure 4-5**). At Sandy Point the average nitrate concentration was about 12 µg/L (0.012 mg/L) and so these sites are much higher – especially the December sample.

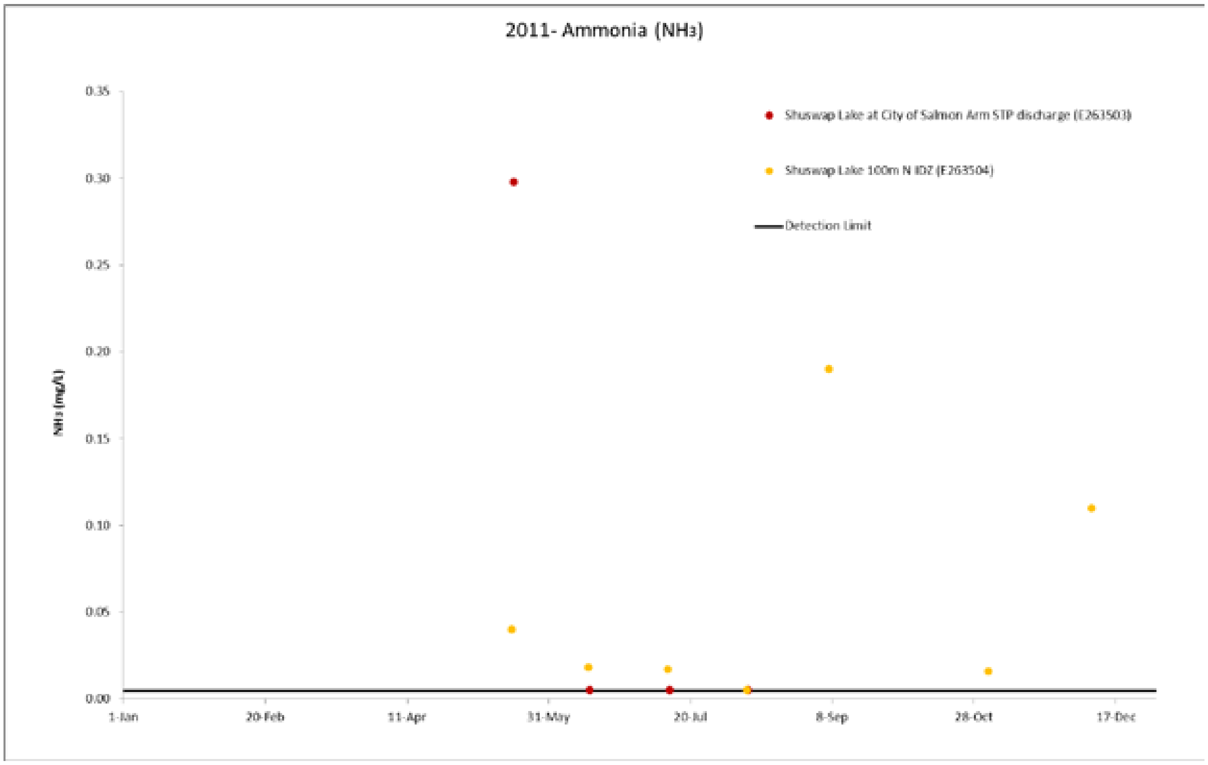
Figure 4-5 Nitrate and nitrite (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake (Detection Limit= 0.002 mg/L)



4.5 Ammonia Nitrogen

Using the average concentration for ammonia sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and these two sites affected by the WWTP is provide in **Figure 4-6**. At Sandy Point the average ammonia concentration was about 20 µg/L (0.020 mg/L) and some of the samples plotted here are much higher.

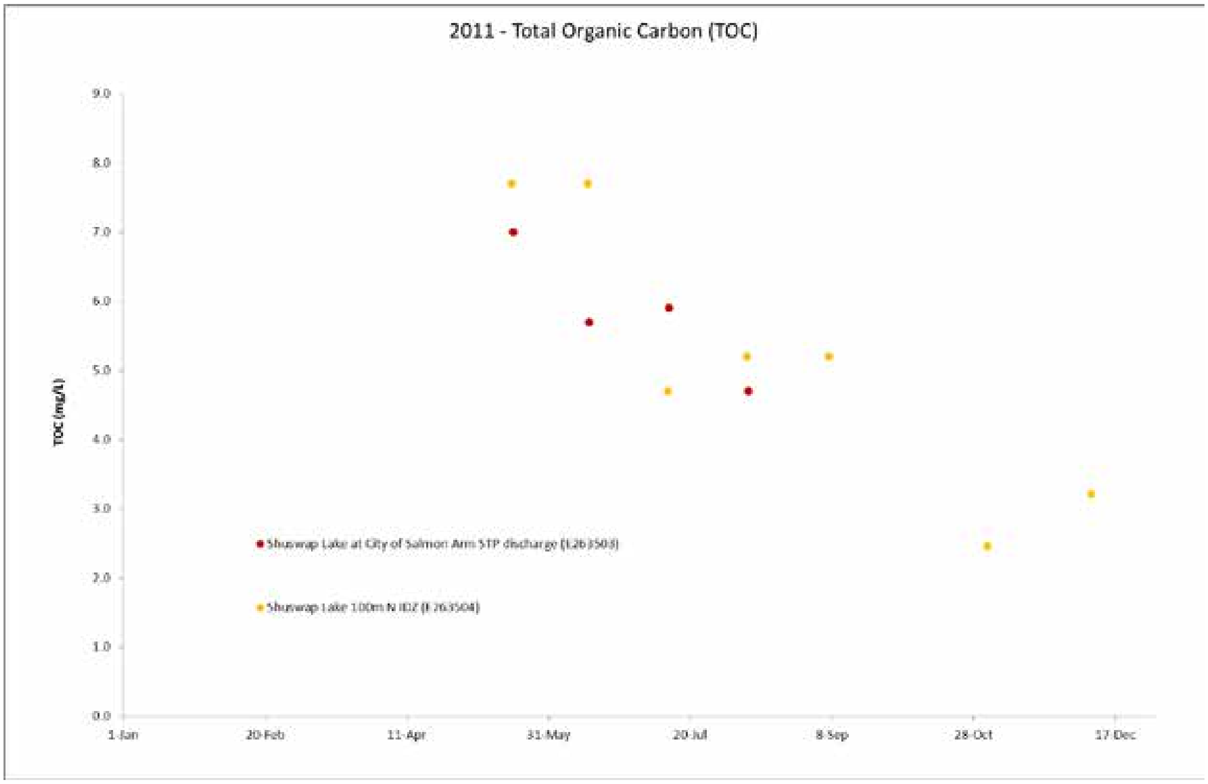
Figure 4-6 Ammonia (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake (Detection Limit= 0.005 mg/L)



4.6 Total Organic Carbon

Using the average concentration for TOC sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and these two sites affected by the WWTP is in **Figure 4-7**. At Sandy Point the average TOC concentration was about 4 mg/L and so the results from these sites are generally much higher.

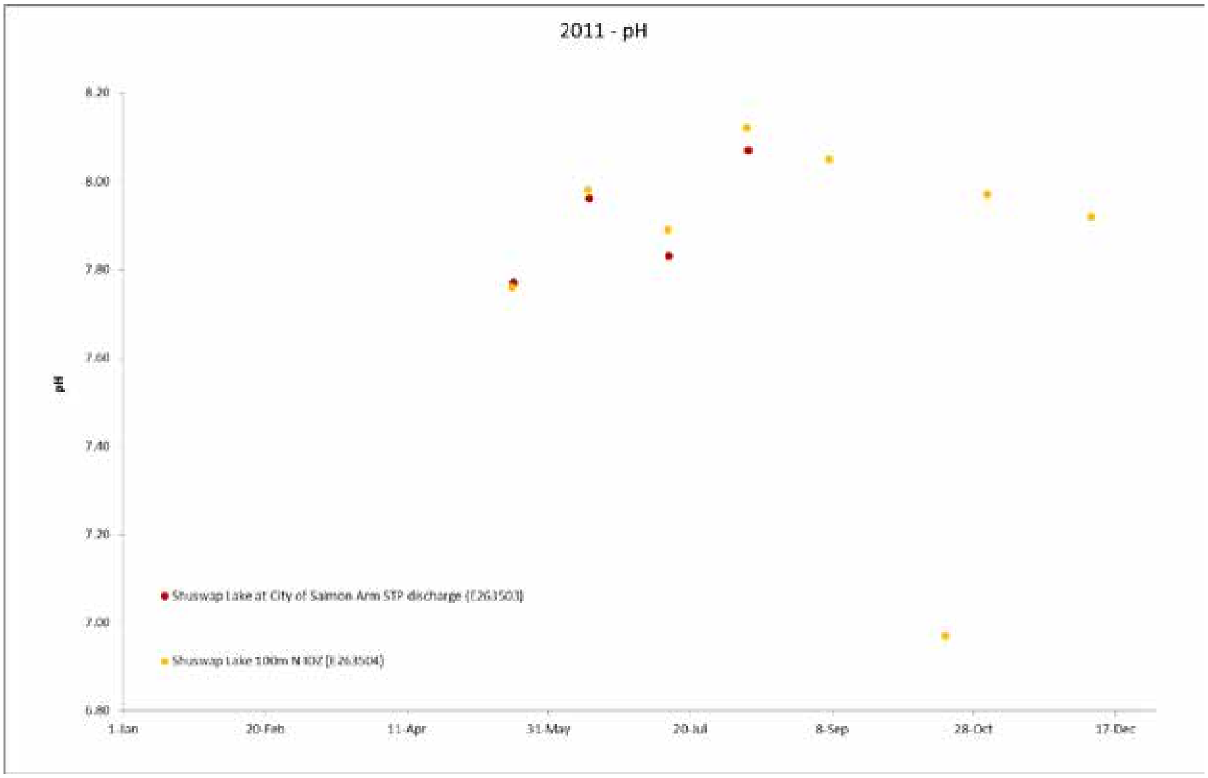
Figure 4-7 Total organic carbon (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake



4.7 pH

Using the average concentration for pH sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and these two sites affected by the WWTP is provided in **Figure 4-8**. At Sandy Point the average pH concentration was about 7.7 and so these sites tend to be somewhat higher. The single sample in October at the IDZ site with a pH less than 7 is very unusual and the reason for this anomalous reading is not clear.

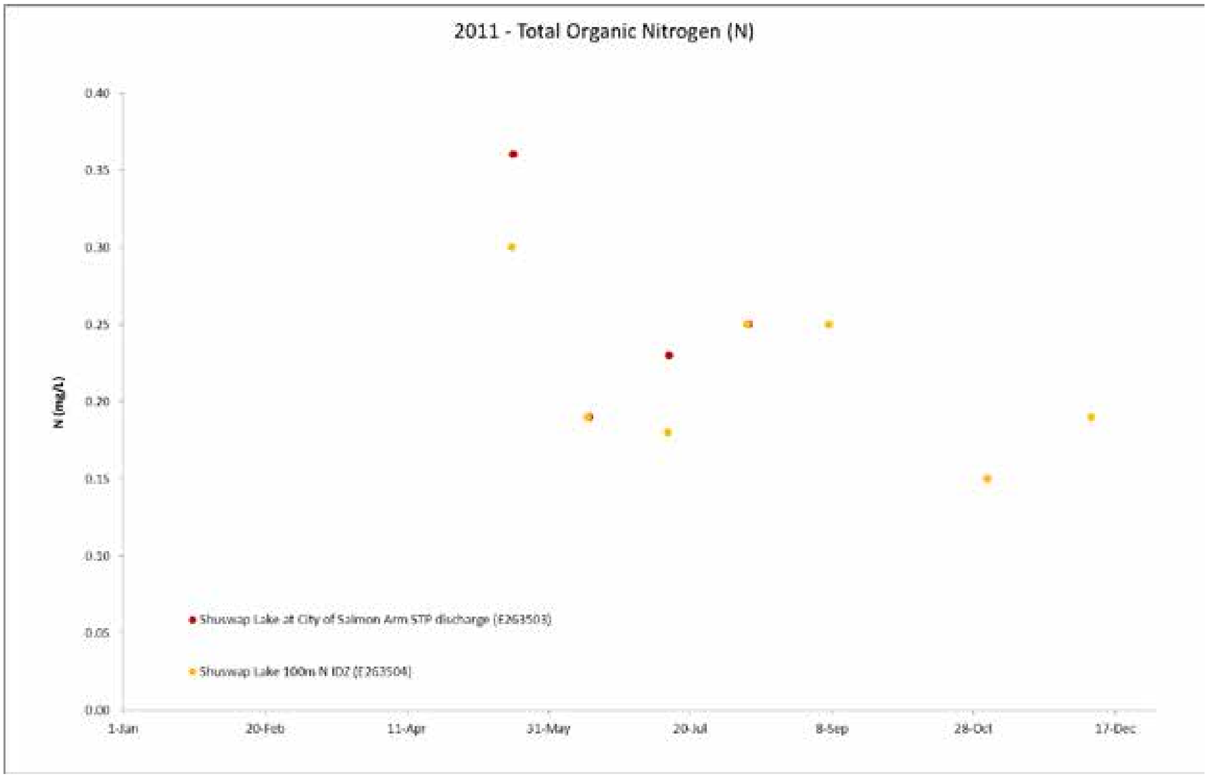
Figure 4-8 pH at near shore WWTP point source monitoring stations in Shuswap Lake



4.8 Total Organic Nitrogen

Using the average concentration for total organic nitrogen sampled at the Sandy Point site (epilimnion) during 2011 as a reference, the comparison between the reference site and these two sites affected by the WWTP is different (**Figure 4-9**). At Sandy Point the average TON concentration was about 220 µg/L and so these sites have data mostly in the same range but two samples (in May) are notably higher.

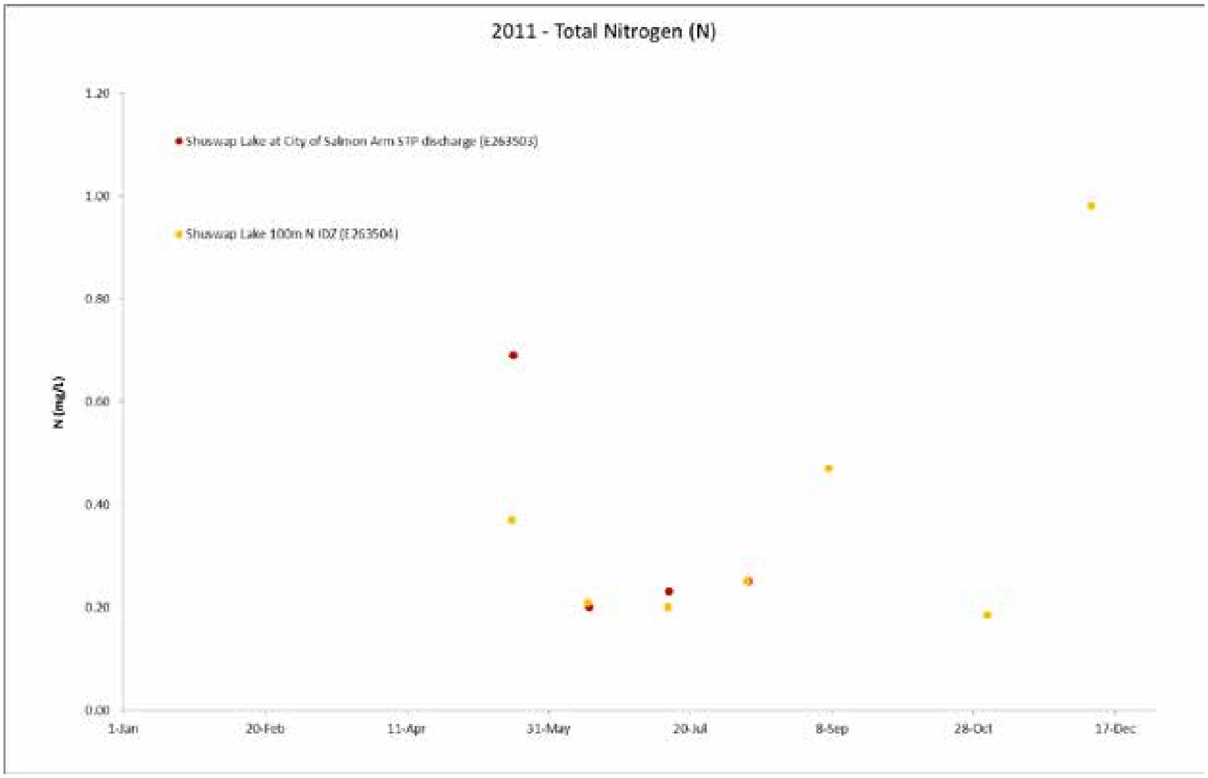
Figure 4-9 Total organic nitrogen (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake



4.9 Total Nitrogen

Using the average concentration for total nitrogen sampled at the Sandy Point site (epilimnion) during 2011 as a reference (250 µg/L), the comparison between the reference site and these two sites affected by the WWTP is mostly in the same range but these sites have some samples that are notably higher (**Figure 4-10**).

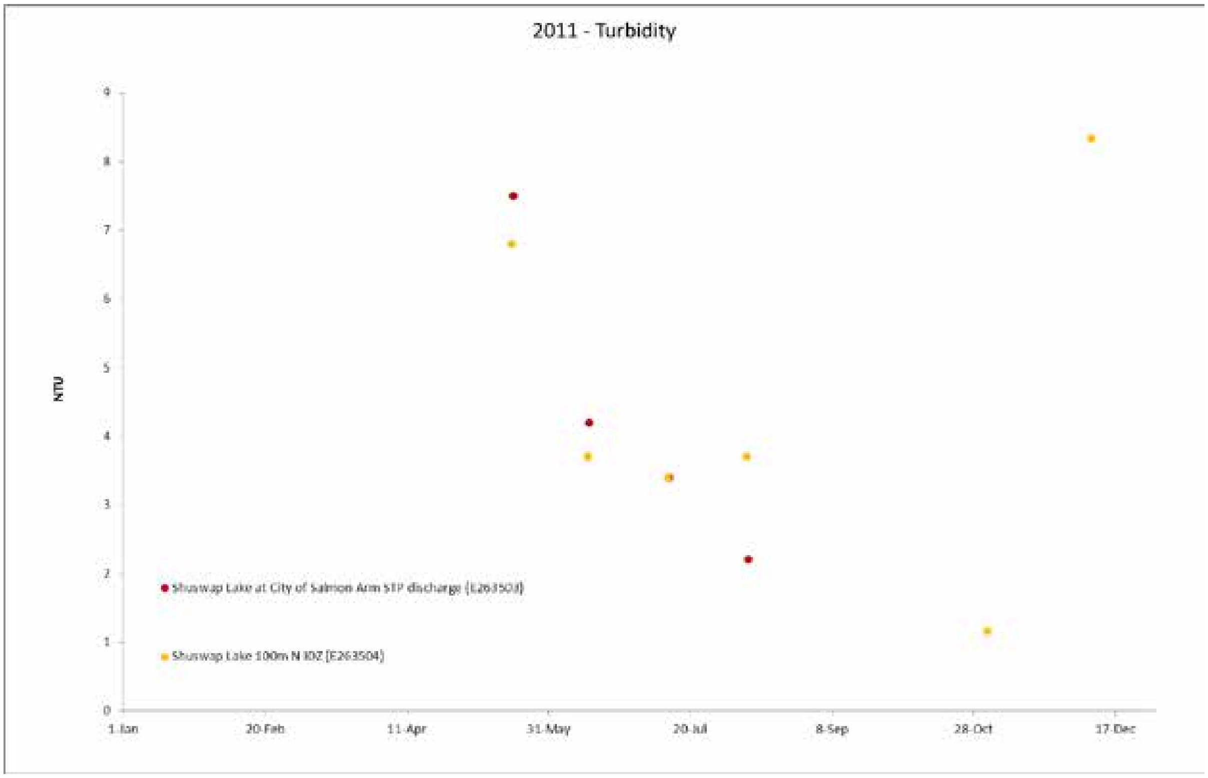
Figure 4-10 Total nitrogen (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake



4.10 Turbidity

Using the average concentration for turbidity sampled at the Sandy Point site (epilimnion) during 2011 as a reference (1.3 NTU), the comparison between the reference site and these two sites affected by the WWTP show notably higher values (**Figure 4-11**).

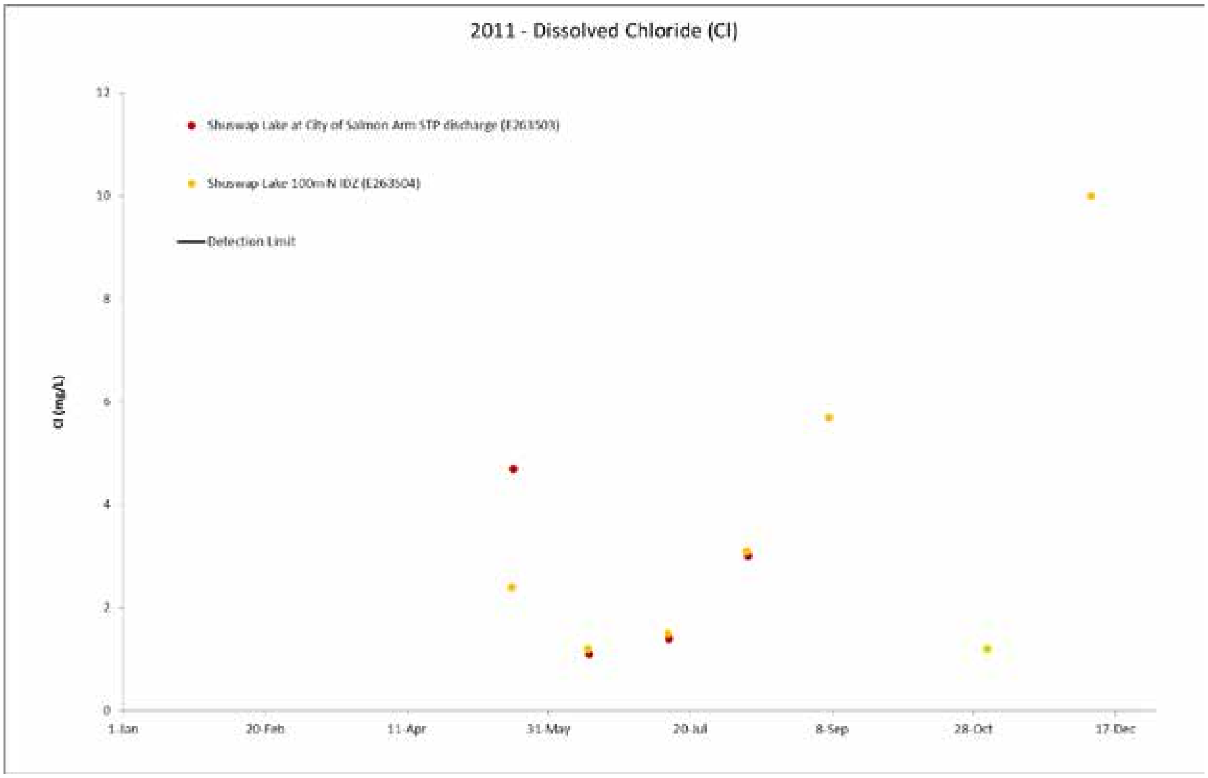
Figure 4-11 Turbidity (NTU) at near shore WWTP point source monitoring stations in Shuswap Lake



4.11 Dissolved Chloride

Using the average concentration for chloride sampled at the Sandy Point site (epilimnion) during 2011 as a reference (1.5 mg/L), the comparison between the reference site and these two sites affected by the WWTP show generally higher values (**Figure 4-12**).

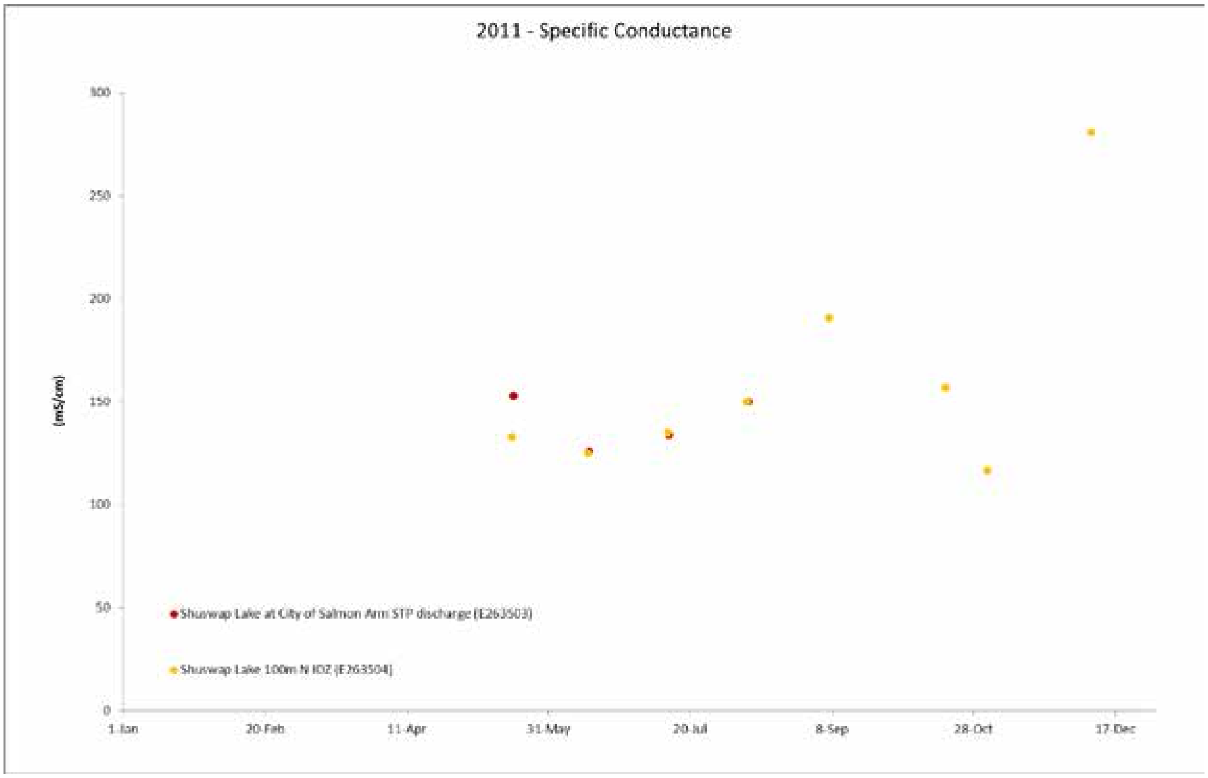
Figure 4-12 Dissolved chloride (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake



4.12 Specific Conductivity

Using the average concentration for specific conductivity sampled at the Sandy Point site (epilimnion) during 2011 as a reference (120 µS/cm), the comparison between the reference site and these two sites affected by the WWTP show consistently higher values (**Figure 4-13**).

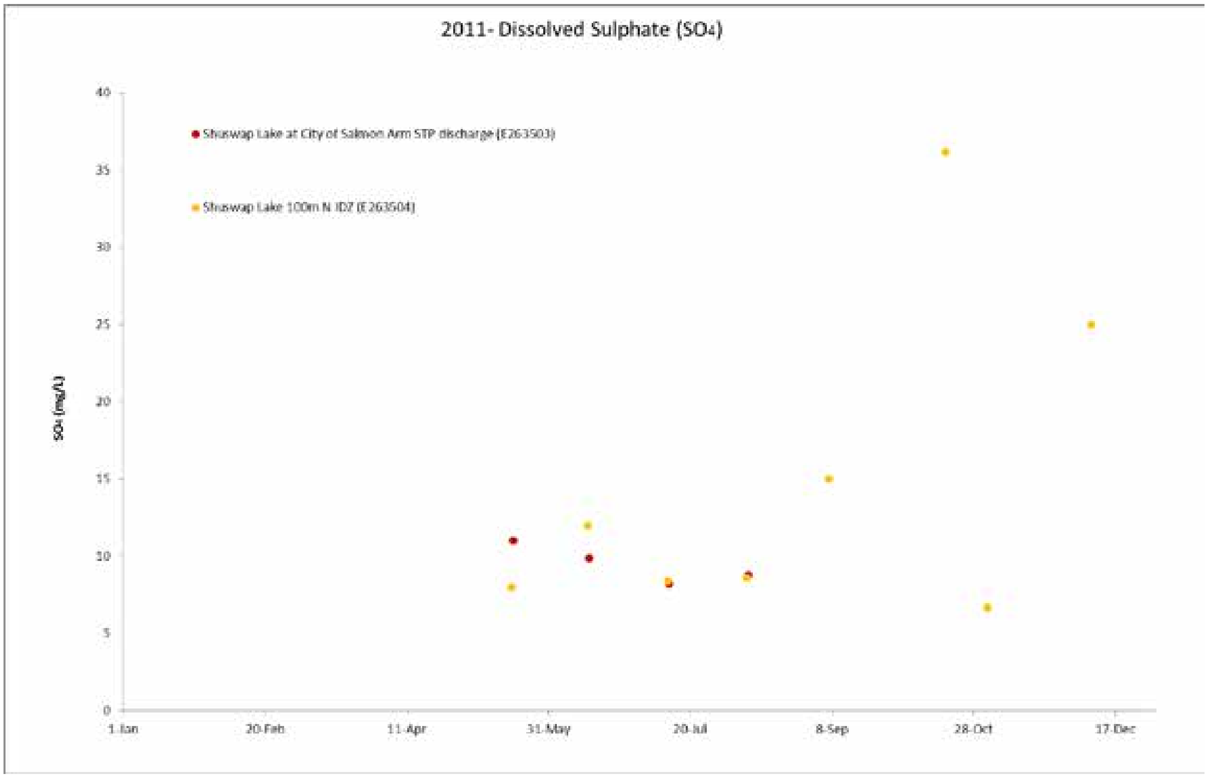
Figure 4-13 Specific conductivity (µs/cm) at near shore WWTP point source monitoring stations in Shuswap Lake



4.13 Dissolved Sulphate

Using the average concentration for sulphate sampled at the Sandy Point site (epilimnion) during 2011 as a reference (8.2 mg/L), the comparison between the reference site and these two sites affected by the WWTP show generally higher values – with two samples September and October being particularly notable (**Figure 4-14**).

Figure 4-14 Dissolved sulphate (mg/L) at near shore WWTP point source monitoring stations in Shuswap Lake



5 Tributary Water Quality – Watershed Monitoring

Watershed nutrient loading samples were collected near the mouth of the Salmon River, Shuswap River, Eagle River, Hummingbird Creek, Sicamous Creek, Anstey River, Seymour River, Scotch Creek, and Albas Creek (**Table 5-1** and **Figure 5-1**). Continuation of sampling occurred on White Creek, Tappen Creek, Canoe Creek, and Newsome Creek. Samples were collected biweekly year round, and weekly during freshet. No sampling was conducted within selected tributaries, as these sites will be selected based on the results of the first two years on monitoring.

Table 5-1 2011 Watershed tributary monitoring site locations

Station No.	Station Name	EMS Site	Latitude	Longitude
Nutrient Loading 1	Scotch Ck. at Celista Rd Bridge	500064	50.93027778	-119.4644444
Nutrient Loading 2	Canoe Ck. at CPR Bridge	207640	50.75416667	-119.2213889
Nutrient Loading 3	Newsome Ck.at mouth	500047	50.88027778	-119.4711111
Nutrient Loading 4	Tappen Ck. at Hwy 1	600246	50.77444444	-119.34
Nutrient Loading 5	Eagle R. at Sicamous CP Bridge	E275709	50.84138889	-118.9830556
Nutrient Loading 6	Hummingbird Ck. Up stream of Mara Lake	E224156	50.76638889	-119.0075
Nutrient Loading 7	Sicamous Creek, at Hwy 97A	E206452	50.80777778	-118.9719444
Nutrient Loading 8	Adams R. at Celista Rd. Bridge	500001	50.90194444	-119.5886111
Nutrient Loading 9	Celista Ck. at Celista Rd. Bridge	500014	51.21638889	-119.0138889
Nutrient Loading 10	Seymour R. at Logging Road	E206964	51.25916667	-118.9497222
Nutrient Loading 11	Anstey R. West	500005	51.13277778	-118.9102778
Nutrient Loading 12	White Ck. at Tappen Hwy 1	500098	50.7875	-119.3288889
Nutrient Loading 13	Shuswap R. upstream Mara LK.	BC08LC0005	50.54583333	-119.0130556
Nutrient Loading 14	Salmon R. at Hwy 1 Bridge	BC08LE0004	50.69305556	-119.3277778

The full range of parameters collected were as follows:

1) Nutrients
2) Dissolved and Total Organic Carbon
3) General Ions
4) Metals
5) Bromide
6) Chloride
7) Sulphate
8) Turbidity

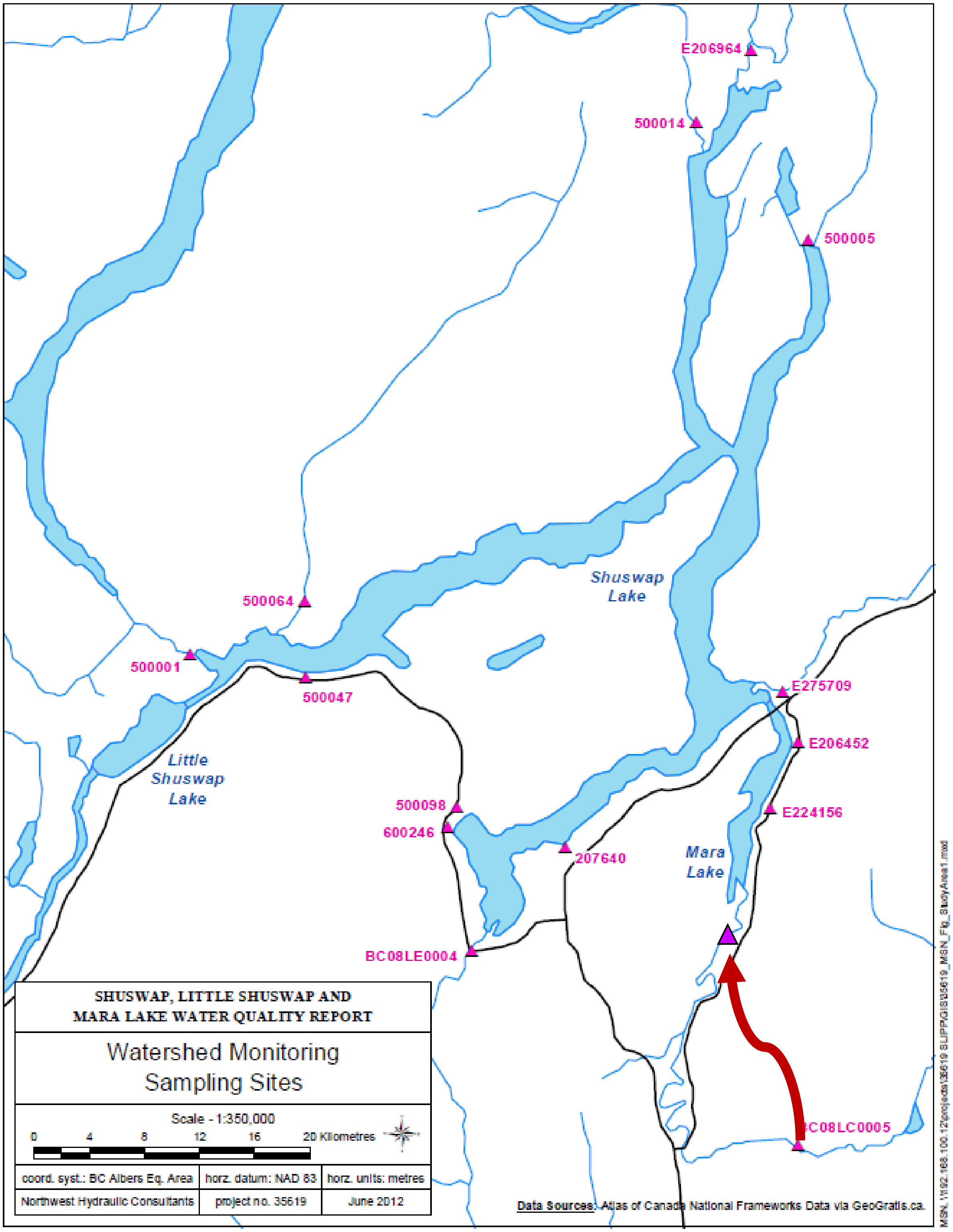
9) Conductivity
10) pH
11) Hardness
12) *E. coli*
13) Fecal coliforms

General land use activities around Shuswap Lake (Figure 5-1) and the watersheds that were monitored for water quality conditions and land-use mapping is provided for interpretation and reference in Table 5-2.

Table 5-2 Tributary Watershed Land-use Mapping

Watershed	Reference Map
Shuswap Lake	**Figure** 7-1
Adams River	**Figure 7-2**
Seymour River and Celista Creek	**Figure 7-3**
Canoe Creek	**Figure 7-4**
Eagle Creek	**Figure 7-5**
Sicamous and Hummingbird Creeks	**Figure 7-6**
Newsome Creek	**Figure 7-7**
Scotch Creek	**Figure 7-8**
Salmon River	**Figure 7-9**
Tappen Creek	**Figure 7-10**
White Creek	**Figure 7-11**

Figure 5-1 Map of SLIPP watershed monitoring sites in Shuswap, Little Shuswap and Mara Lakes



General water quality conditions for field measurements of dissolved oxygen and temperature, microbiology (*E. coli*) as well as specific conductivity (an estimate of dissolved solids) and particulate substances (suspended solids and turbidity) for the 14 tributaries are summarized in **Table 5-3**.

The water temperature varies from -0.8 to 21.2 for the 14 tributaries. Any values less than 0.0 C should be ice so these two winter values for the Salmon and Shuswap rivers probably reflect measurements in rather turbulent water or the influence of air temperatures on the thermistor thermometer when the measurements were made.

Most of the smaller tributaries had summer high temperatures between 11 and 15 degrees C which is quite favourable for salmonids (Joblin 1981). An exception to this was White Creek and Celesta Creek with maximum summer temperatures of 20 and 21.2 degrees C respectively. The larger rivers (Adams, Shuswap, and Salmon) had summer temperatures approaching 20 degrees C (i.e., between 18.9 and 19.7 degrees C). Joblin (1981) reported that the preferred temperature for salmonids is 12 to 18 degrees C with lethal temperatures 23-27 degrees C.

Dissolved oxygen concentrations for most tributaries were between 9 to 15 mg/L which were very close to saturated conditions and were quite adequate for aquatic organisms. A low oxygen value of 7.1 mg/L in White Creek could be detrimental if these conditions persisted for a long period. The BC Government-approved site specific Water Quality Objectives recommend an objective for the Salmon River with a minimum not lower than 9 mg/L (E.C. and M of E.L. & P. 1998). Saturation values for oxygen in freshwater are 14.2 mg/L at 1 degree C and 9.1 mg/L at 20 degrees C (APHA, 1989) and the values in **Table 5-3** are in this range.

E. coli are a measure of microbial contamination which can result from human activities such as septic tank seepage or runoff from agricultural land. The small creeks around Salmon Arm of Shuswap Lake (Canoe, Tappen and White) and Newsome Creek (along Highway 1) had exceptionally high levels of *E. coli* with average values between 60 to 170 and maximum values in White Creek of 780. The recommended long term average is not above 10 colonies/100 mL (E.C. & E.L.P., 1998) and less than 77 CFU/100 mL (geometric mean) for primary contact recreation (Nagpal *et al*. 1995) which was exceeded considerably by these streams.

This area around Shuswap Lake has the highest population and the Trans-Canada highway (Highway 1) runs right around this area of Shuswap Lake where there is considerable human activity especially in the summer recreational season. There is also considerable land use in agriculture in Canoe Creek watershed (**Figure 5-5**), Newsome Creek watershed (**Figure 5-8**) and Tappen Creek watershed (**Figure 5-11**).The Salmon River had an average value of *E. coli* of 31 with a maximum of 130 which is lower than the four more contaminated creeks, but there is cause for concern since there is considerable agricultural activity in this watershed which is probably one of the main factors contributing to this microbial contamination.

Other creeks and rivers (Celesta, Adams, Eagle, Hummingbird, Scotch, Seymour, Sicamous, West Anstey and Shuswap had average *E. coli* values of 10 or less with many average values less than 5 CFU/100 mL probably attributable to the lower population densities and less human activity in these watersheds. There is considerable agricultural activity in the lower reaches of the Shuswap River but the large size of this watershed with considerable drainage at higher elevations probably helps to keep the *E. coli* values somewhat lower (average of 8.8 CFU/100 mL).

Dissolved materials, as estimated by specific conductivity, are again quite high for the four creeks that have high *E. coli*, specifically in Canoe, Newsome, Tappen and White Creeks with average values 347 to 545 µS/cm. The Salmon River also has a relatively high level of dissolved solids (average specific conductivity of 360 µS/cm). High dissolved solids can be contributed by the geology of the watershed as well as by human activity, and the relative influxes can be determined by examining low flow, groundwater periods versus high flow, surface run-off periods..

It would require more detailed sampling along these waterways to determine the influence of human activity on the dissolved solids level. However, the fact that several of these tributaries have high levels of microbial contamination (*E. coli*) make these higher levels of specific conductivity suspect. The higher areas of impervious surfaces in the populated areas and along the transportation routes can also cause dissolved substances that would normally be adsorbed by the soil profile, to be transported to the creeks and rivers.

Particulate substances as determined by suspended solids and turbidity measurements (**Table 5-3**) indicate that there can be considerable variability in the solids transport by these waterways. Generally suspended solids transports are higher during the period of high flow which occurs in the spring (April and May) as the snow melts. This relationship is shown in the seasonal changes of suspended solids with the estimated discharge hydrographs. Evaluation of suspended solids transport is important since many contaminants such as trace metals and hydrophobic organic compounds which are not highly water soluble are adsorbed to particulate substances and move with them. Some of the highest levels of suspended solids occurred in Canoe Creek, Newsome Creek and the Seymour River with maximum values between 280 and 2,700 mg/L.

However, land-use activities such as construction (road building), logging and mining which disturb the land surface and remove protective forest cover can cause high levels of sediment transport in the creeks and rivers. Urbanization with higher areas of effective impervious surfaces (e.g., pavement, roof tops, road surfaces) can generate more runoff per unit precipitation, increasing flood flows, erosion and sedimentation.

It is recommended for the protection of aquatic life that turbidity levels are kept less than 10 NTUs over the background level in the short term and that total suspended solids in the long term are less than 10 mg/L over the background levels (Salmon River recommendations -E.C. and E. L. and P. 1998) and that turbidity at 8 NTU above background when background is between 8 and 80 and suspended solids at 25 mg/L above background when background is between 25 and 250 mg/L (BCG Approved Water Quality Guidelines, Nagpal *et al*. 1998).

For compliance to these recommended objectives it would probably require some more frequent sampling of these watersheds and would best be evaluated by some continuous turbidity monitoring to establish background levels and periods of high sediment transport.

Table 5-3 General Water Quality Characteristics of Tributaries Discharging to Shuswap Lake

Tributary	Site No.	Temperature (C)	Dissolved Oxygen (mg/L)	*E. coli* (CFU per 100mL)	Specific Conductivity (S/cm)	Turbidity (NTU)	Total Suspended Solids (mg/L)
Celesta Creek	500014	4.7-21.2	9.4-13	(7.4) 1-58	(34.7) 29-57	0.1-4.2	1-10
Adams R.	500001	6.6-18.9	9-17	(1.8) 1-10	(75.4) 56-174	0.2-2	1-15
Canoe Creek	207640	3-14	9-13	(115) 1-310	(528) 433-713	0.2-36	3-280
Eagle River	E275709	1.8-15.1	9.2-12	(10.9) 1-27	(55.9) 34-88	0.3-11.6	1-57
Hummingbird Creek	E224166	1.1-14.7	9-14	(1) 1-5	(41) 14-69	0.1-4.3	1-5
Newsome Creek	500047	3-13.8	9.8-13.1	(71.9) 10-230	(545) 377-667	1.3-2600	2-2700
Scotch Creek	500064	3-15.2	10.4-15	(2.6) 1-12	(114) 51-186	0.25-13.1	1-46
Seymour Creek	E206964	4-15	10.6-13	(9.5) 1-70	(32) 17-49	0.8-15.3	1-450
Sicamous Creek	E206452	1-12.3	11-14.2	(3.1) 1-25	(36) 23-107	0.1-3.4	1-6
Tappen Creek	600246	6.6-11.6	10-12	(59.4) 3-130	(347) 338-358	1.6-10.2	8-15.3
West Anstey R.	500005	3.4-11	11.7-13	(2) 1-32	(44.5) 30-358	0.1-9.8	1-38
White Creek	500098	1.3-20	7.1-12.5	(173) 5-780	(388) 325-447	1.9-17.1	4-45
Salmon R.	BC08LE0 004	-0.5-19.7	9-13.2	(31.2) 1-130	(360) 128-472	0.8-32.6	1.2-32.6
Shuswap R.	BC08LC0 005	-0.8-19.7	9.1-13	(8.8) 1-29	(102) 81-139	0.8-7.2	2-25

Table shows range of values with arithmetic mean in brackets.

5.1 Seasonal Distribution of Tributary Water Quality

The water quality data for each watershed are plotted to show the seasonal variation along with the estimated discharge hydrographs. They are organized sequentially in this report from phosphorus (Total P, Dissolved P, and ortho-P), nitrogen (ammonia, nitrate, organic nitrogen and total nitrogen – on two figures), carbon (dissolved and total), chloride, total suspended solids, pH, and turbidity. There are approximately eight (8) figures for each watershed and they are presented in **Figure 5-13** to **Figure 5-116**. The trace metal data are not plotted in these seasonal figures due to more infrequent sampling with only 2 to 7 samples for most watersheds.

These plotted data consistently show that the peak flows occur with the spring snow melt. These higher flows transport higher levels of suspended solids which often reach their maximum levels with the peak flow or slightly before the peak flow. The dynamics of sediment transport on this rising hydrograph depend upon a variety of factors including the elevation profile of the watershed, the temperature distribution over this elevation profile, the geology of the watershed, riparian buffers along the water courses and land use activities.

Particle-associated contaminants as reflected in large components of the total phosphorus and total nitrogen usually reach their highest concentrations during these spring periods. Soluble contaminants often show an increase during the early part of the snowmelt as the ground is still frozen and these soluble substances move with the overland surface runoff. This is demonstrated for the nitrate seasonal profiles for the Shuswap River (**Figure 5-103**) and the Salmon River (**Figure 5-110**) which both have large components of agricultural land use at their lower elevations and since nitrate is very soluble it will move readily with the overland runoff in very early spring.

Natural dissolved substances such as hardness (Ca, Mg), alkalinity (bicarbonates, carbonates), chloride, sulphate, sodium and potassium ,which contribute to a major part of the specific conductivity, are often higher during the lower winter and lower summer flow periods due to ground water making a larger contribution to the creek and river flow. For example, the seasonal chloride plots for the Eagle River (**Figure 5-41**) and Newsome Creek (**Figure 5-57**) with their higher late summer, fall and winter chloride concentrations illustrate how groundwater can influence the seasonal water quality in a watershed. This will depend upon the groundwater geology in each watershed. However, this seasonal flow pattern of dissolved materials can be complicated in urban areas and along transportation routes where there is considerable use of road salt (mainly Na and Cl).

5.1.1 Adams River

Figure 5-2 Discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in the Adams River

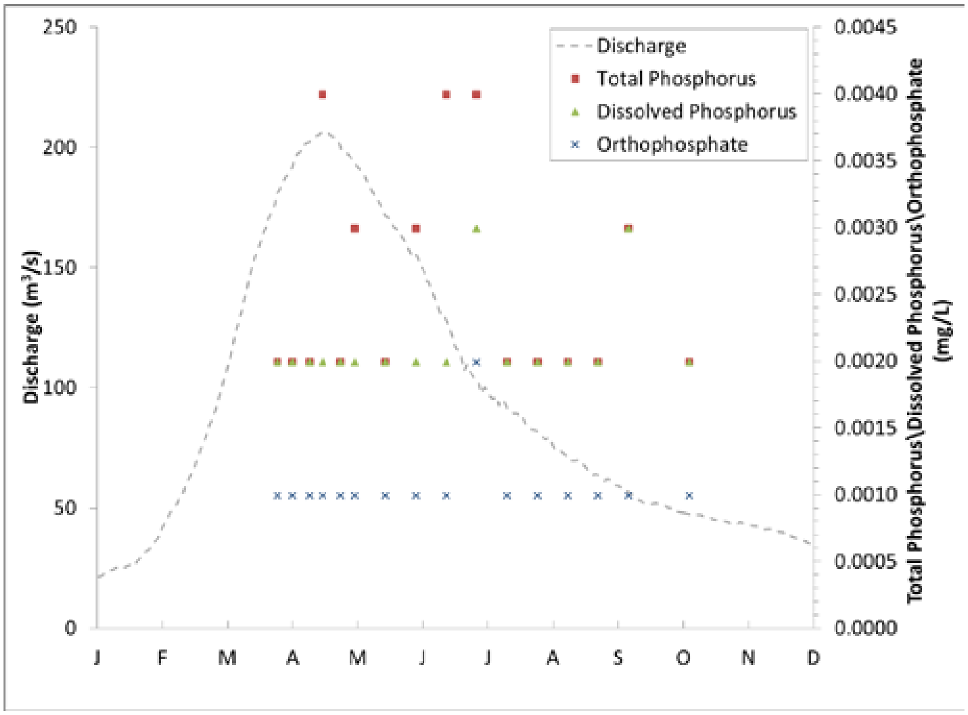


Figure 5-3 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in the Adams River

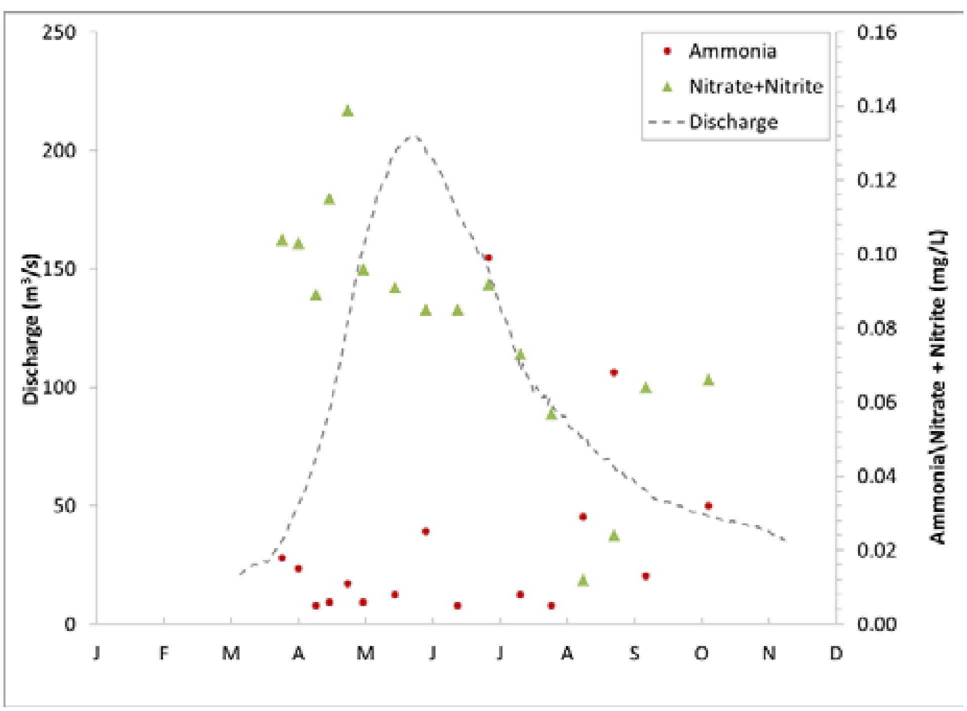


Figure 5-4 **Discharge hydrograph (m^3/s) and concentration of organic nitrogen and total nitrogen (mg/L) in the Adams River**

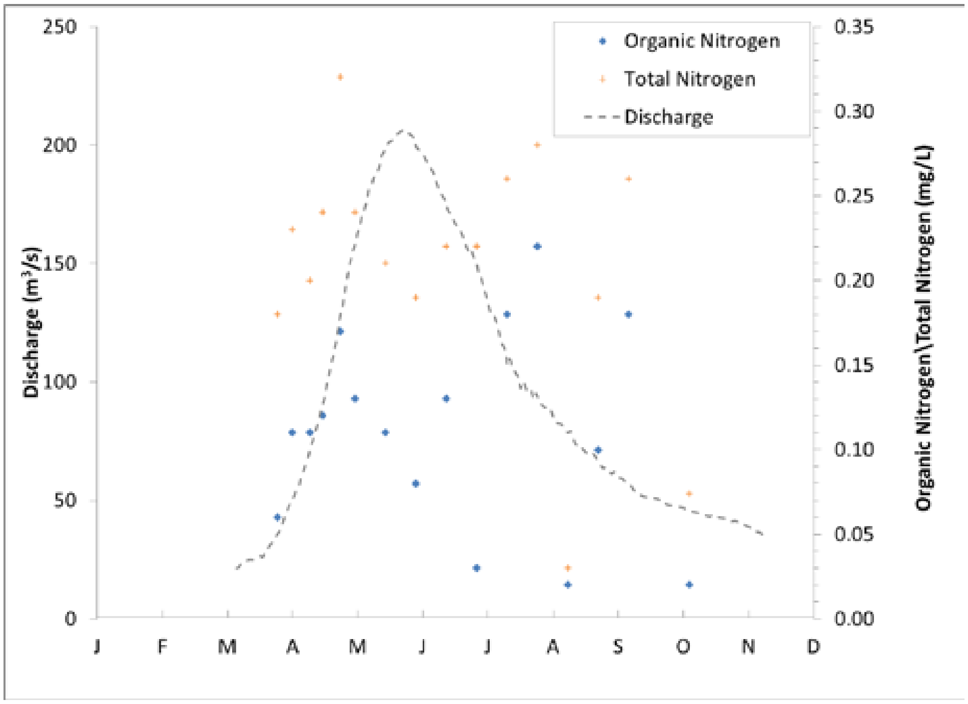


Figure 5-5 **Discharge hydrograph (m^3/s) and concentration of dissolved organic carbon and total organic carbon (mg/L) in the Adams River**

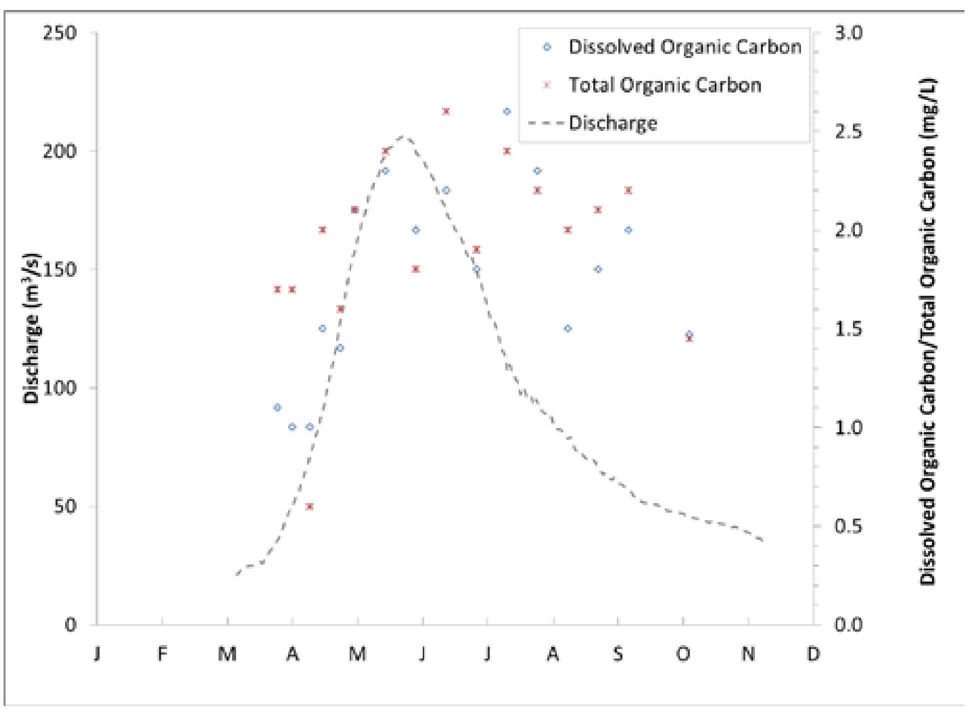


Figure 5-6 Discharge hydrograph (m^3/s) and concentration of dissolved chloride (mg/L) in the Adams River

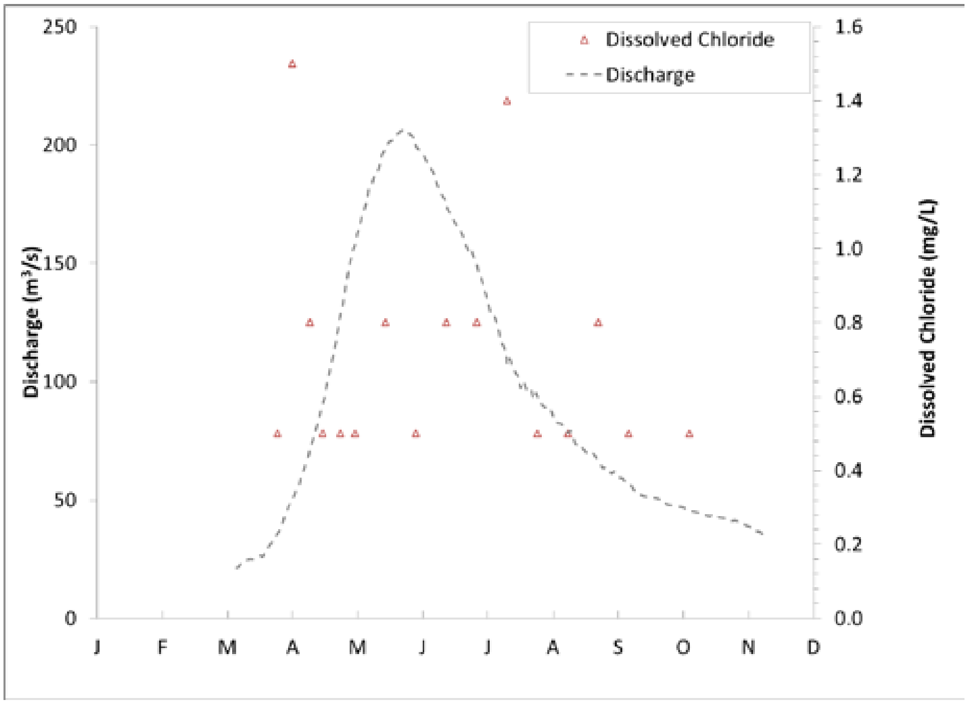


Figure 5-7 Discharge hydrograph (m^3/s) and concentration of total suspended solids (mg/L) in the Adams River

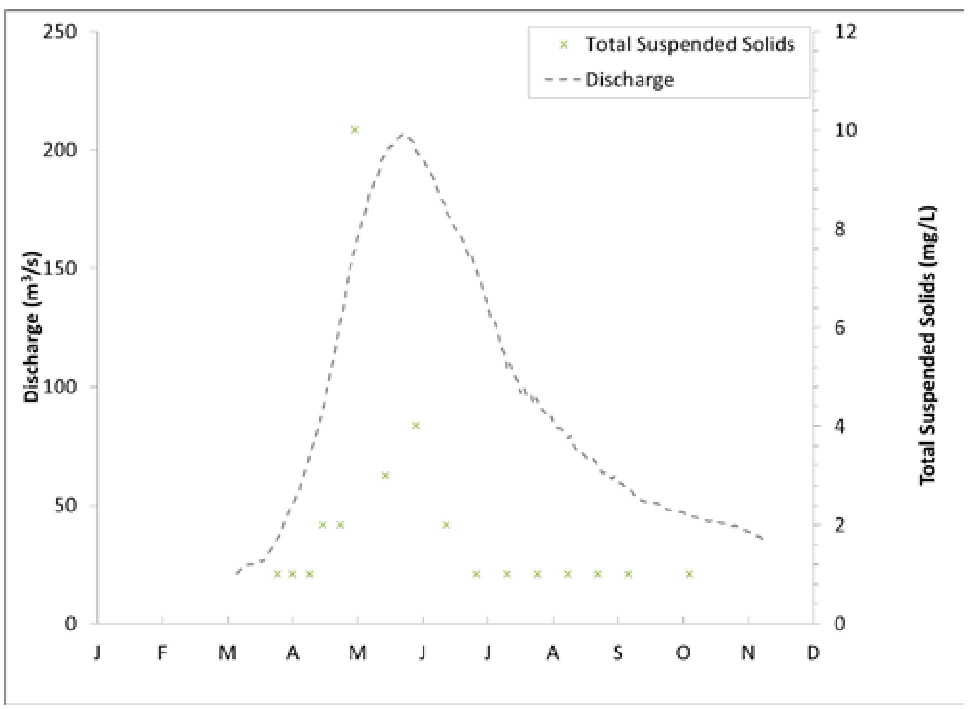


Figure 5-8 Discharge hydrograph (m^3/s) and pH in the Adams River

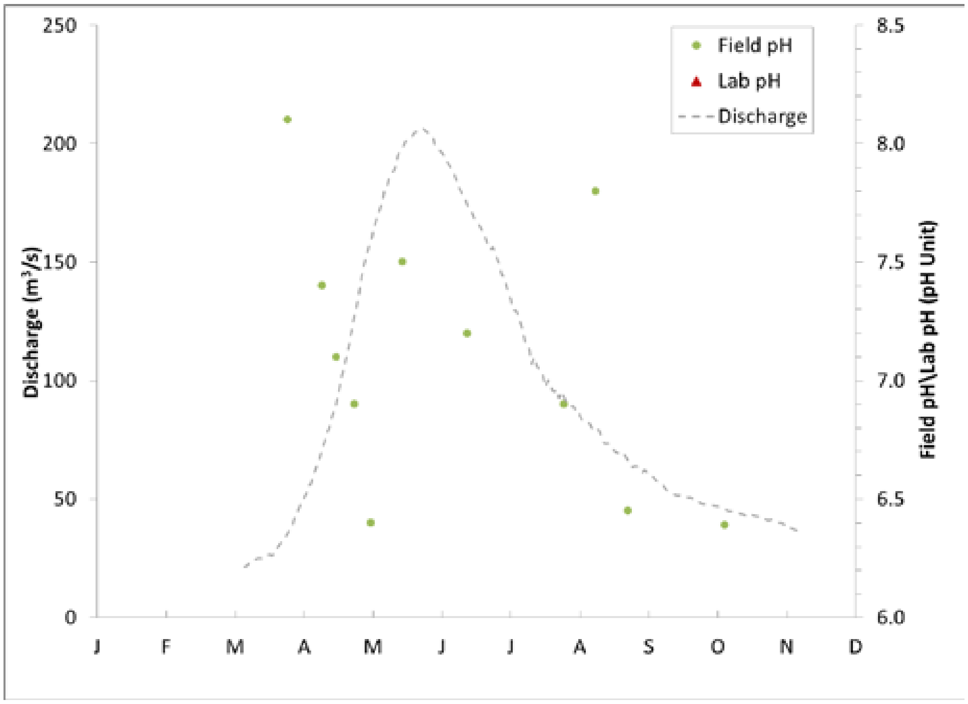
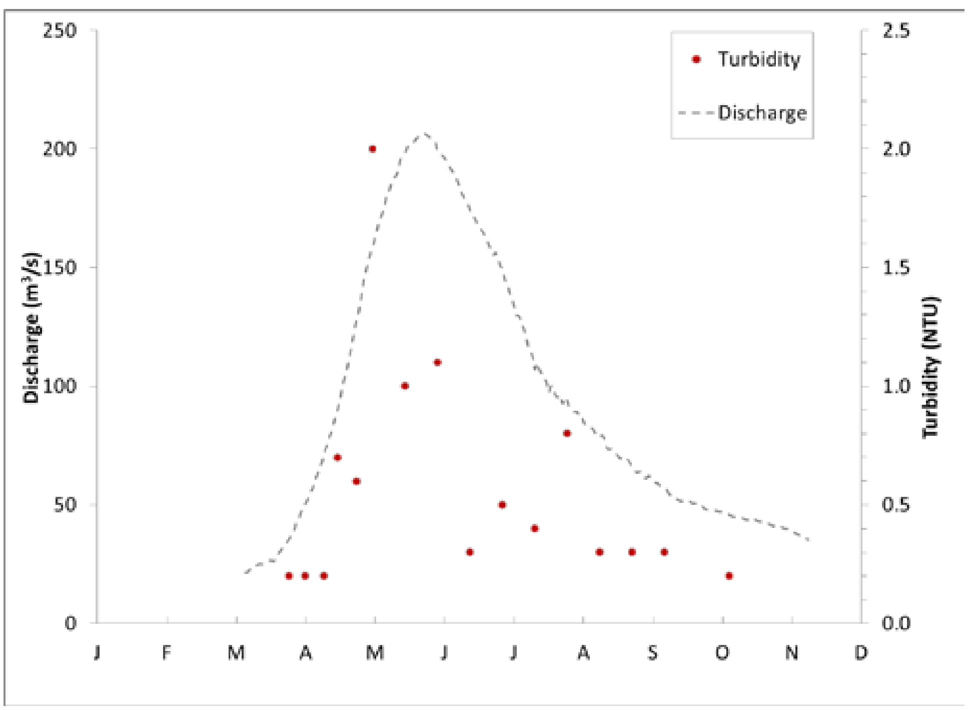


Figure 5-9 Discharge hydrograph (m^3/s) and turbidity (NTU) in the Adams River



5.1.2 Celista Creek

Figure 5-10 Estimated discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in Celista Creek

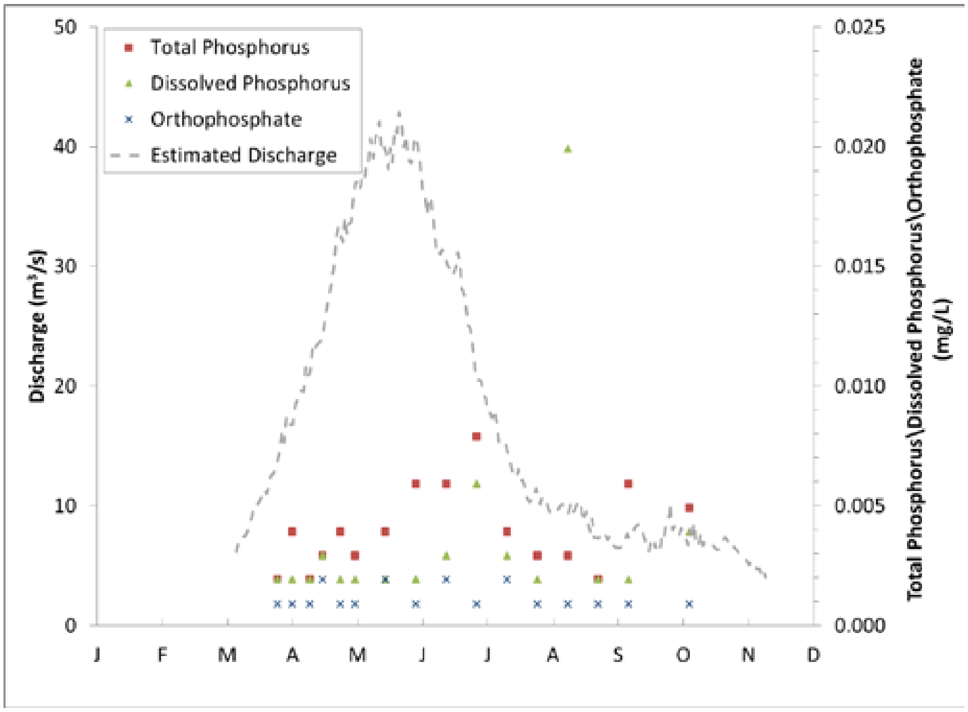


Figure 5-11 Concentration of ammonia and nitrate + nitrite (mg/L) in Celista Creek

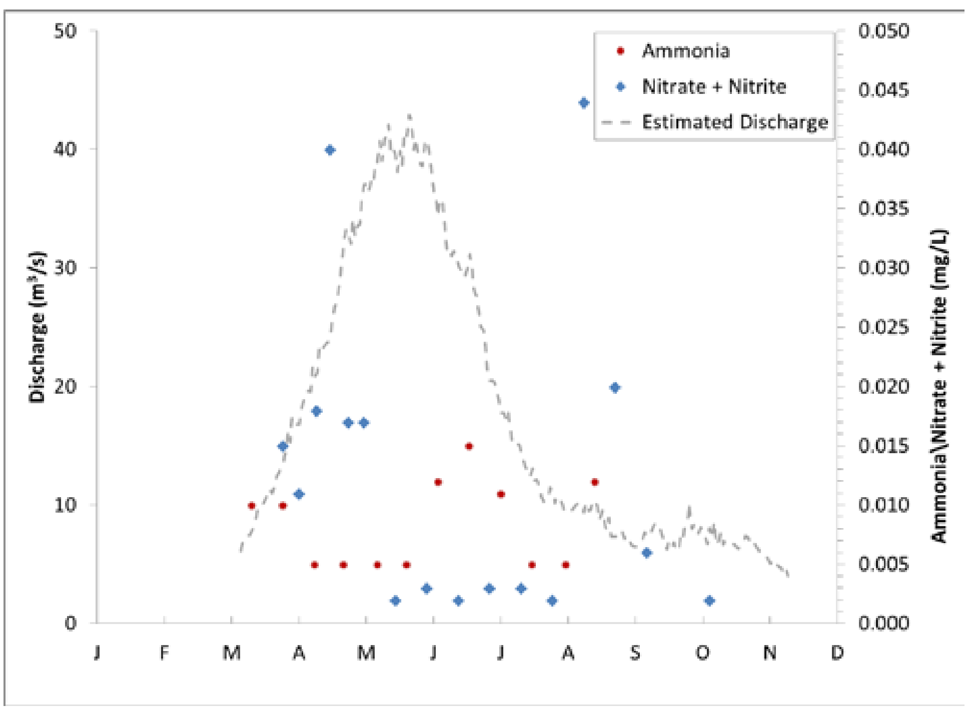


Figure 5-12 Concentration of organic nitrogen and total nitrogen (mg/L) in Celista Creek

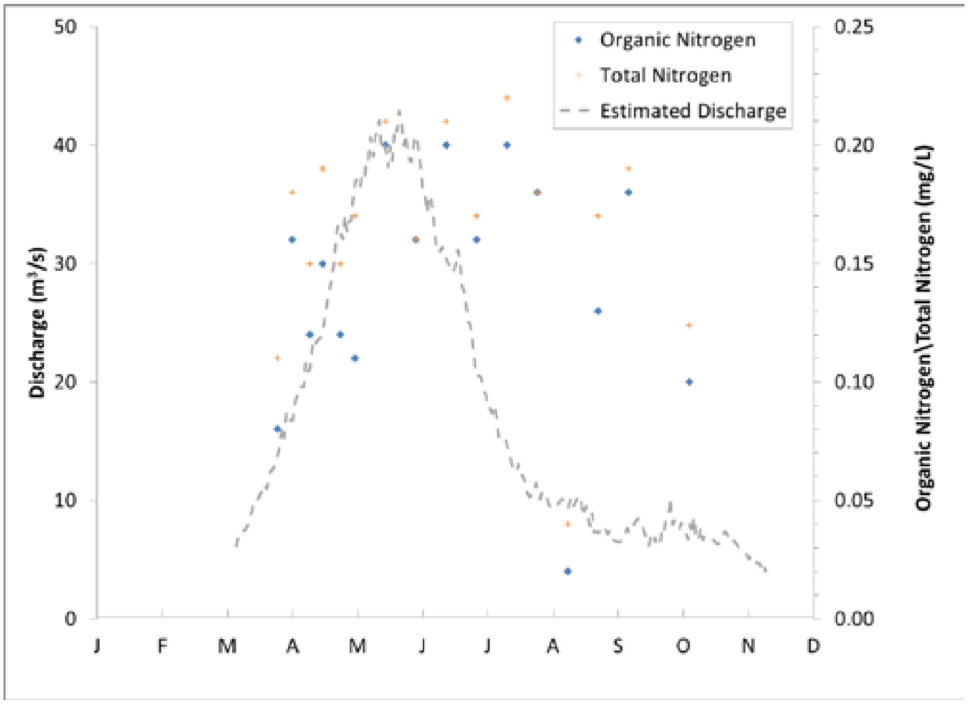


Figure 5-13 Concentration of dissolved organic carbon and total organic carbon (mg/L) in Celista Creek

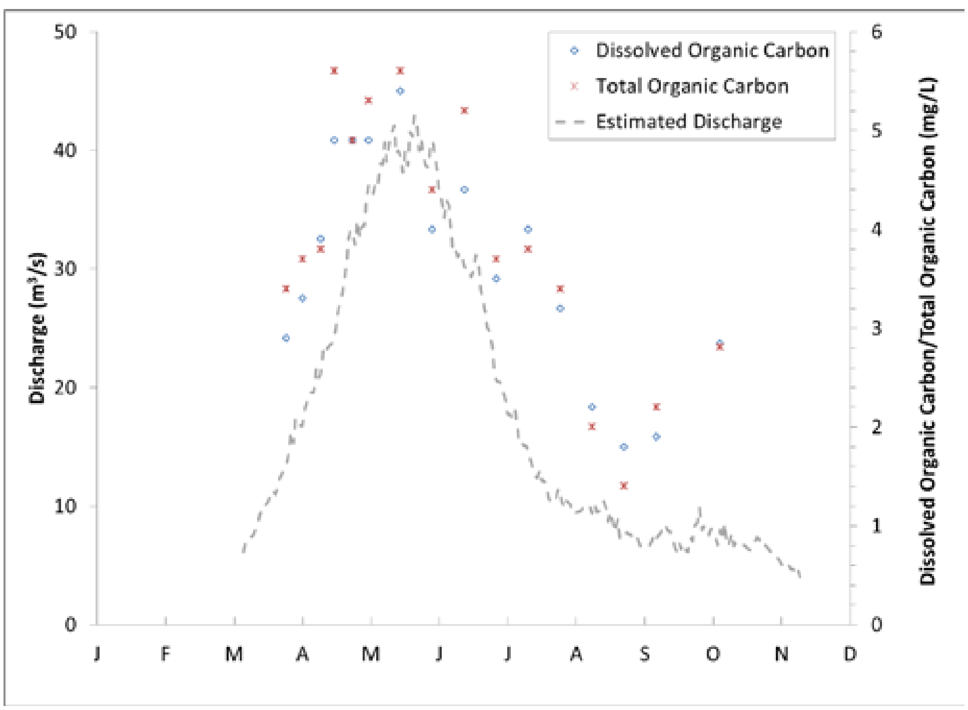


Figure 5-14 Concentration of dissolved chloride (mg/L) in Celista Creek

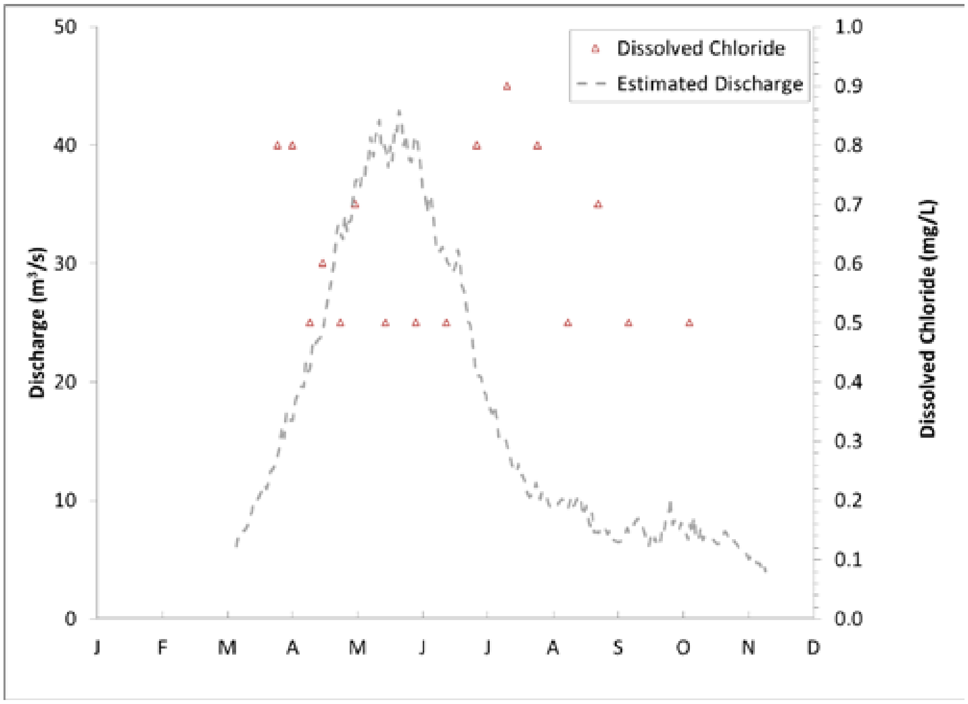


Figure 5-15 Concentration of total suspended solids (mg/L) in Celista Creek

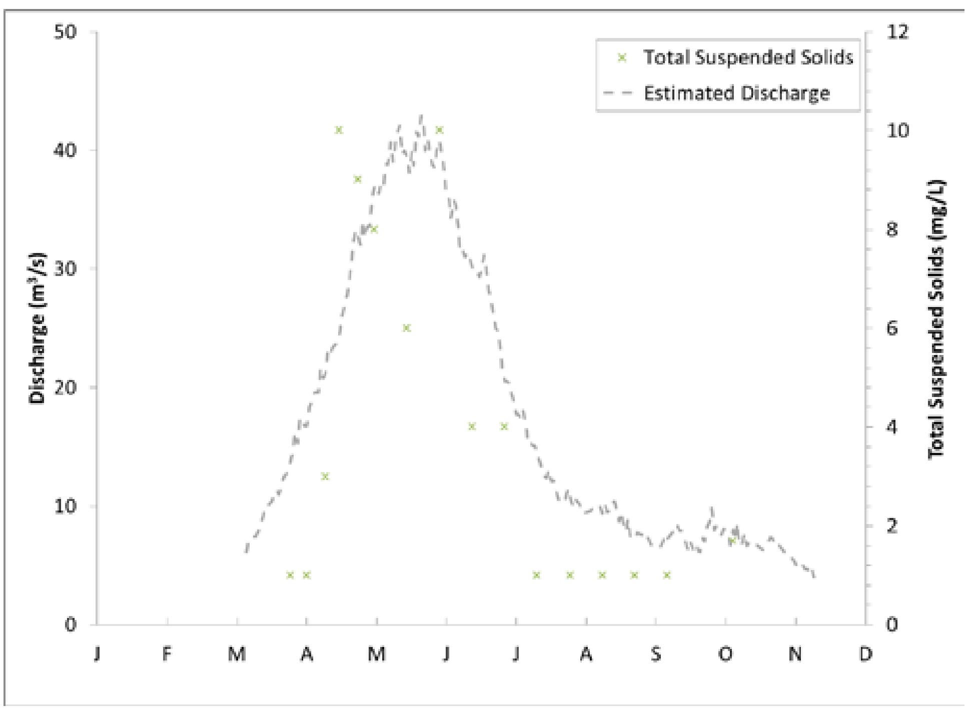


Figure 5-16 pH in Celista Creek

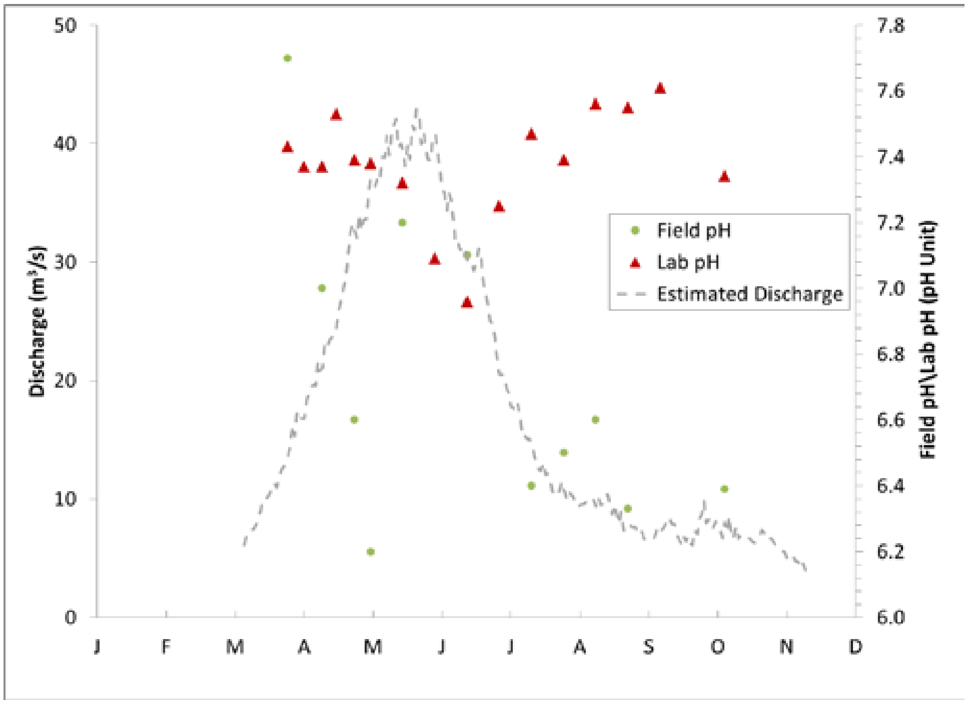
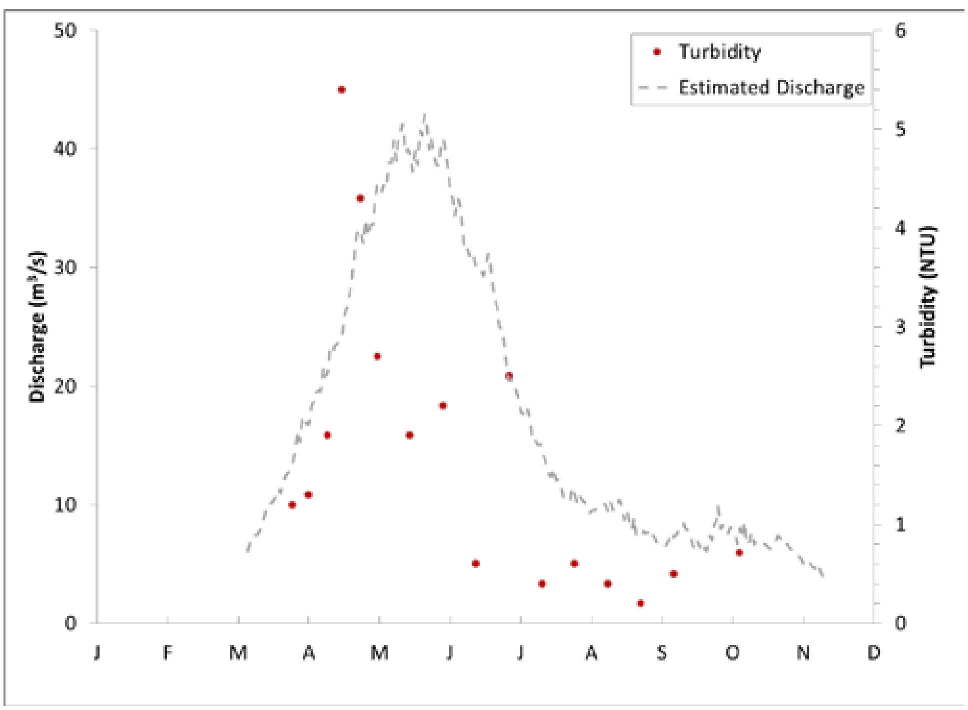


Figure 5-17 Turbidity (NTU) in Celista Creek



5.1.3 Canoe Creek

Figure 5-18 Estimated discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in Canoe Creek

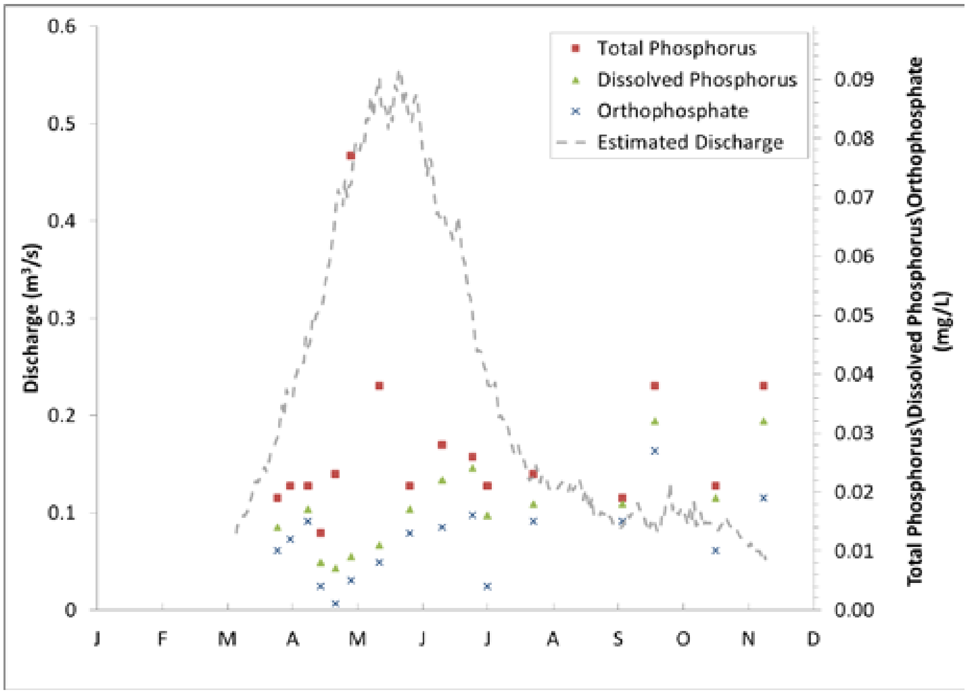


Figure 5-19 Concentration of ammonia and nitrate + nitrite (mg/L) in Canoe Creek

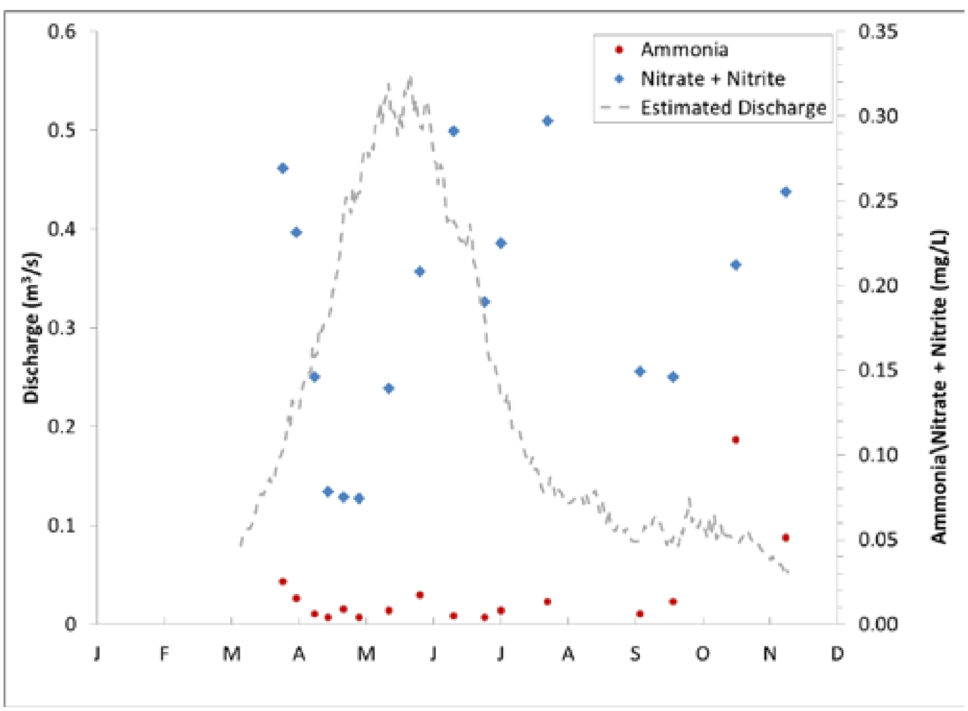


Figure 5-20 Concentration of organic nitrogen and total nitrogen (mg/L) in Canoe Creek

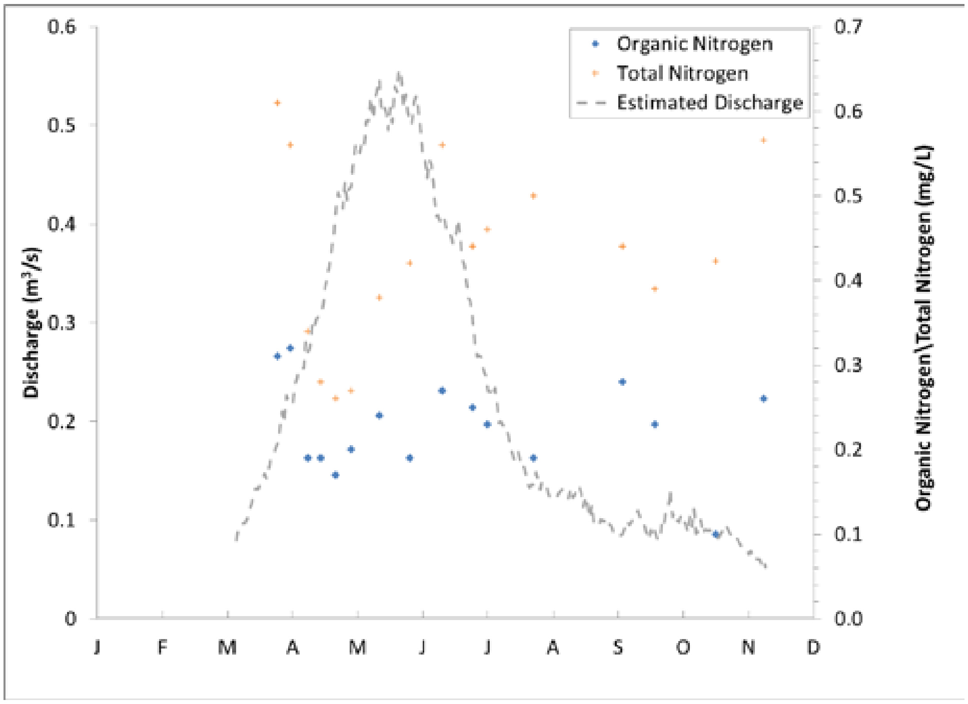


Figure 5-21 Concentration of dissolved organic carbon and total organic carbon (mg/L) in Canoe Creek

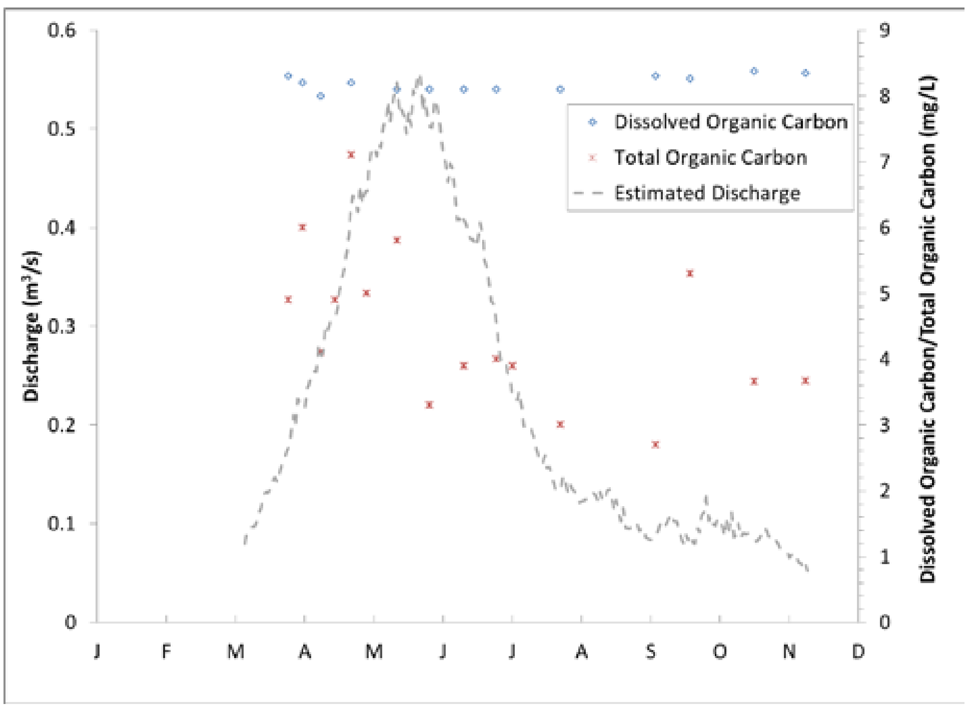


Figure 5-22 Concentration of dissolved chloride (mg/L) in Canoe Creek

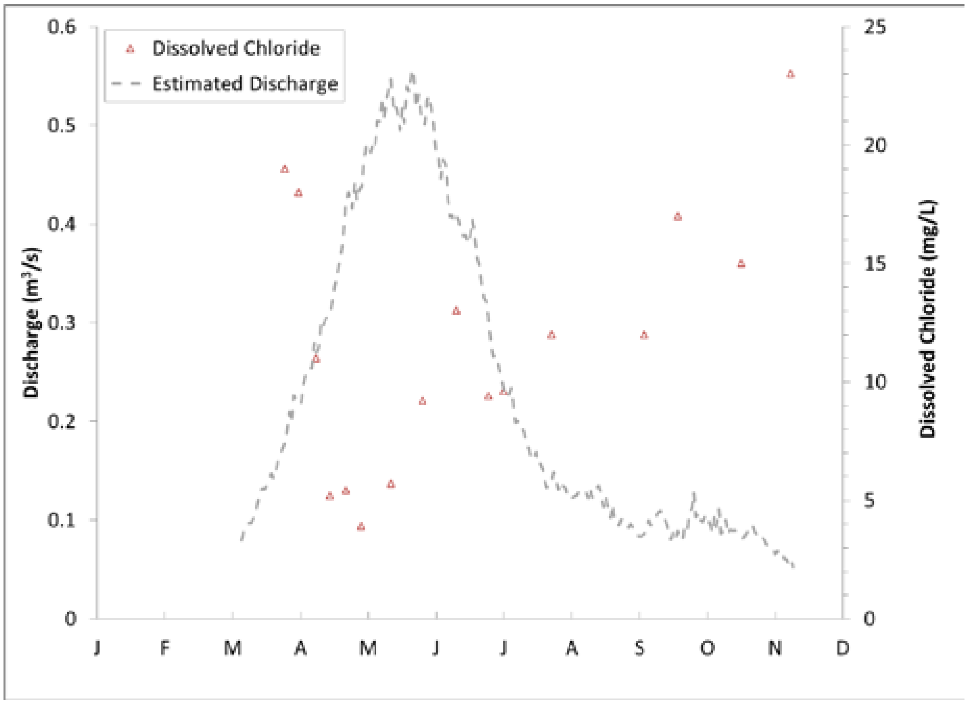


Figure 5-23 Concentration of total suspended solids (mg/L) in Canoe Creek

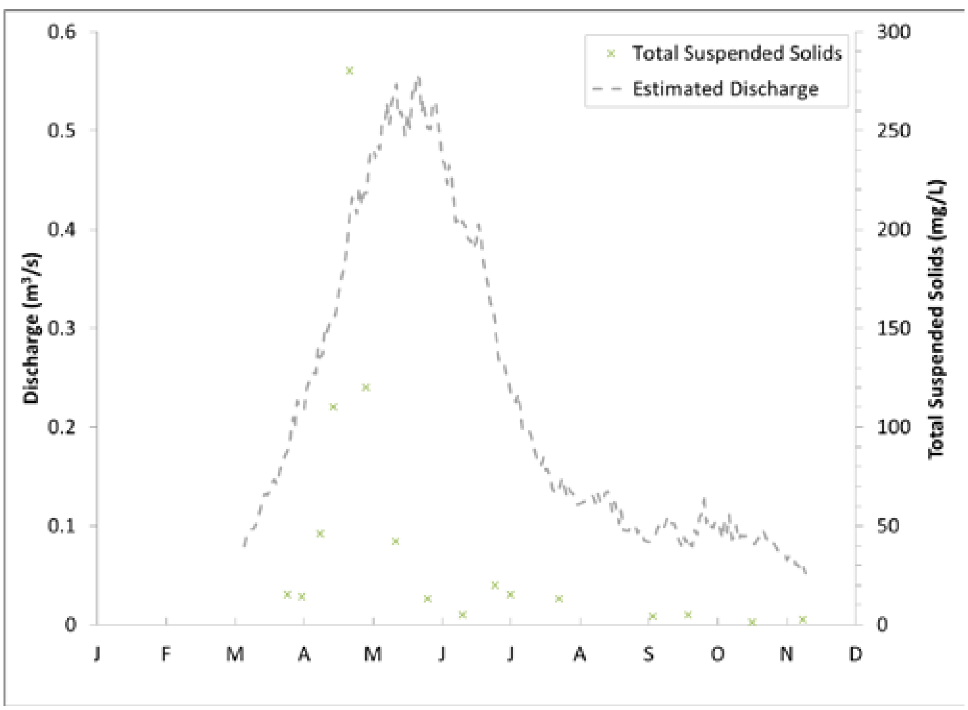


Figure 5-24 pH in Canoe Creek

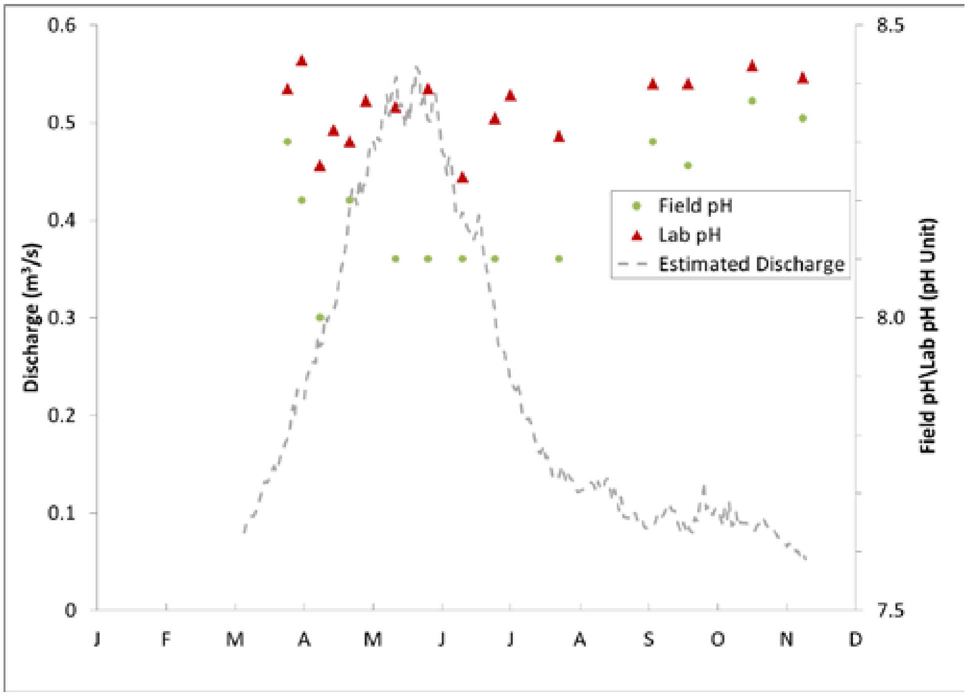
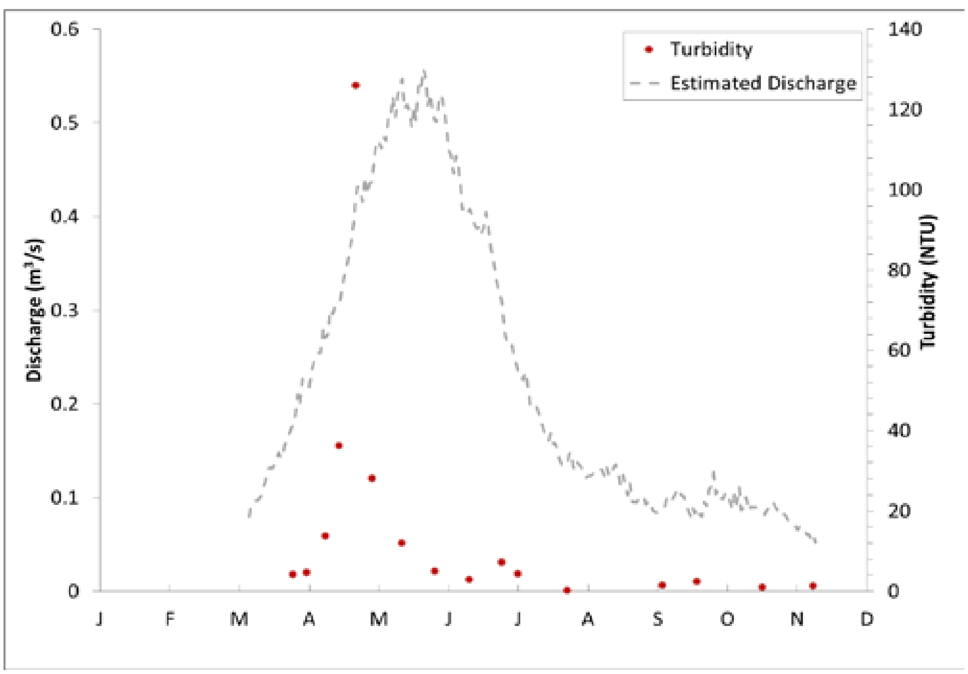


Figure 5-25 Turbidity (NTU) in Canoe Creek



5.1.4 Eagle River

Figure 5-26 Discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in the Eagle River

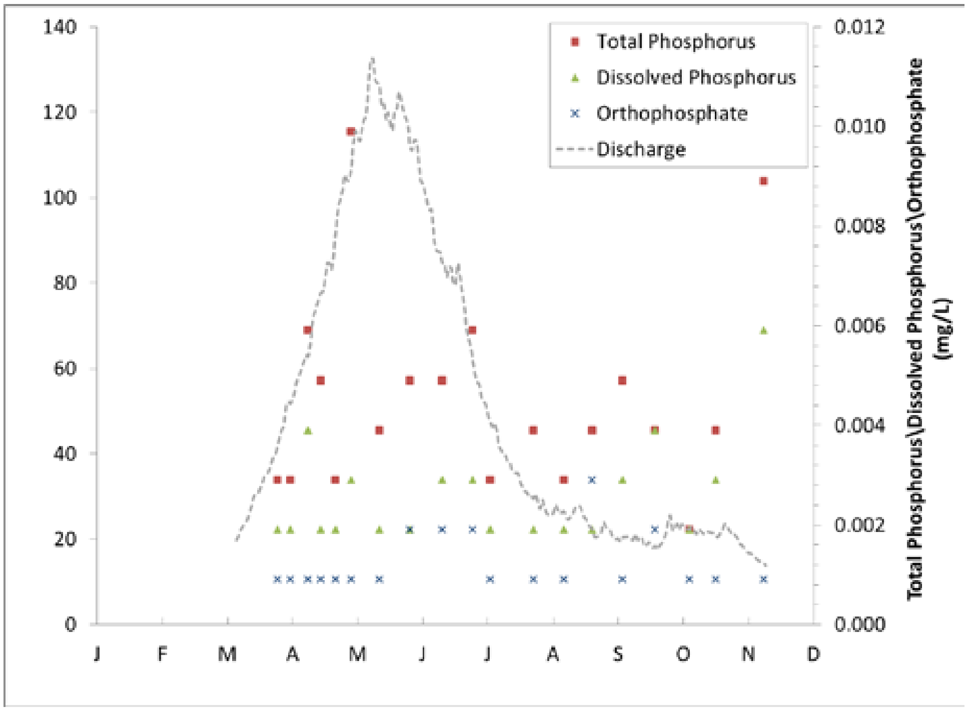


Figure 5-27 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in the Eagle River

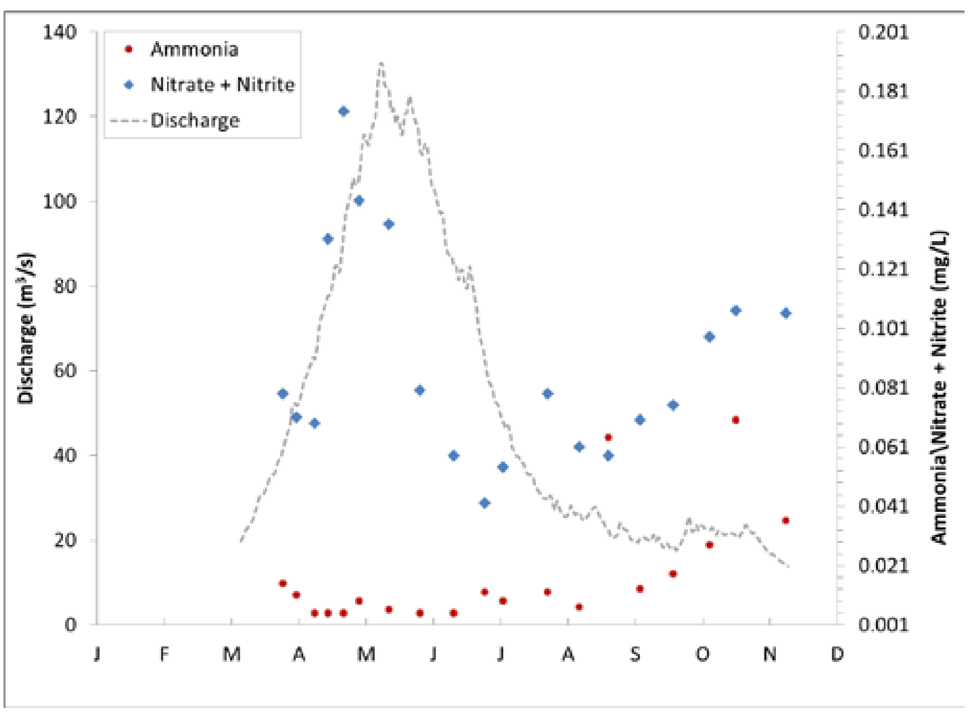


Figure 5-28 Discharge hydrograph (m^3/s) and concentration of organic nitrogen and total nitrogen (mg/L) in the Eagle River

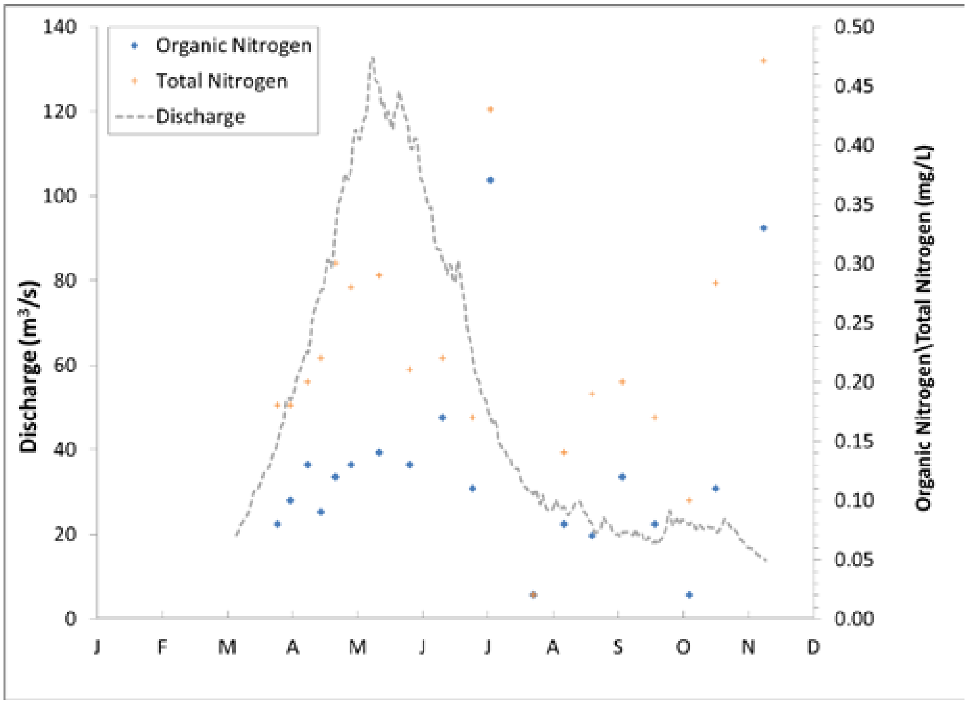


Figure 5-29 Discharge hydrograph (m^3/s) and concentration of dissolved organic carbon and total organic carbon (mg/L) in the Eagle River

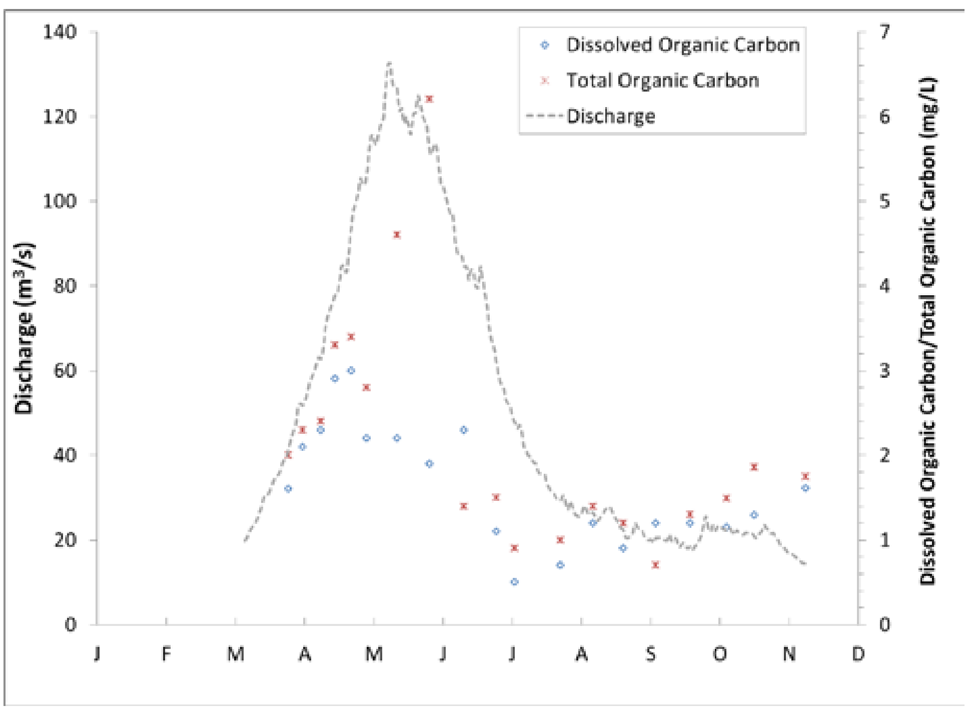


Figure 5-30 **Discharge hydrograph (m^3/s) and concentration of dissolved chloride (mg/L) in the Eagle River**

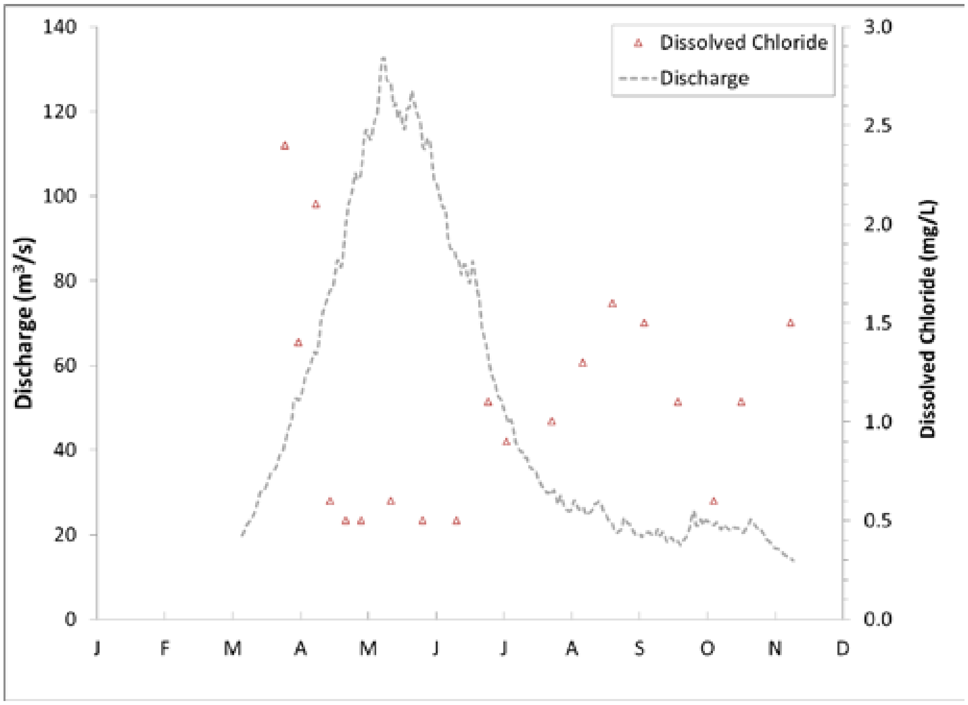


Figure 5-31 **Discharge hydrograph (m^3/s) and concentration of total suspended solids (mg/L) in the Eagle River**

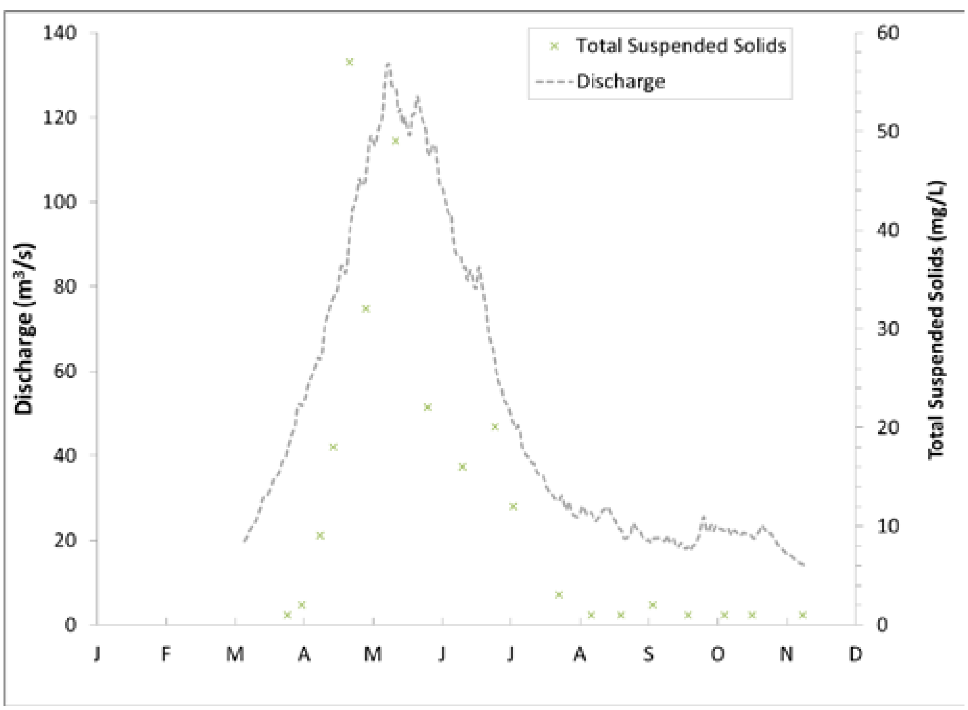


Figure 5-32 Discharge hydrograph (m^3/s) and pH in the Eagle River

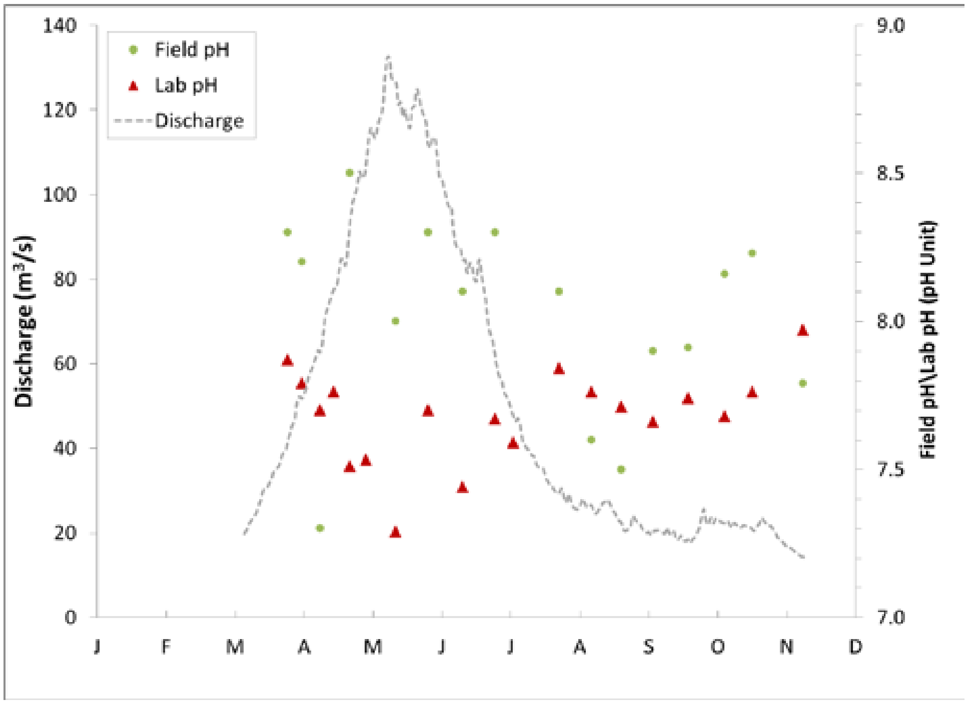
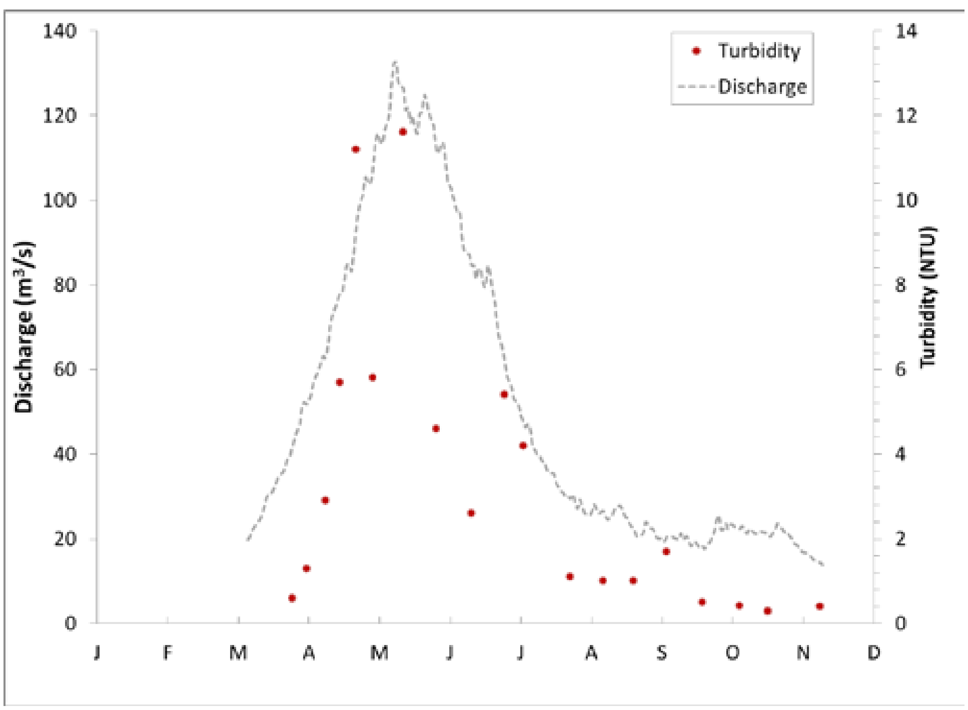


Figure 5-33 Discharge hydrograph (m^3/s) and turbidity (NTU) in the Eagle River



5.1.5 Hummingbird Creek

Figure 5-34 Estimated discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in Hummingbird Creek

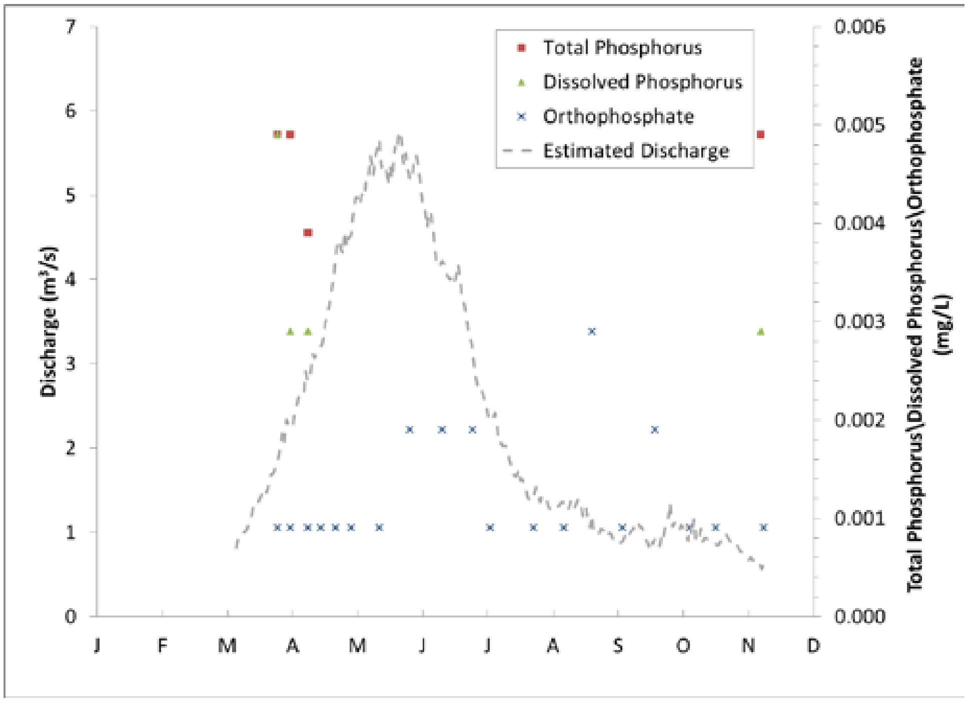


Figure 5-35 Concentration of ammonia and nitrate + nitrite (mg/L) in Hummingbird Creek

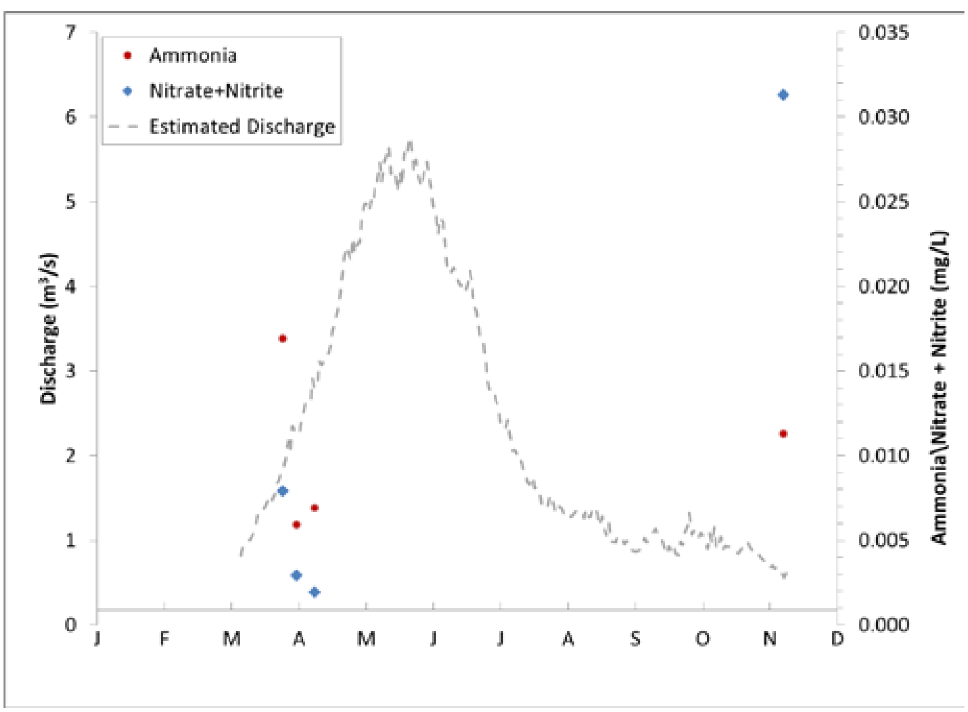


Figure 5-36 Concentration of organic nitrogen and total nitrogen (mg/L) in Hummingbird Creek

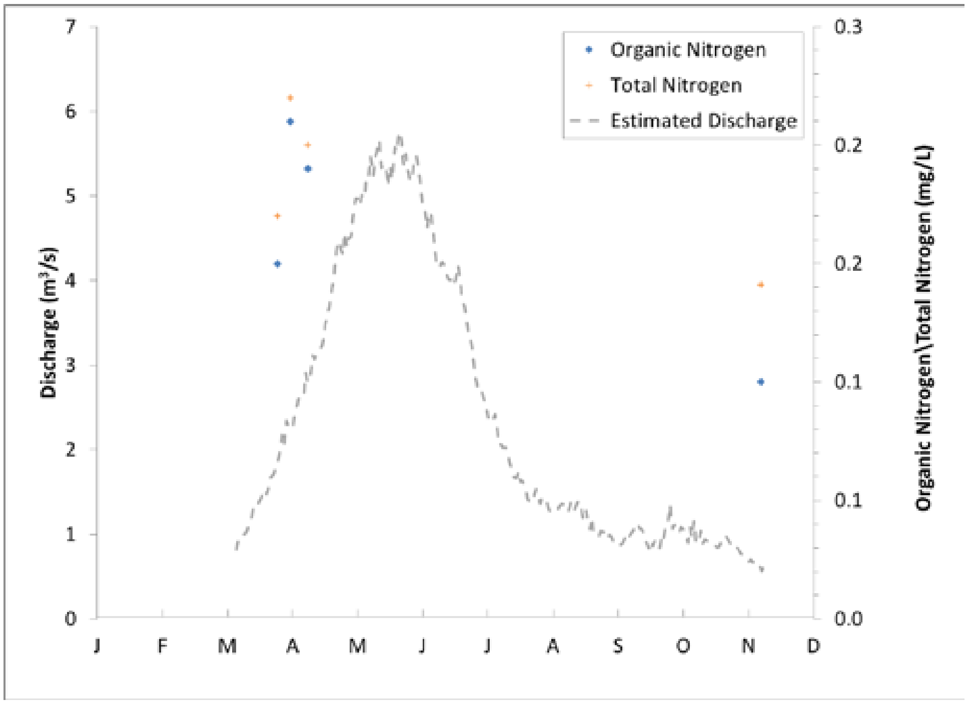


Figure 5-37 Concentration of dissolved organic carbon and total organic carbon (mg/L) in Hummingbird Creek

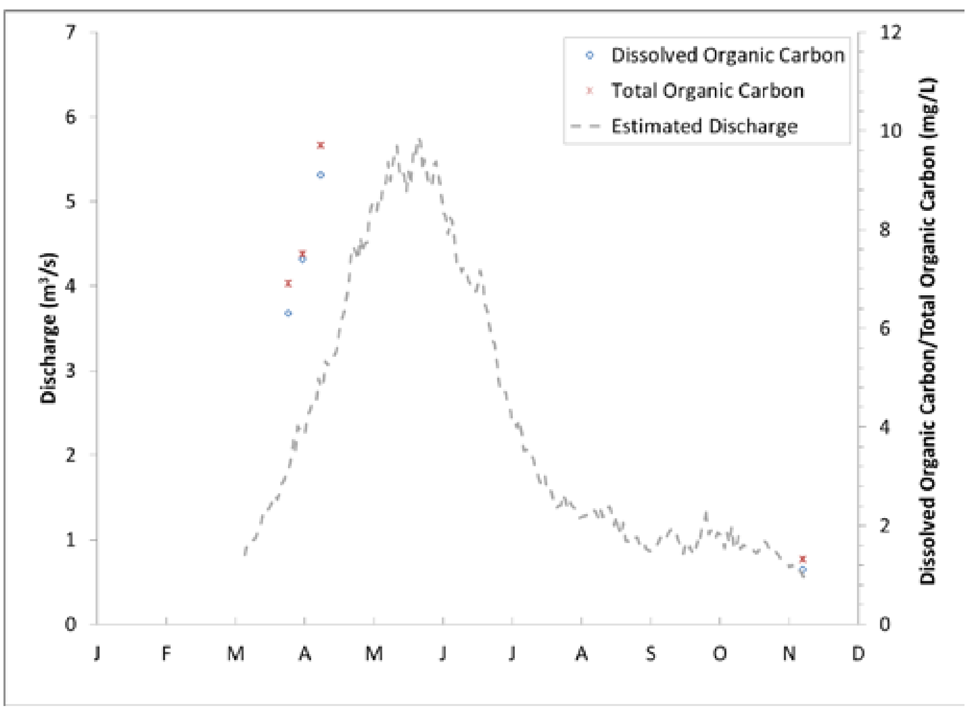


Figure 5-38 Concentration of dissolved chloride (mg/L) in Hummingbird Creek

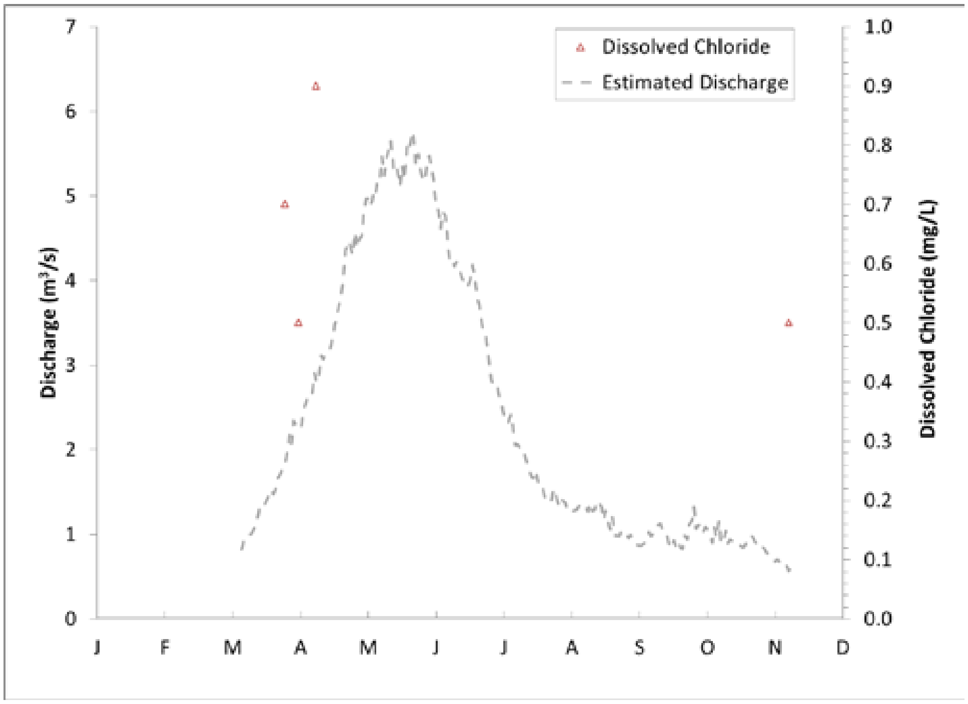


Figure 5-39 Concentration of total suspended solids (mg/L) in Hummingbird Creek

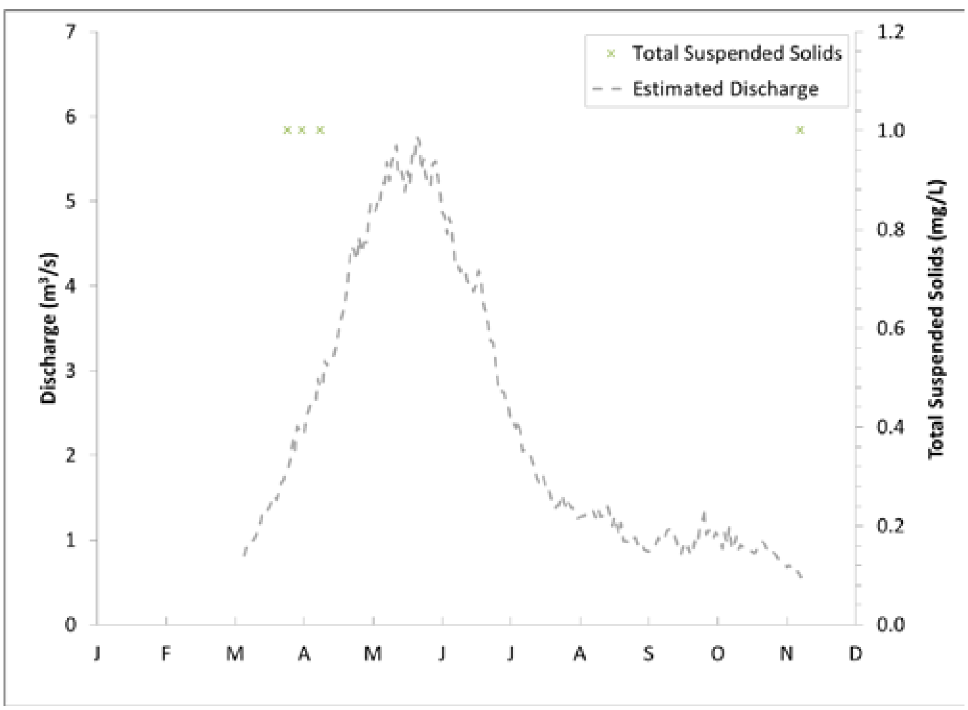


Figure 5-40 pH in Hummingbird Creek

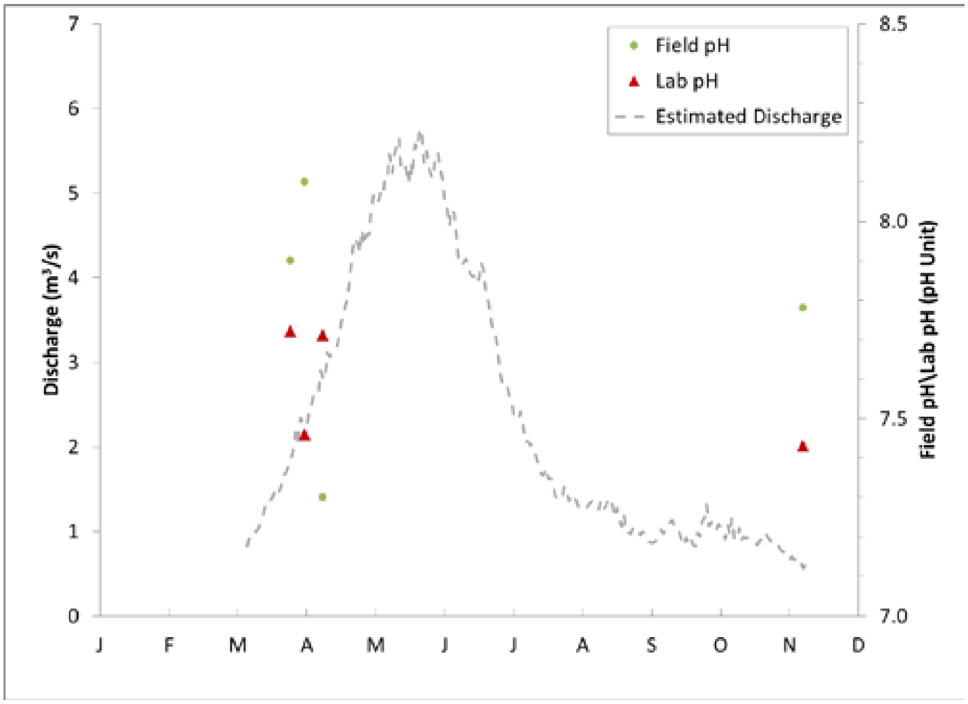
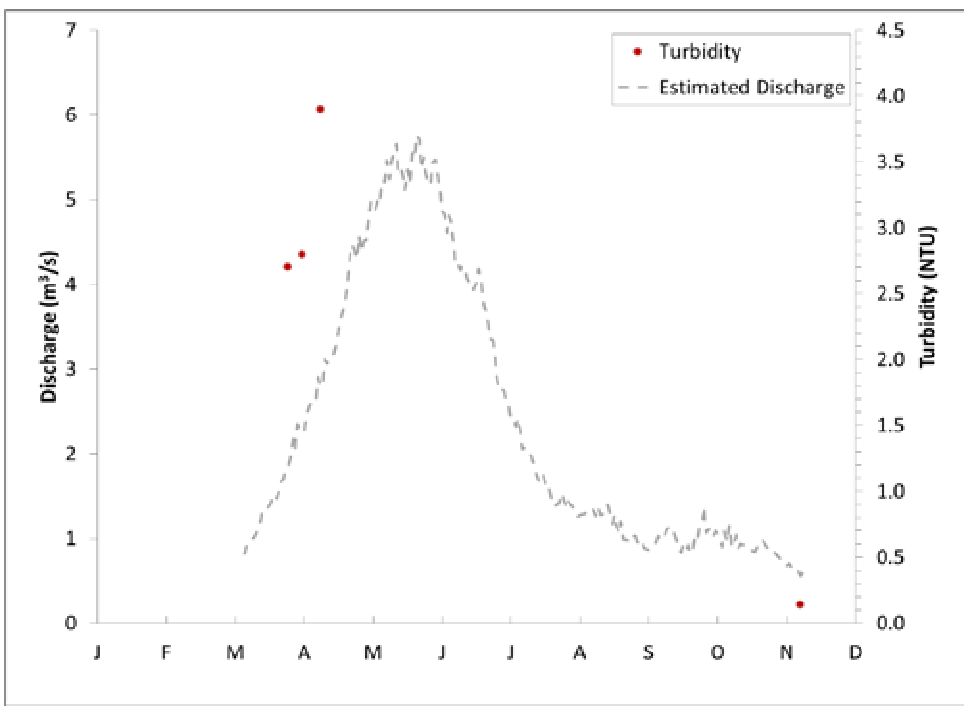


Figure 5-41 Turbidity (NTU) in Hummingbird Creek



5.1.6 Newsome Creek

Figure 5-42 Measured discharge and estimated discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in Newsome Creek

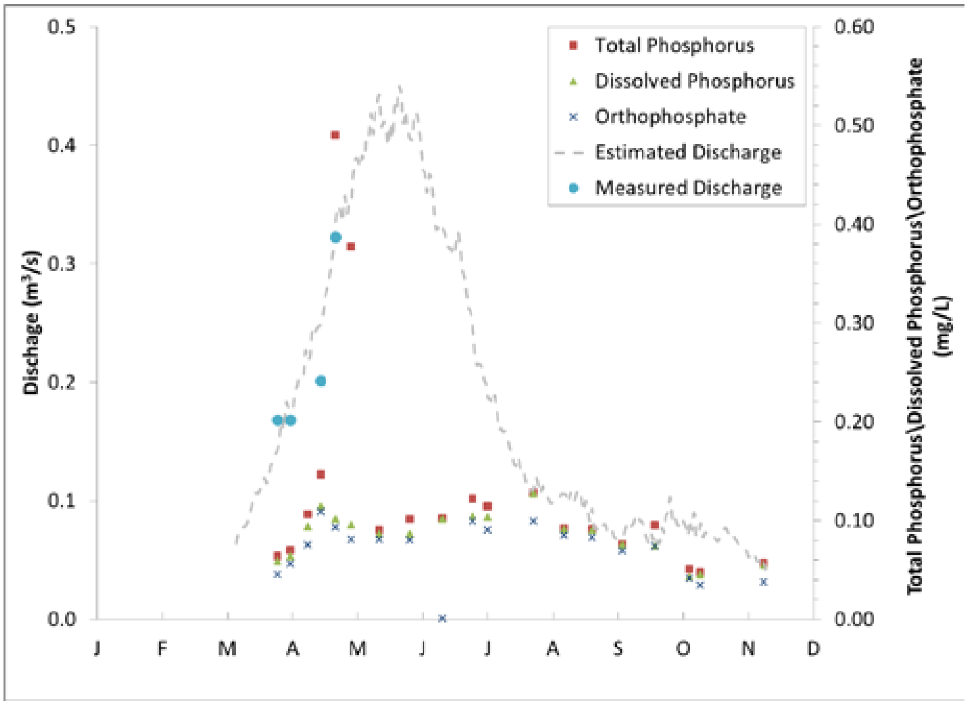


Figure 5-43 Concentration of ammonia and nitrate + nitrite (mg/L) in Newsome Creek

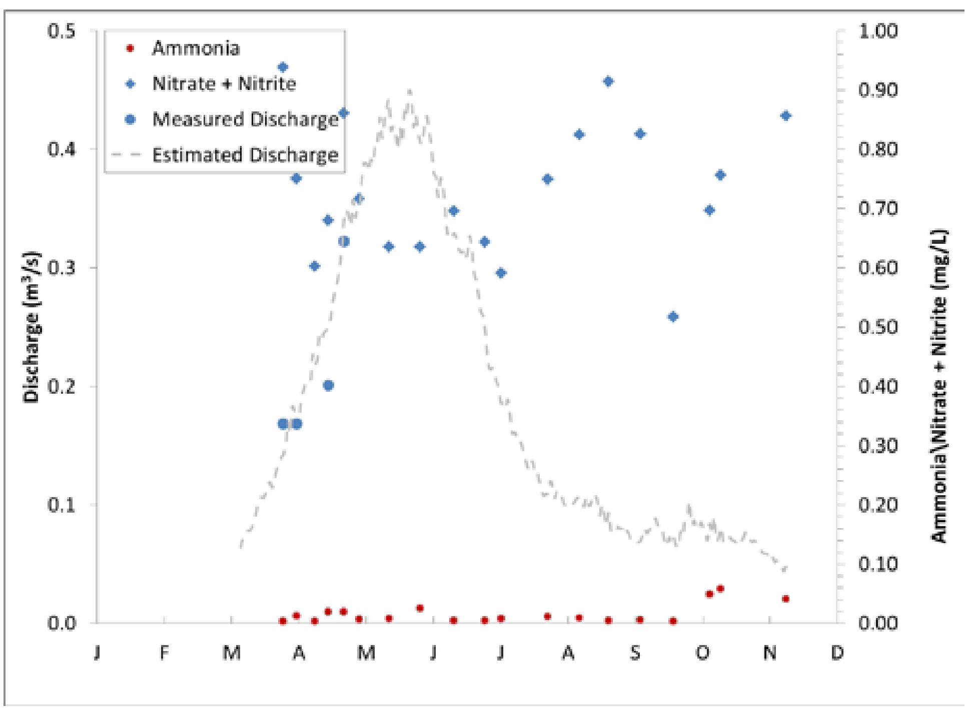


Figure 5-44 Concentration of organic nitrogen and total nitrogen (mg/L) in Newsome Creek

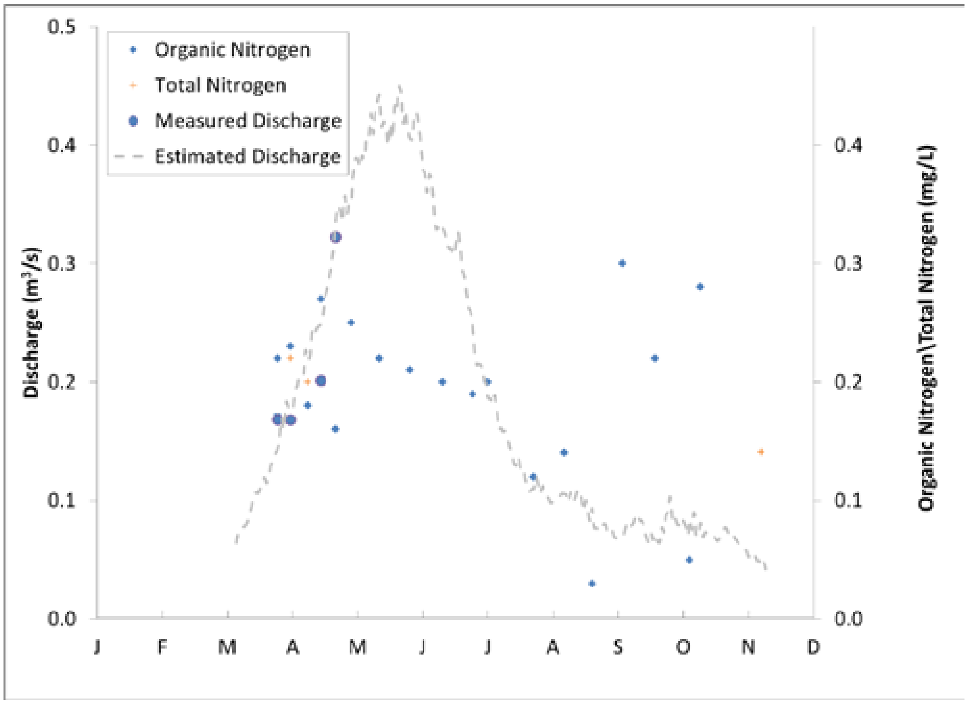


Figure 5-45 Concentration of dissolved organic carbon and total organic carbon (mg/L) in Newsome Creek

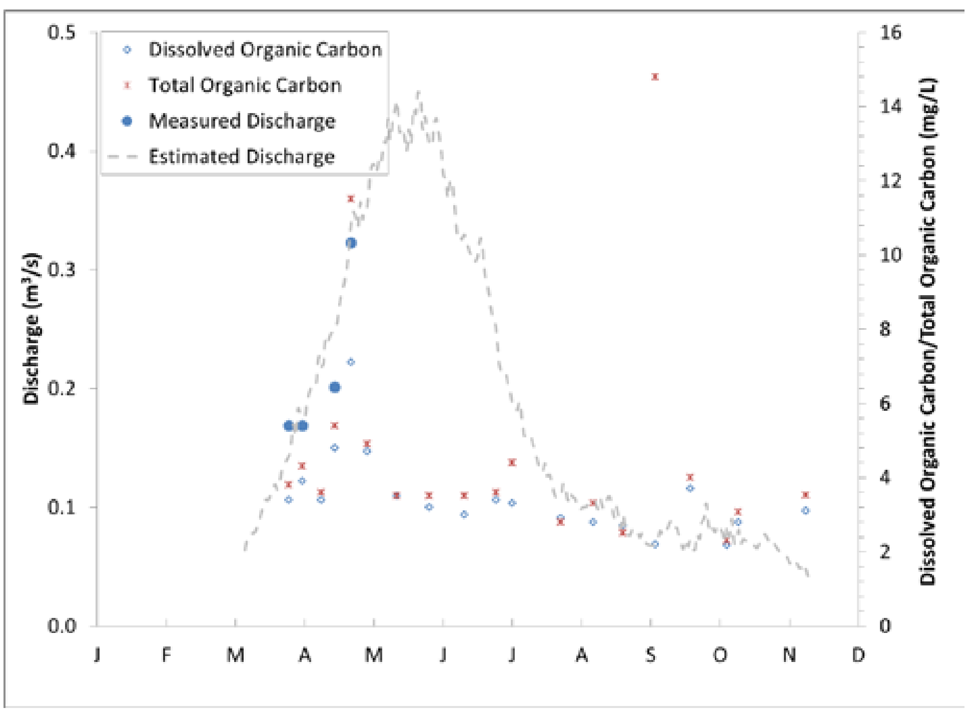


Figure 5-46 Concentration of dissolved chloride (mg/L) in Newsome Creek

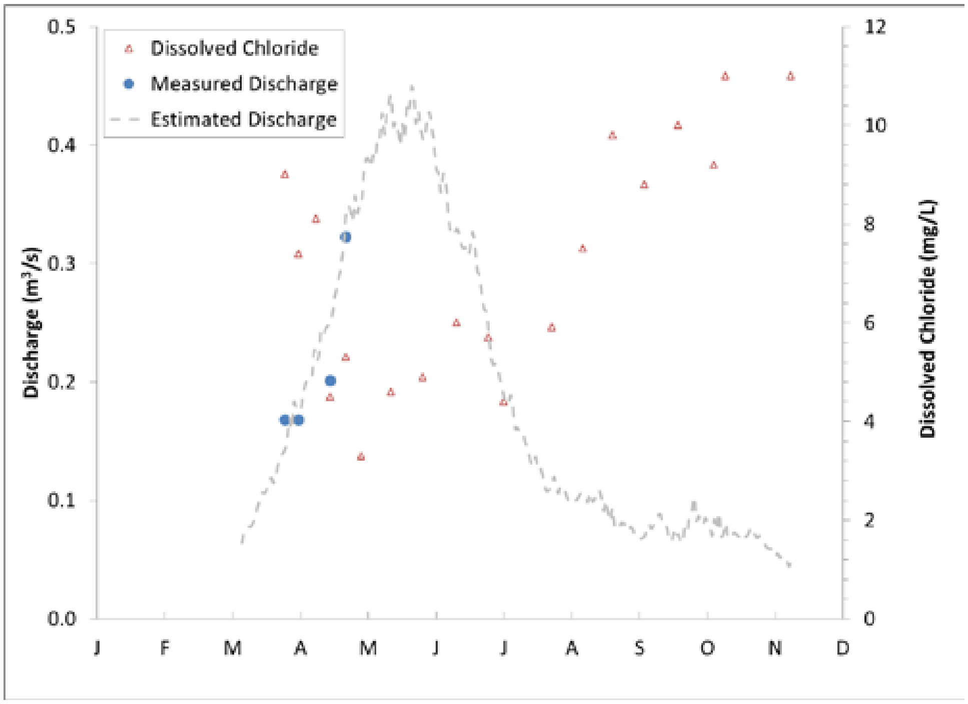


Figure 5-47 Concentration of total suspended solids (mg/L) in Newsome Creek

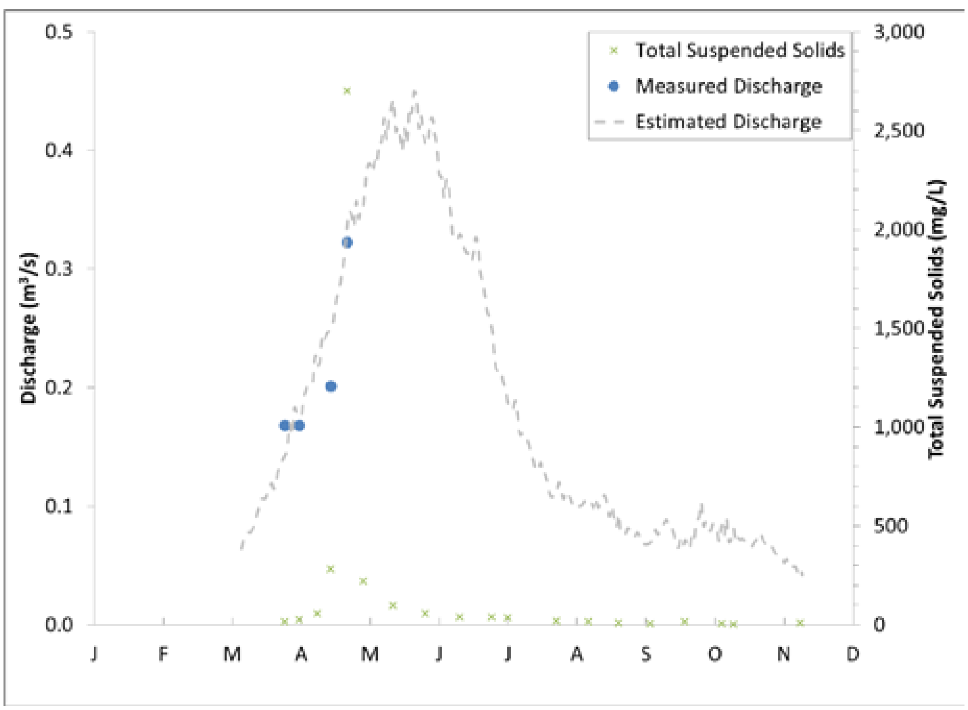


Figure 5-48 pH in Newsome Creek

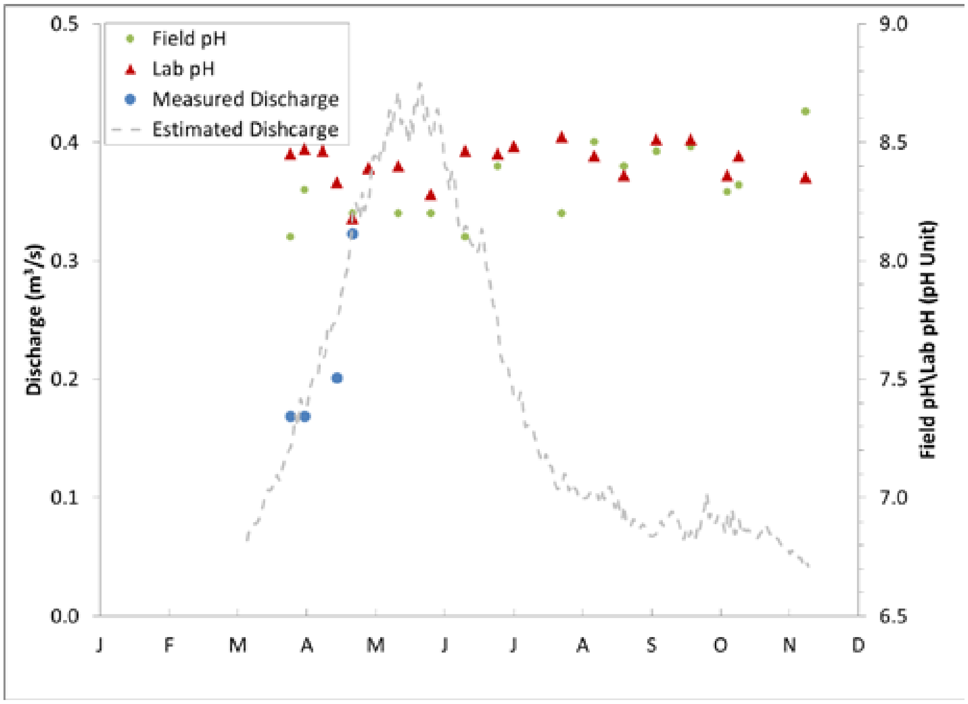
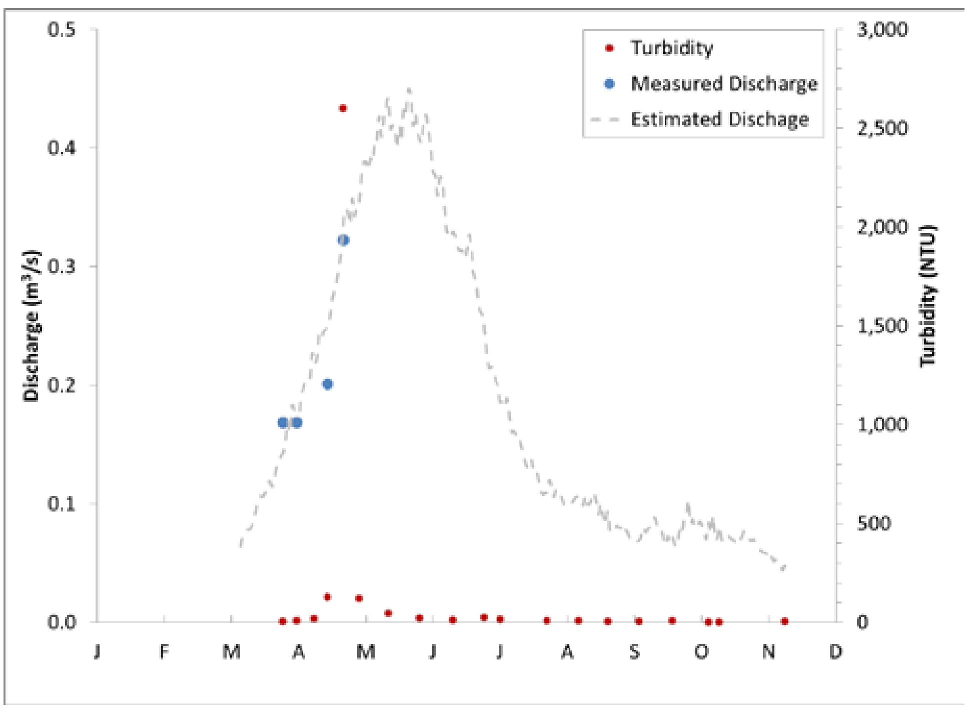


Figure 5-49 Turbidity in Newsome Creek (NTU)



5.1.7 Scotch Creek

Figure 5-50 Estimated discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in Scotch Creek

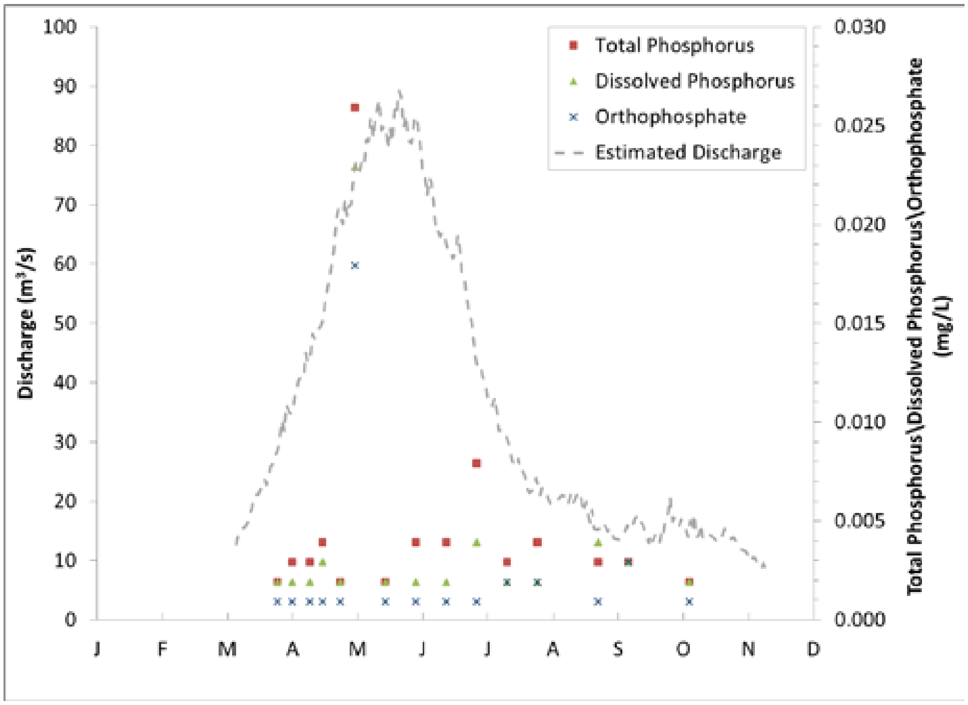


Figure 5-51 Concentration of ammonia and nitrate + nitrite (mg/L) in Scotch Creek

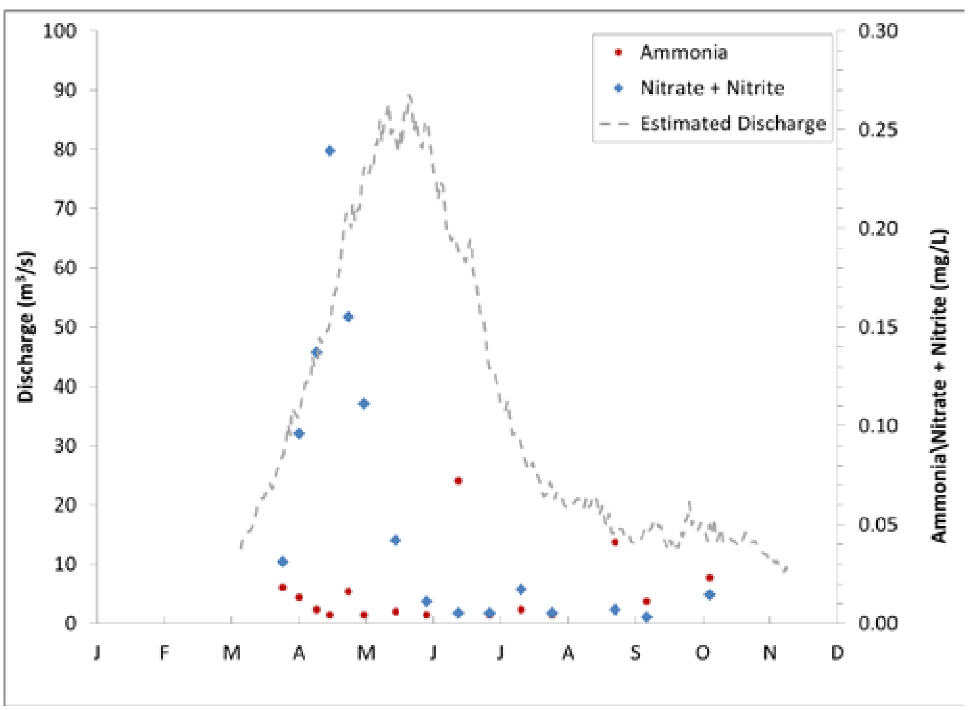


Figure 5-52 Concentration of organic nitrogen and total nitrogen (mg/L) in Scotch Creek

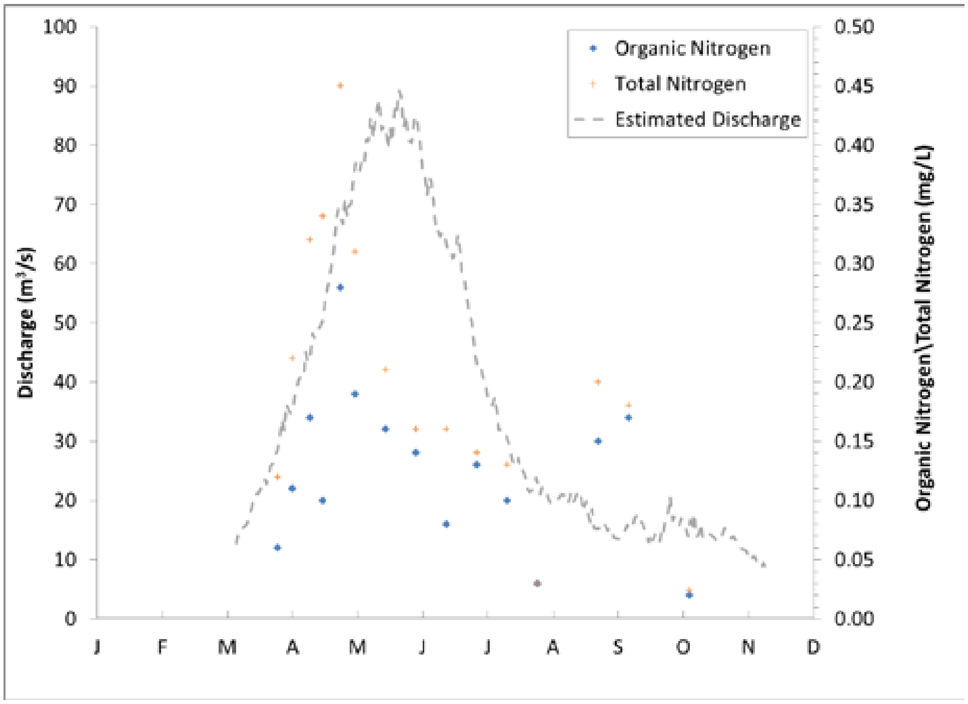


Figure 5-53 Concentration of dissolved organic carbon and total organic carbon (mg/L) in Scotch Creek

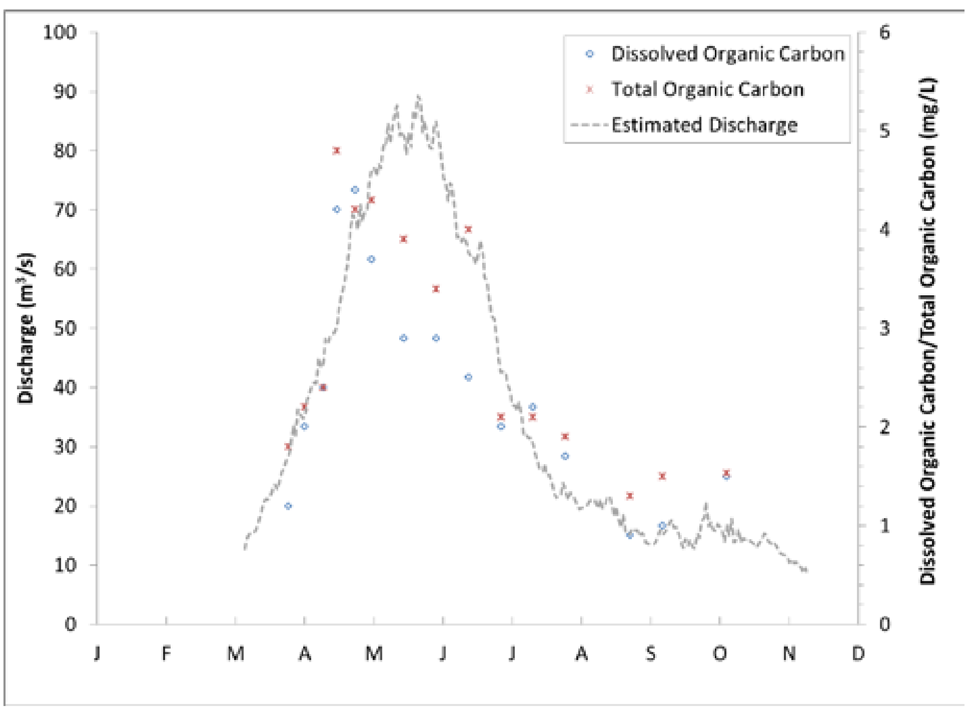


Figure 5-54 Concentration of dissolved chloride (mg/L) in Scotch Creek

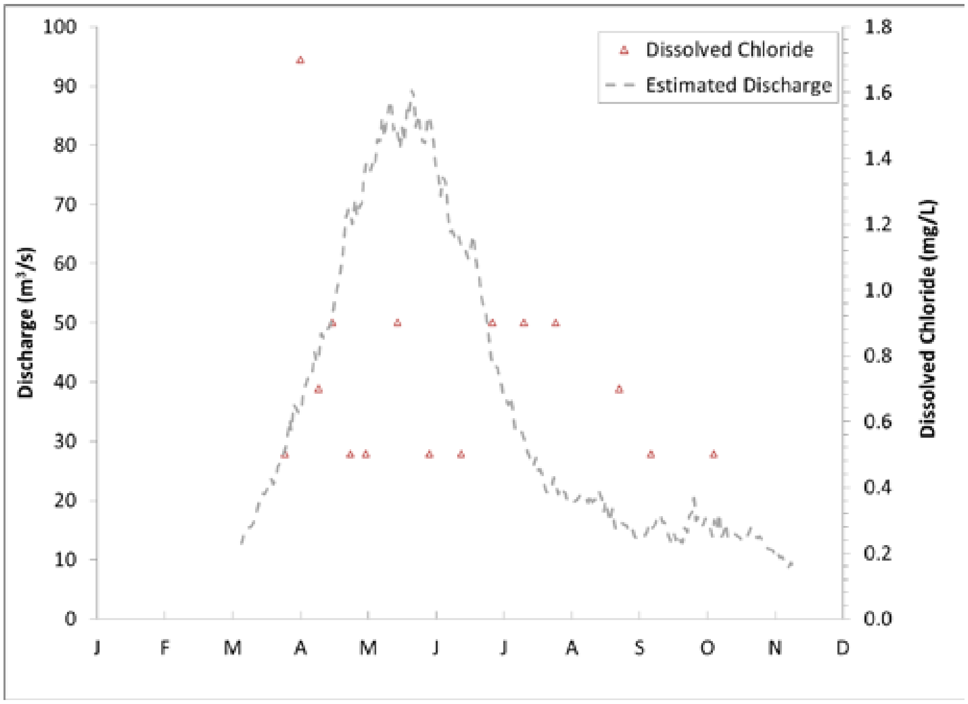


Figure 5-55 Concentration of total suspended solids (mg/L) in Scotch Creek

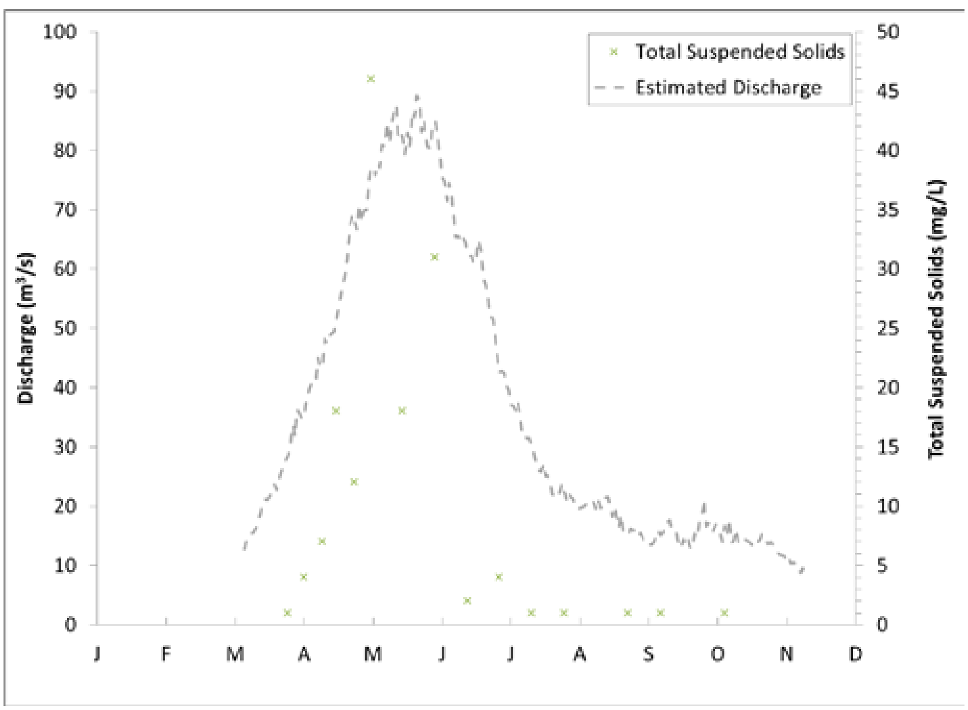


Figure 5-56 pH in Scotch Creek

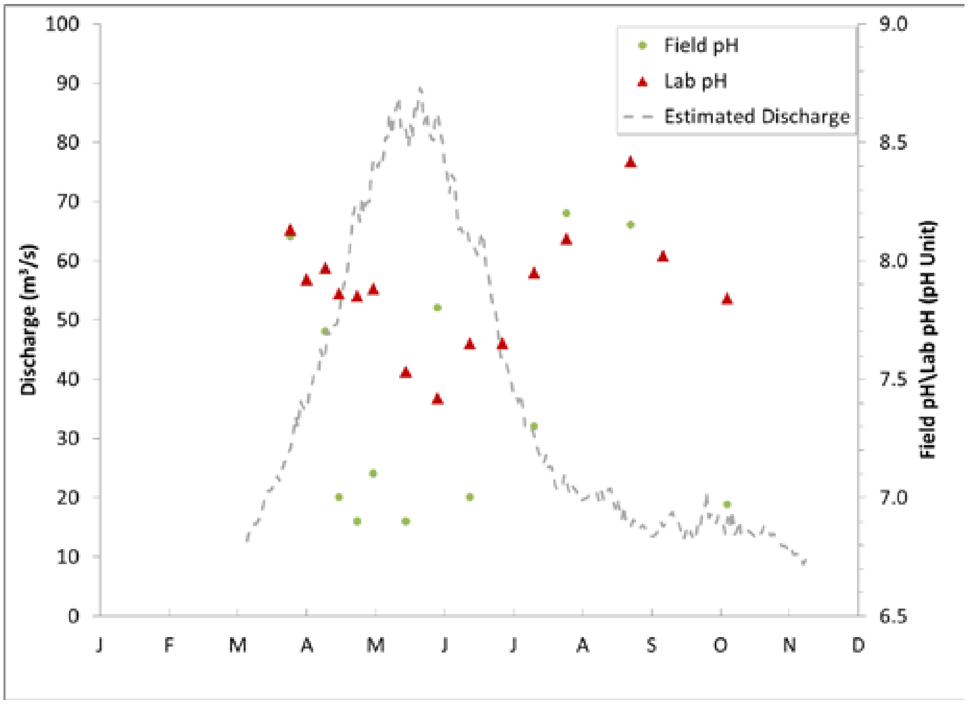
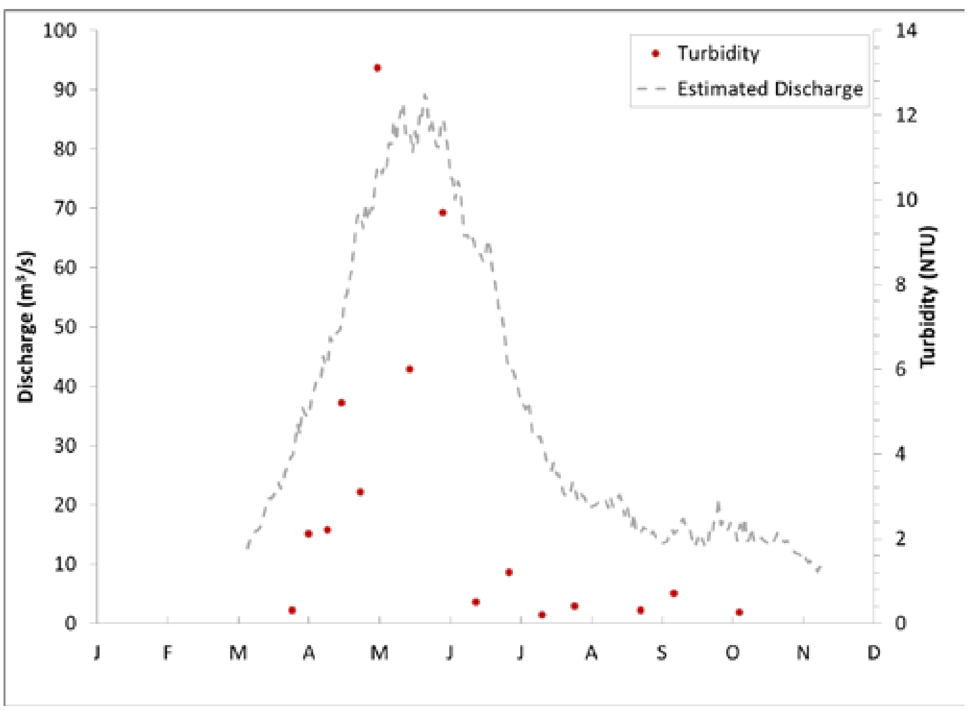


Figure 5-57 Turbidity (NTU) in Scotch Creek



5.1.8 Sicamous River

Figure 5-58 Estimated discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in the Sicamous River

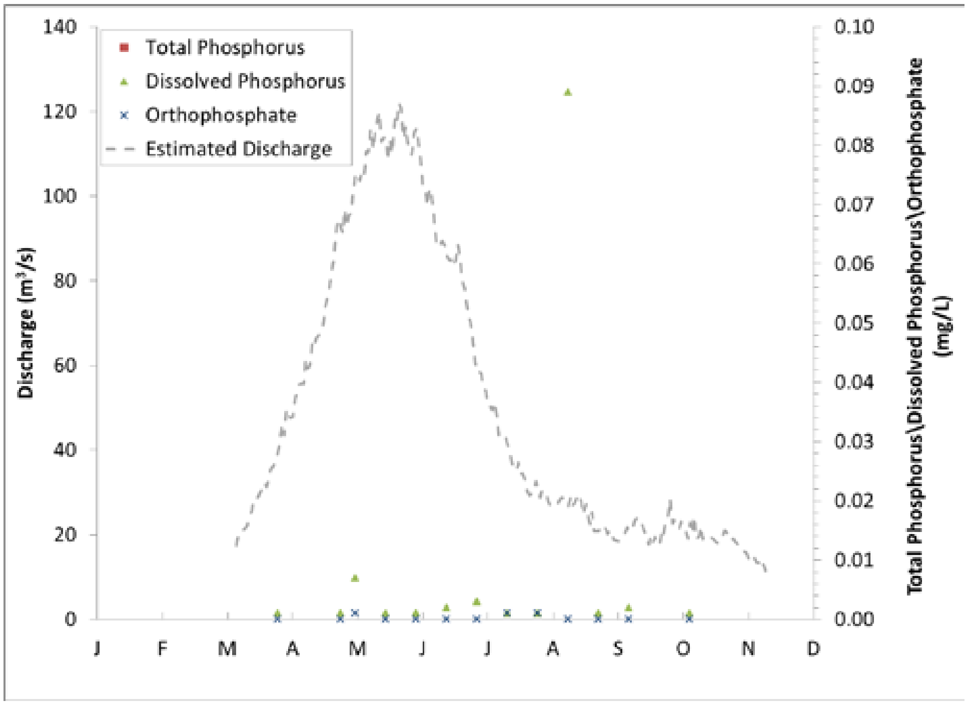


Figure 5-59 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in the Sicamous River

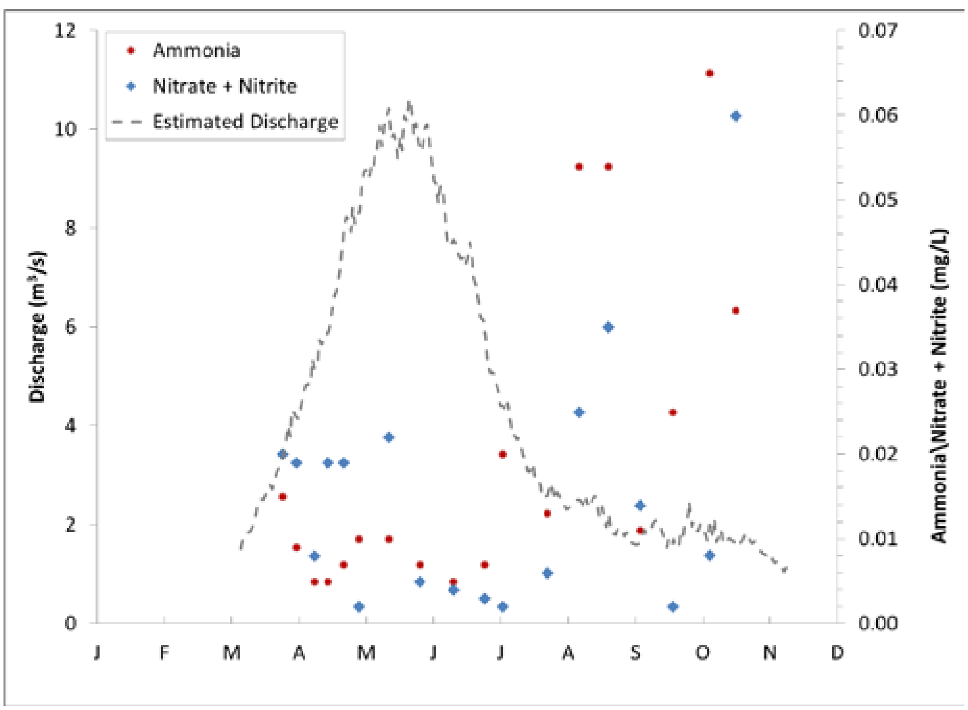


Figure 5-60 Concentration of organic nitrogen and total nitrogen (mg/L) in the Sicamous River

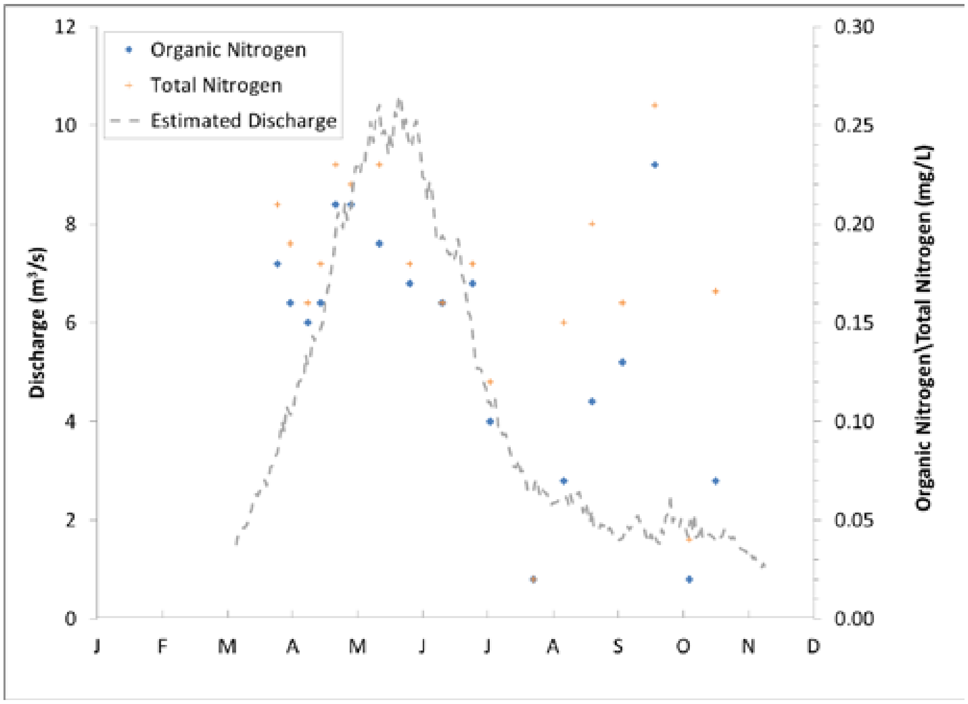


Figure 5-61 Concentration of dissolved organic carbon and total organic carbon (mg/L) in the Sicamous River

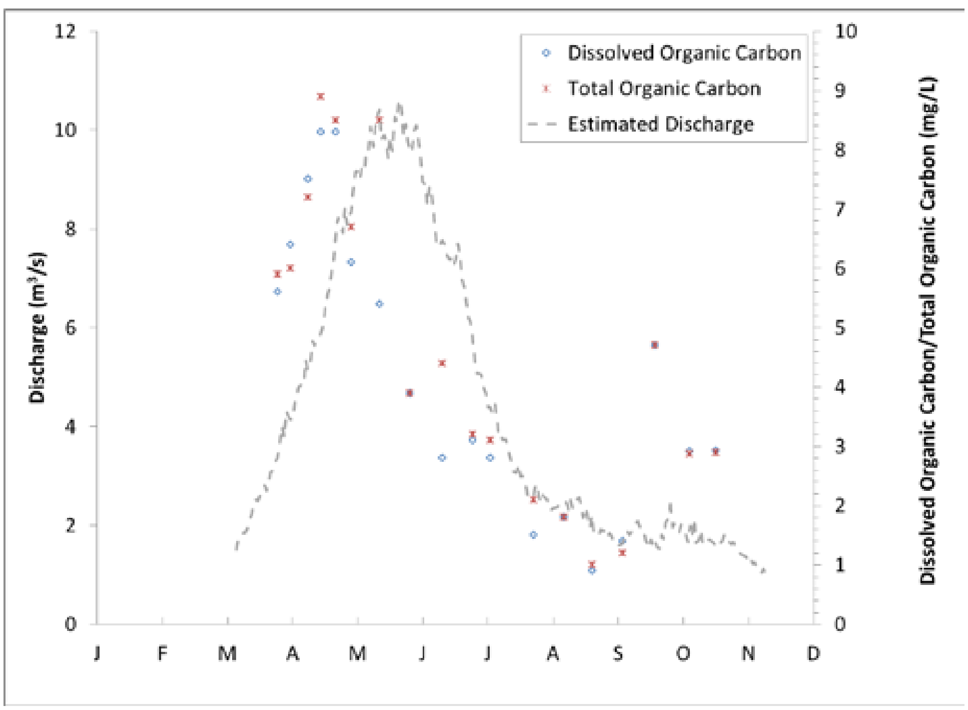


Figure 5-62 Concentration of dissolved chloride (mg/L) in the Sicamous River

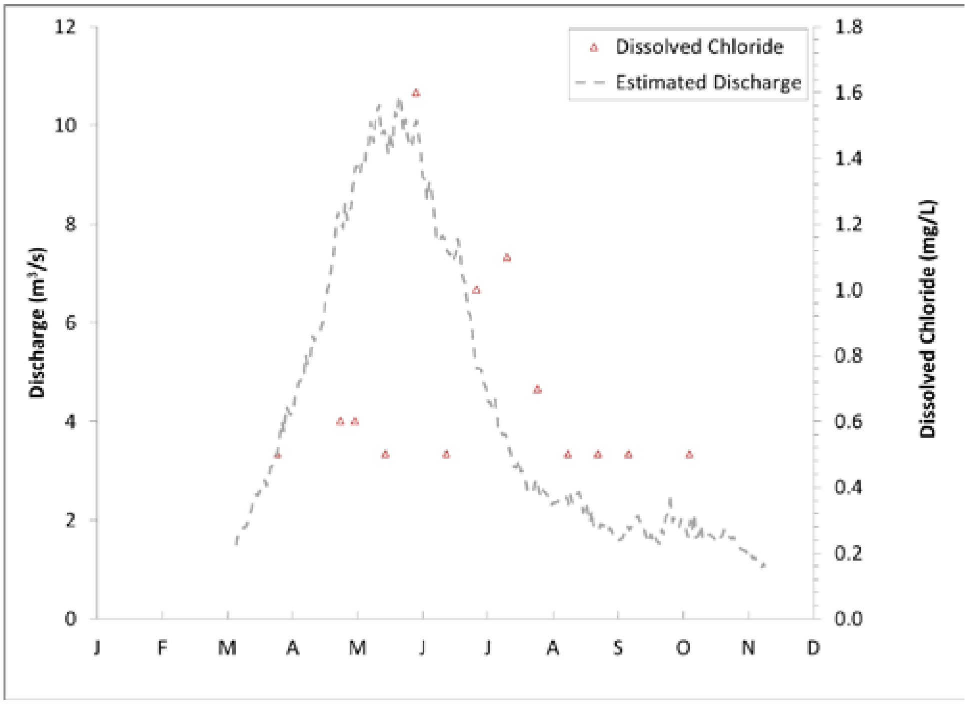


Figure 5-63 Concentration of total suspended solids (mg/L) in the Sicamous River

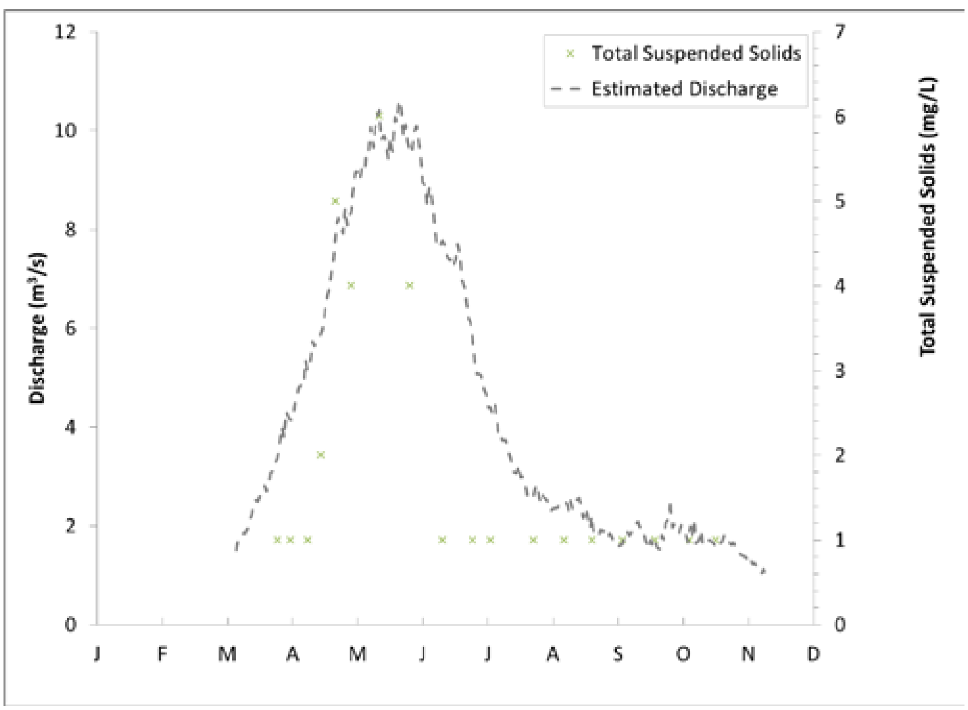


Figure 5-64 pH in the Sicamous River

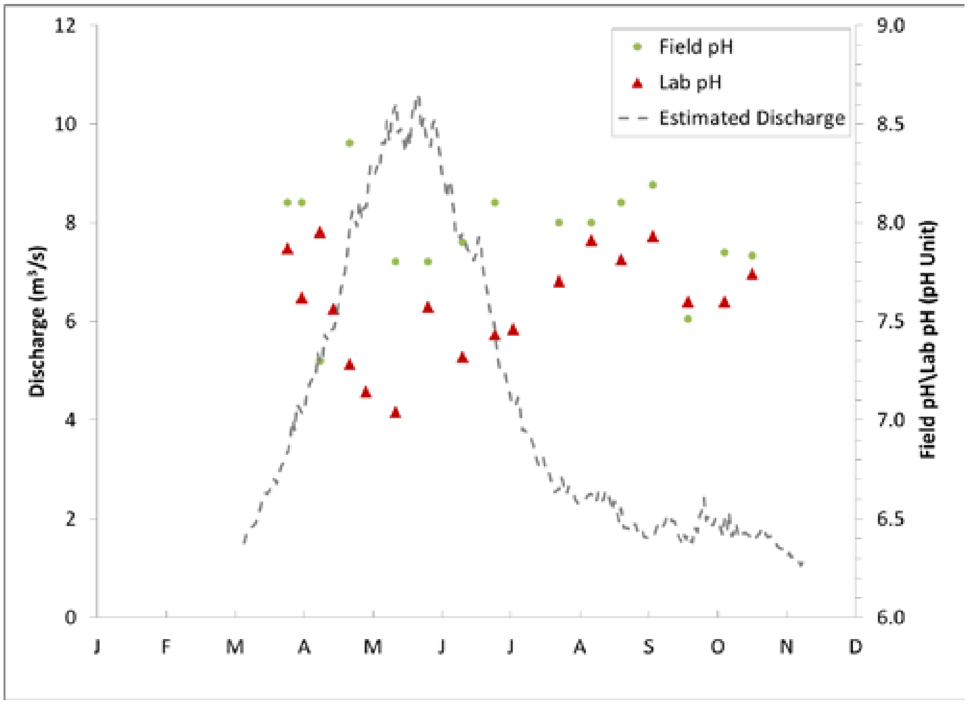
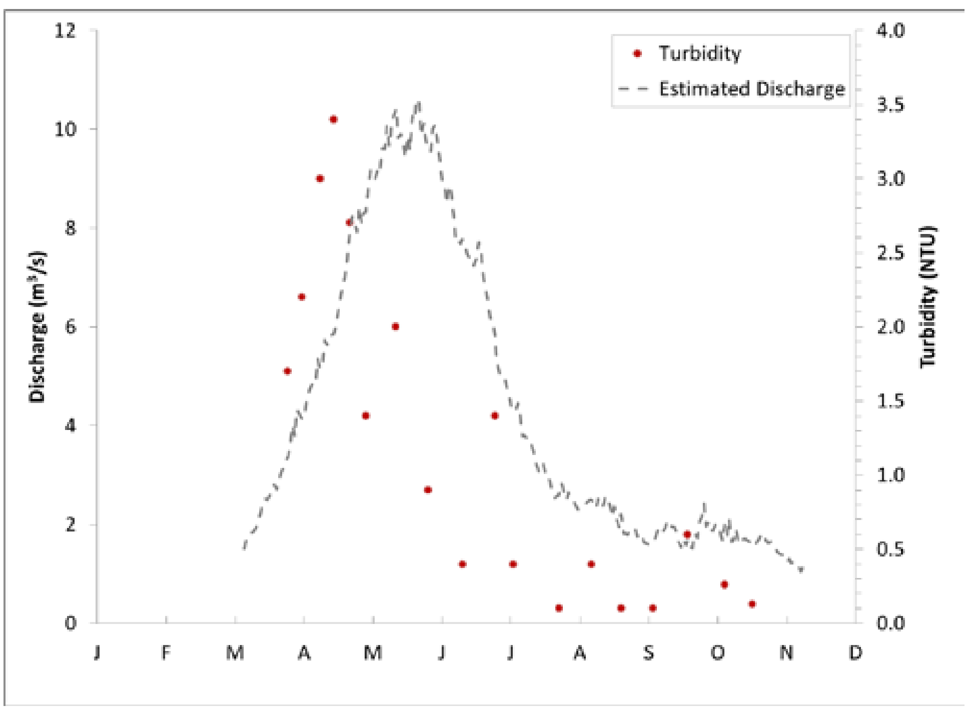


Figure 5-65 Turbidity (NTU) in the Sicamous River



5.1.9 Seymour River

Figure 5-66 Discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in the Seymour River

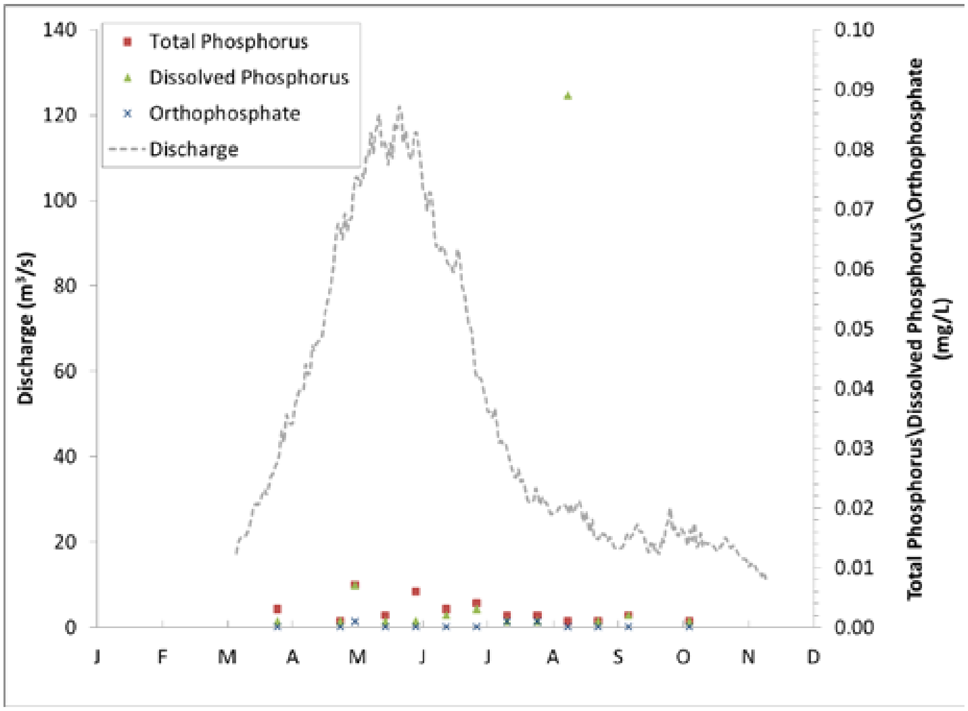


Figure 5-67 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in the Seymour River

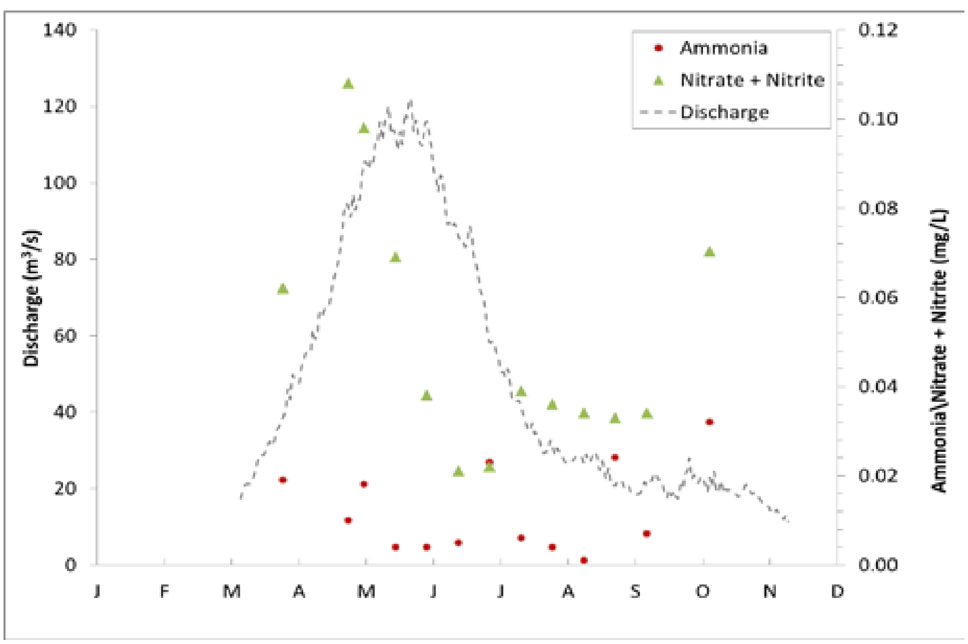


Figure 5-68 Discharge hydrograph (m^3/s) and concentration of organic nitrogen and total nitrogen (mg/L) in the Seymour River

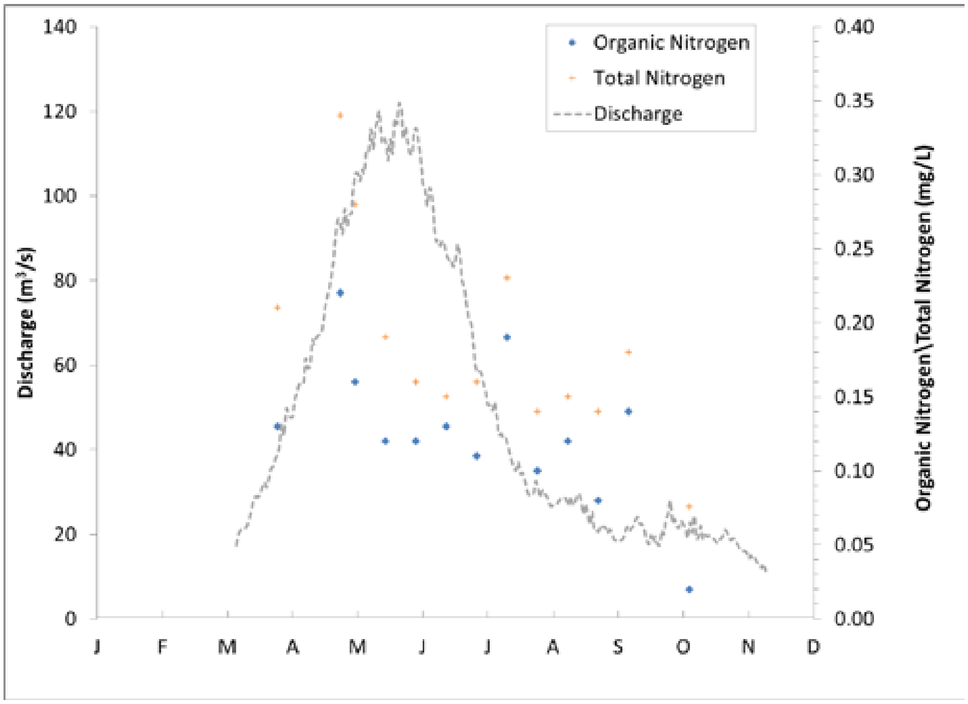


Figure 5-69 Discharge hydrograph (m^3/s) and concentration of dissolved organic carbon and total organic carbon (mg/L) in the Seymour River

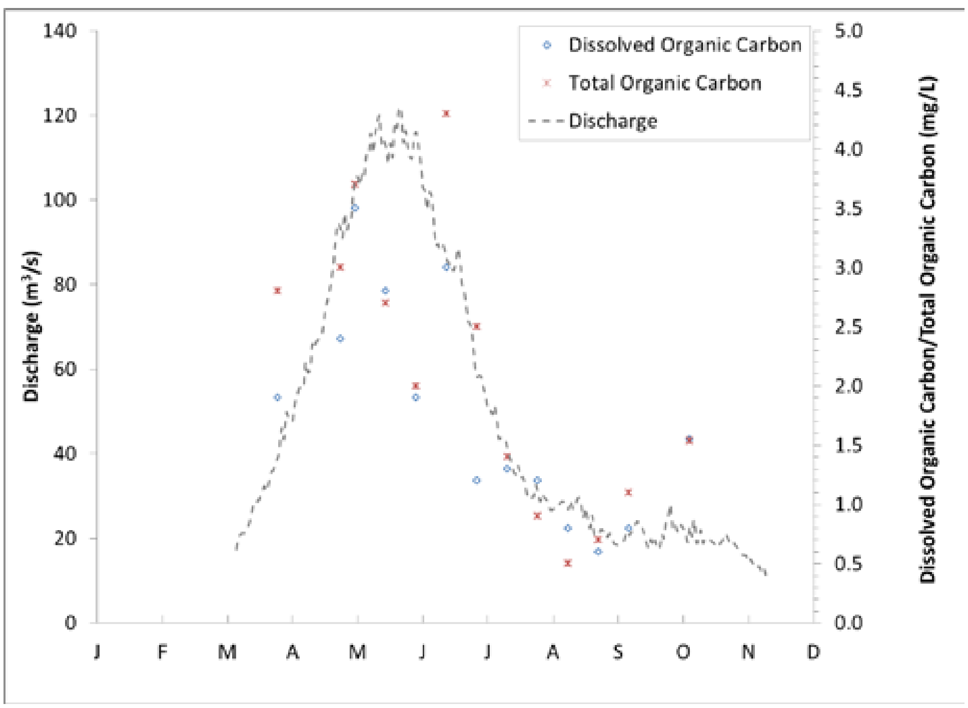


Figure 5-70 Discharge hydrograph (m^3/s) and concentration of dissolved chloride (mg/L) in the Seymour River

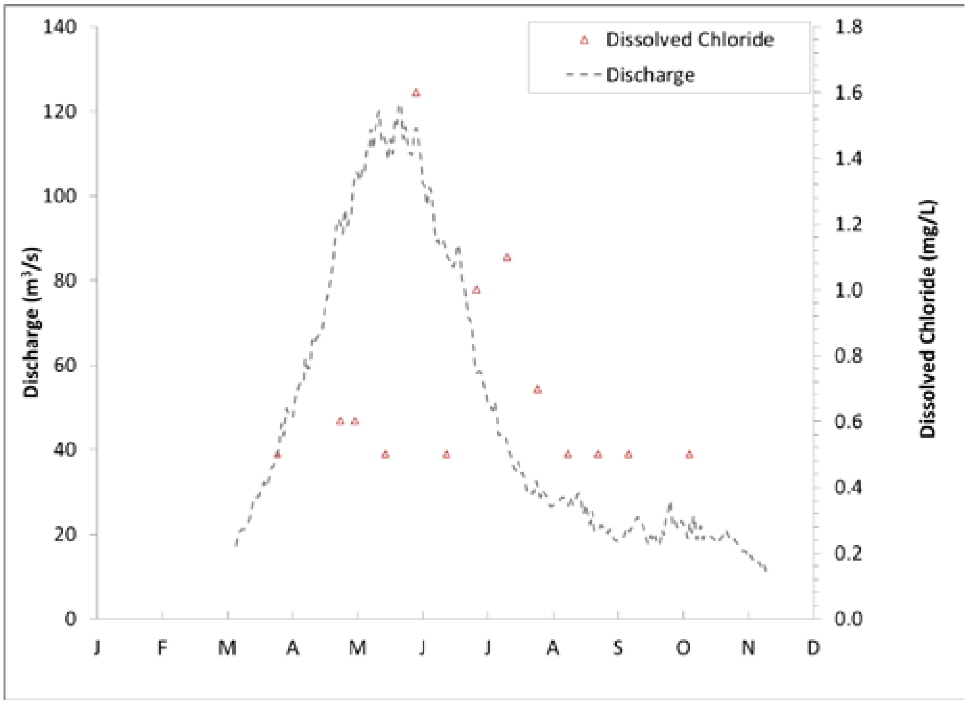


Figure 5-71 Discharge hydrograph (m^3/s) and concentration of total suspended solids (mg/L) in the Seymour River

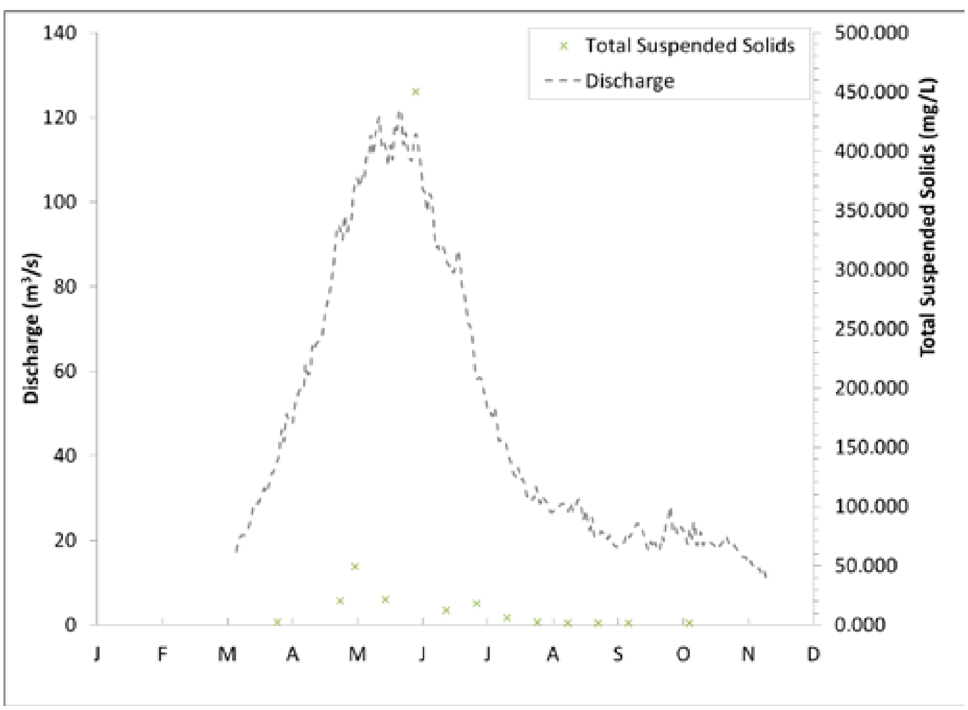


Figure 5-72 Discharge hydrograph (m^3/s) and pH in the Seymour River

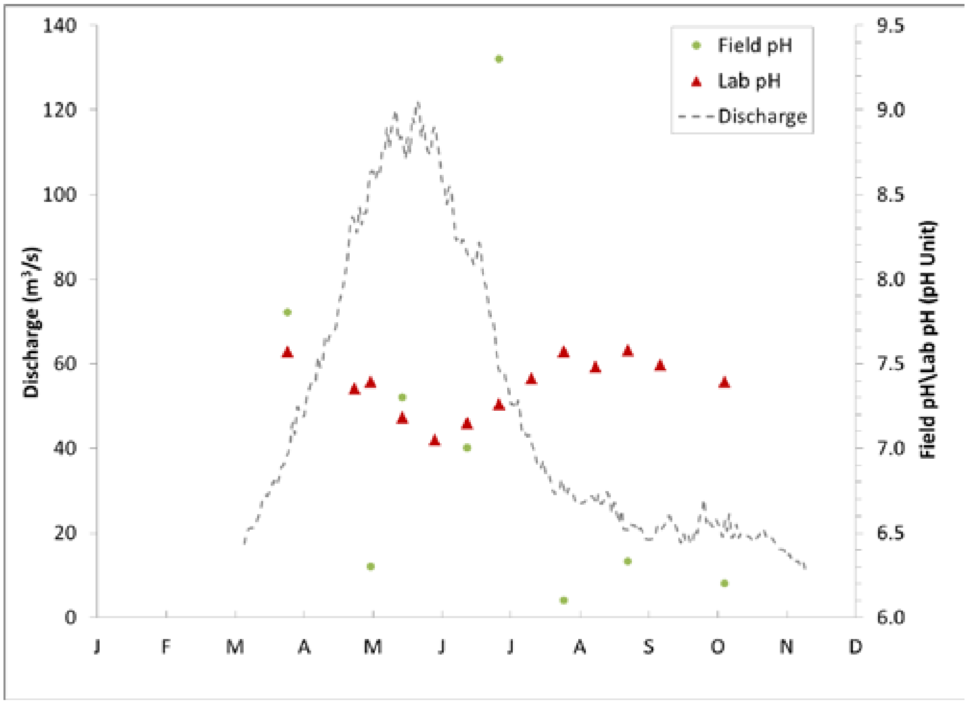
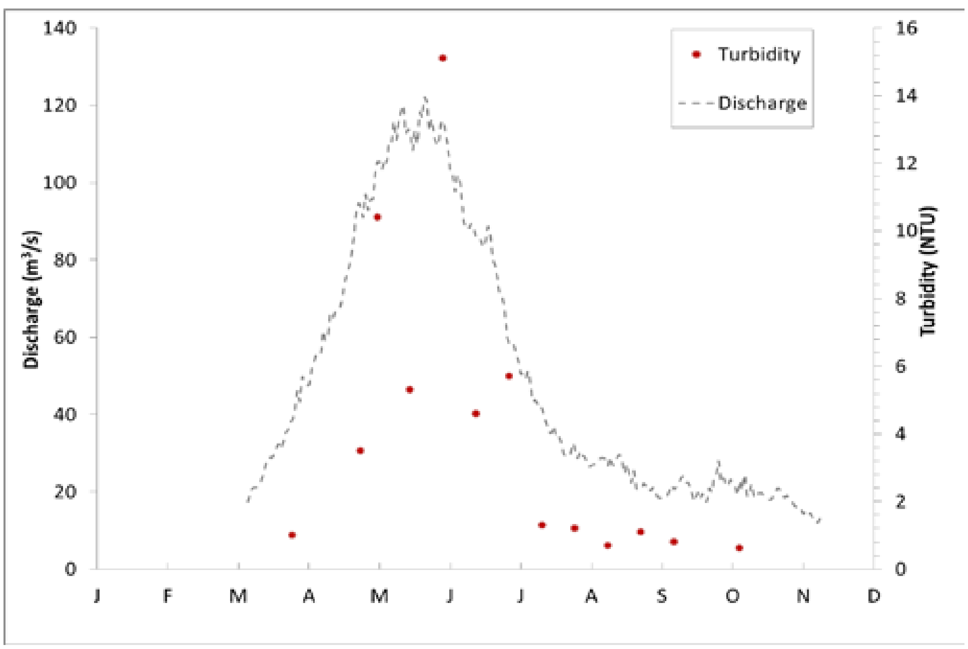


Figure 5-73 Discharge hydrograph (m^3/s) and turbidity (NTU) in the Seymour River



5.1.10 Tappen Creek

Figure 5-74 Discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in Tappen Creek

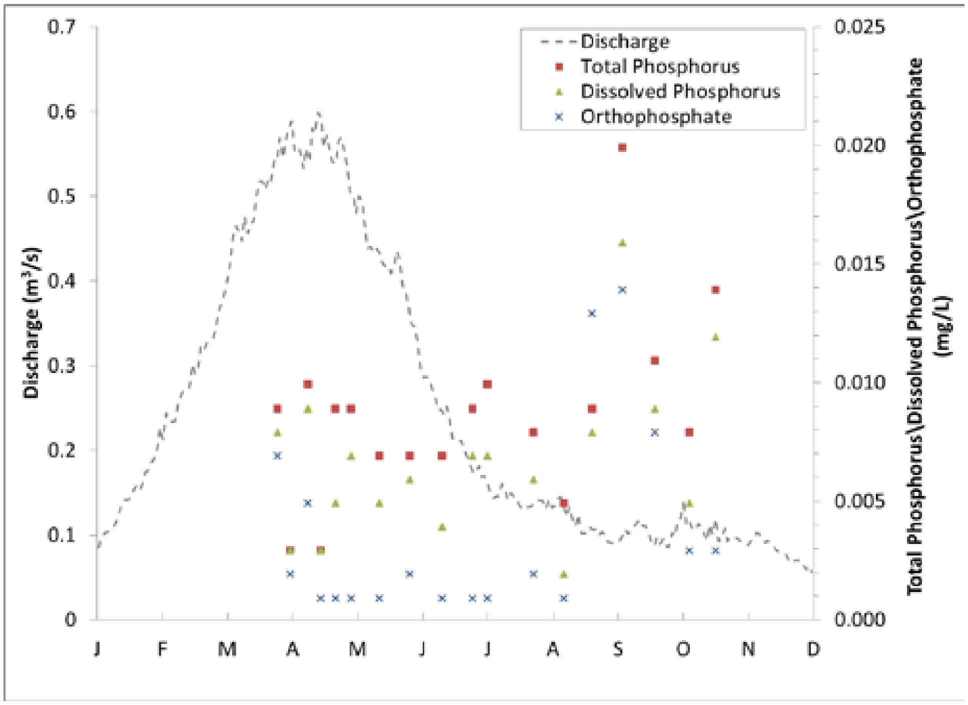


Figure 5-75 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in Tappen Creek

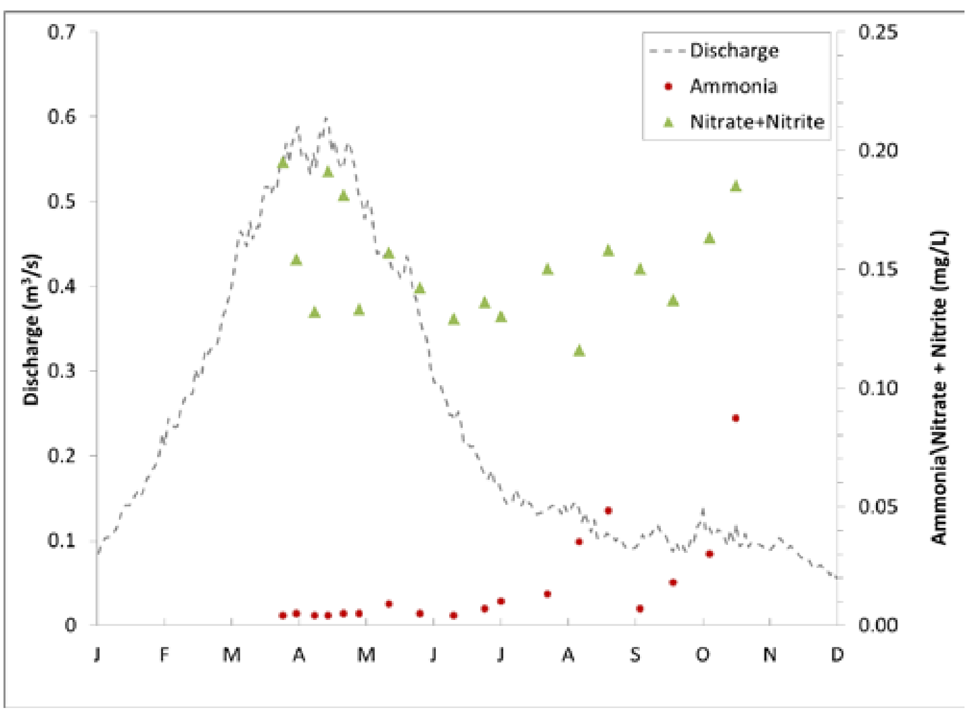


Figure 5-76 Concentration of organic nitrogen and total nitrogen (mg/L) in Tappen Creek

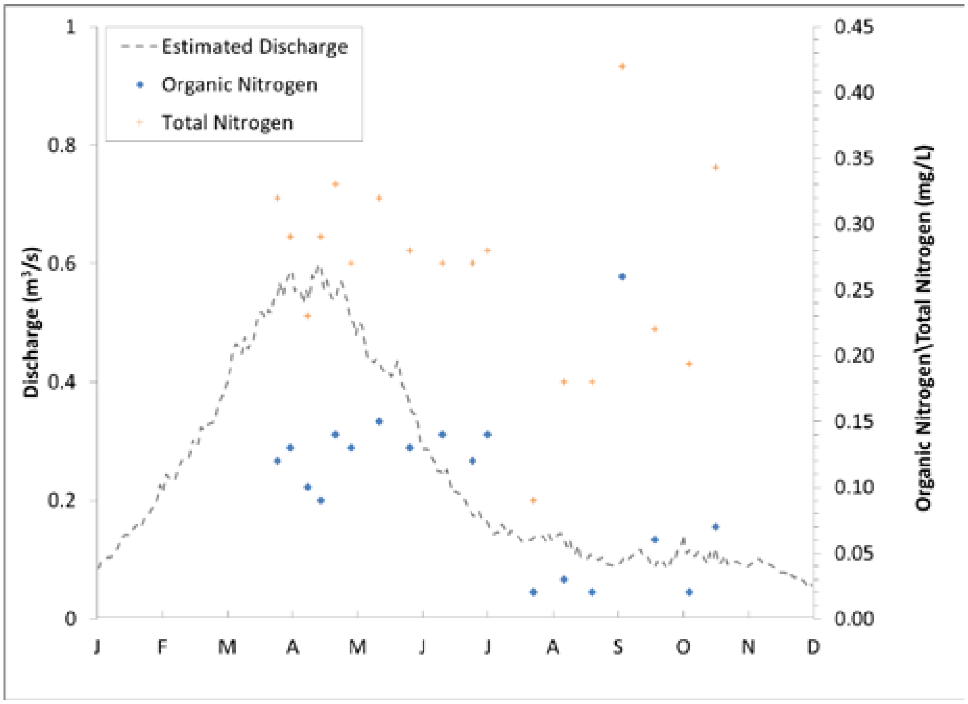


Figure 5-77 Concentration of dissolved organic carbon and total organic carbon (mg/L) in Tappen Creek

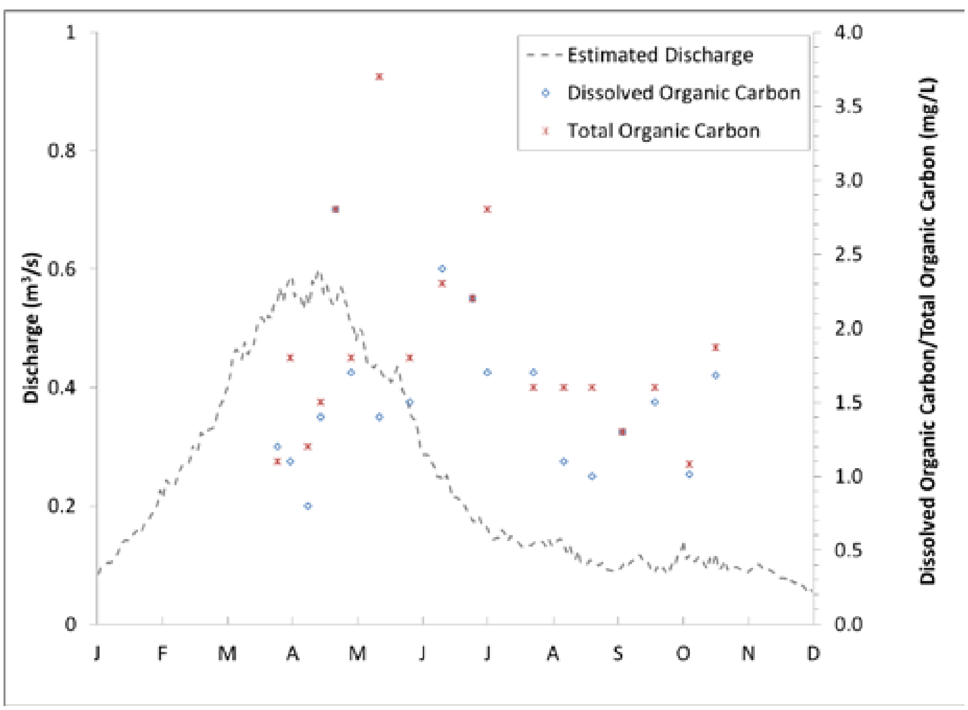


Figure 5-78 Concentration of dissolved chloride (mg/L) in Tappen Creek

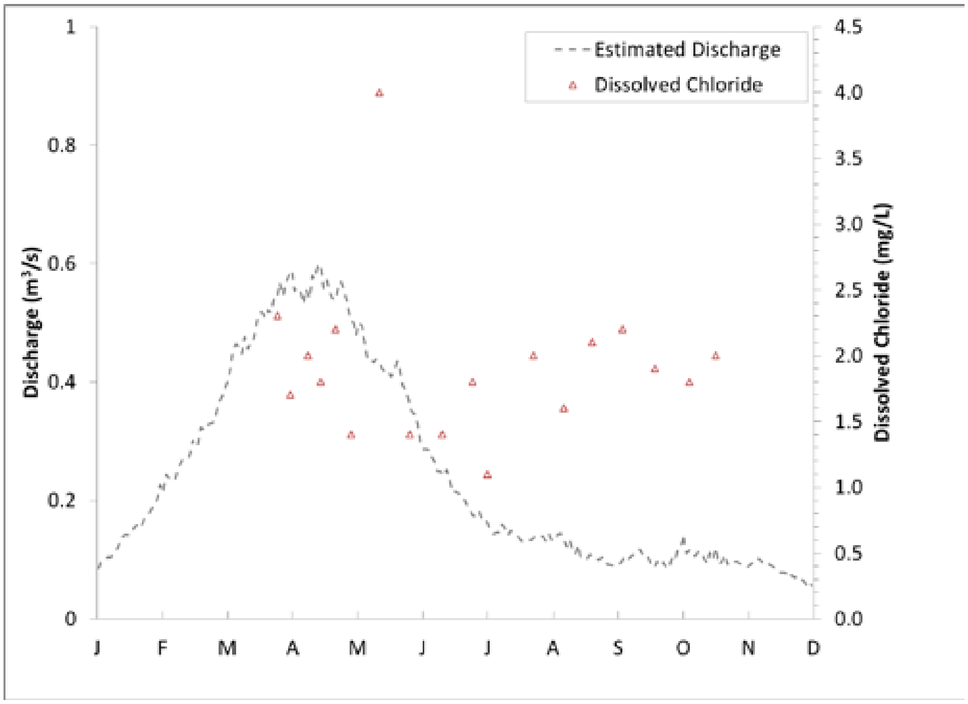


Figure 5-79 Concentration of total suspended solids (mg/L) in Tappen Creek

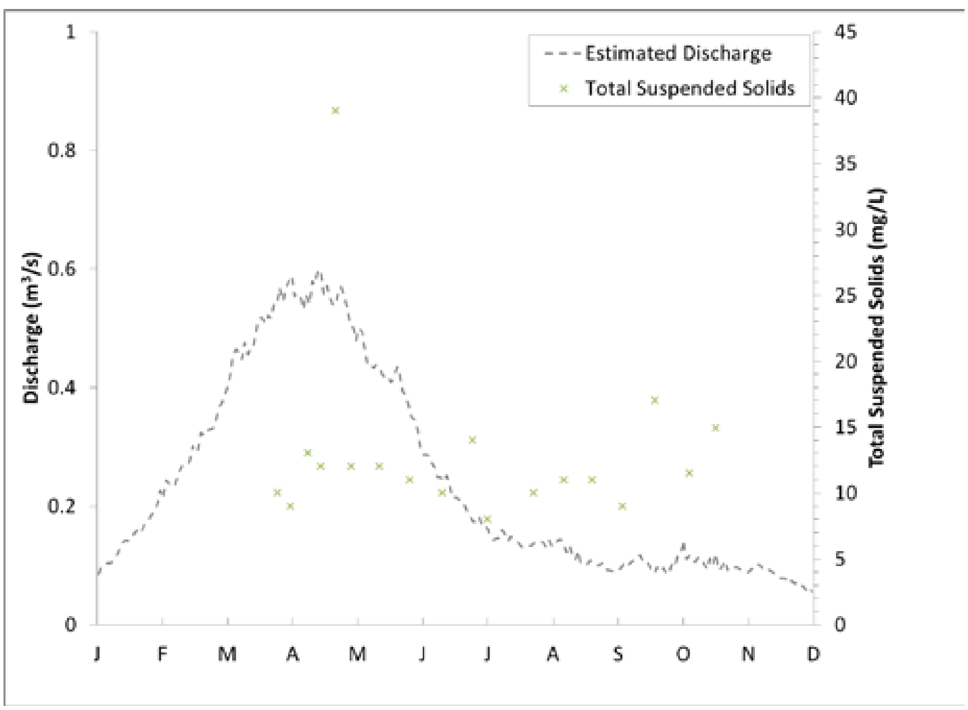


Figure 5-80 pH in Tappen Creek

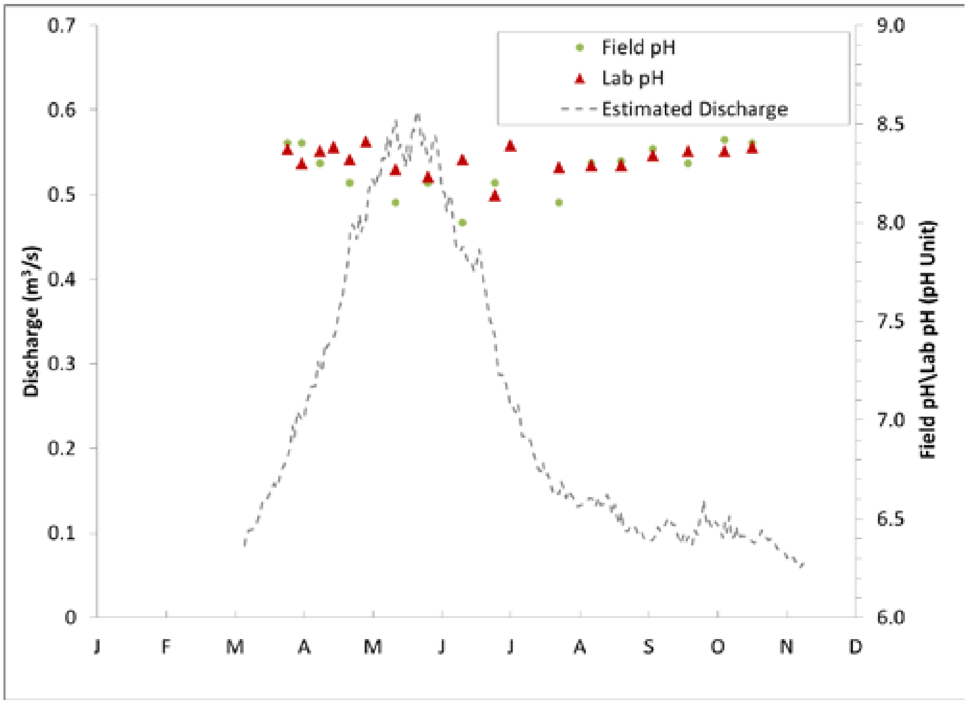
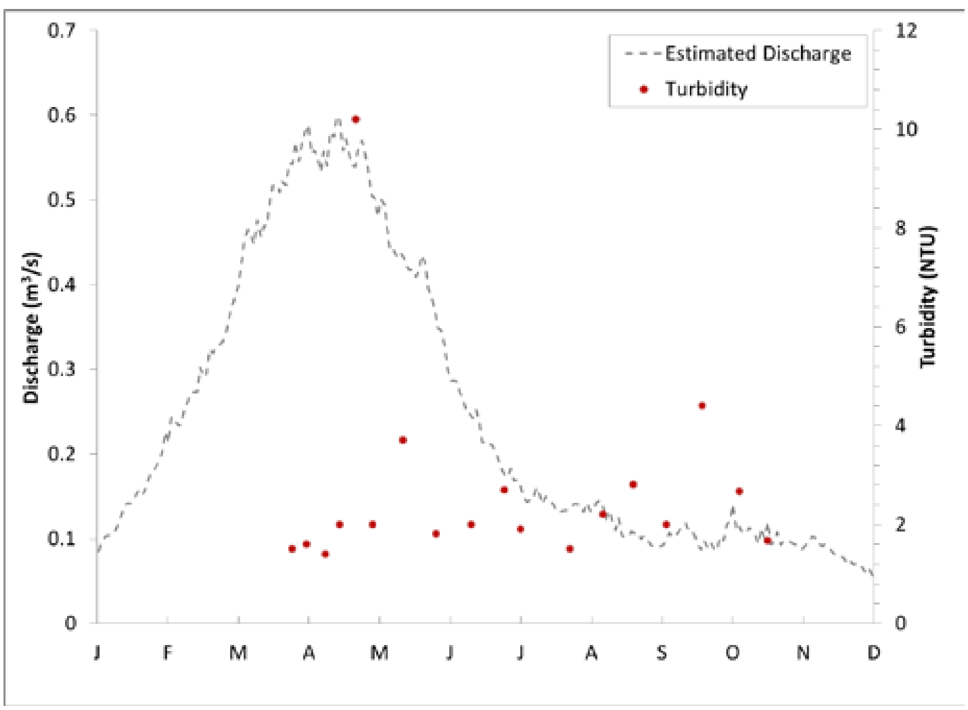


Figure 5-81 Turbidity (NTU) in Tappen Creek



5.1.11 White Creek

Figure 5-82 Measured discharge and estimated discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in White Creek

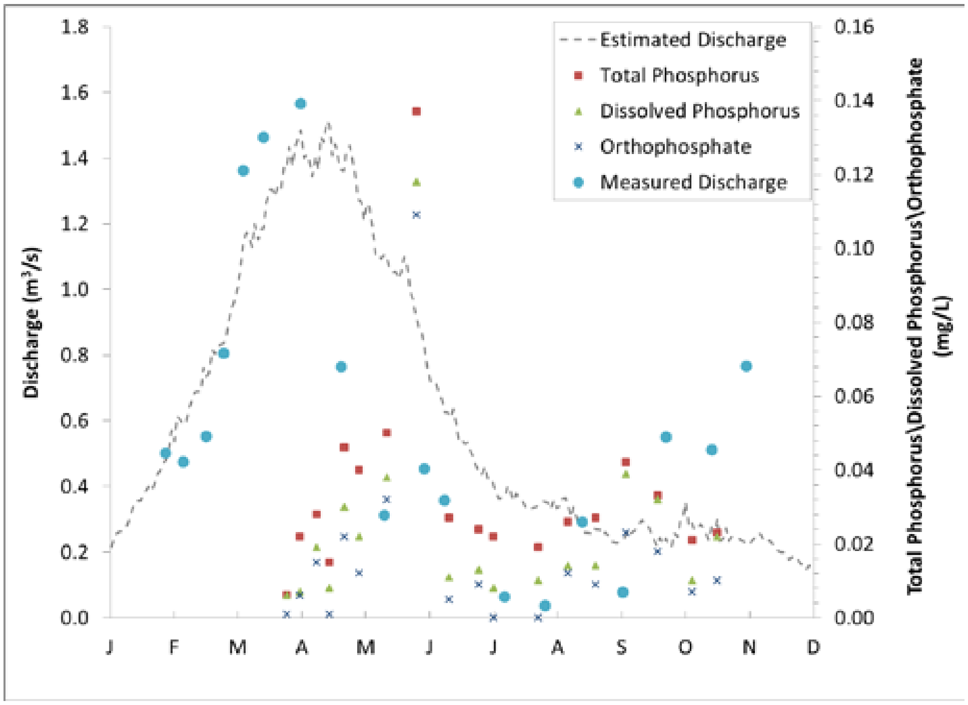


Figure 5-83 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in White Creek

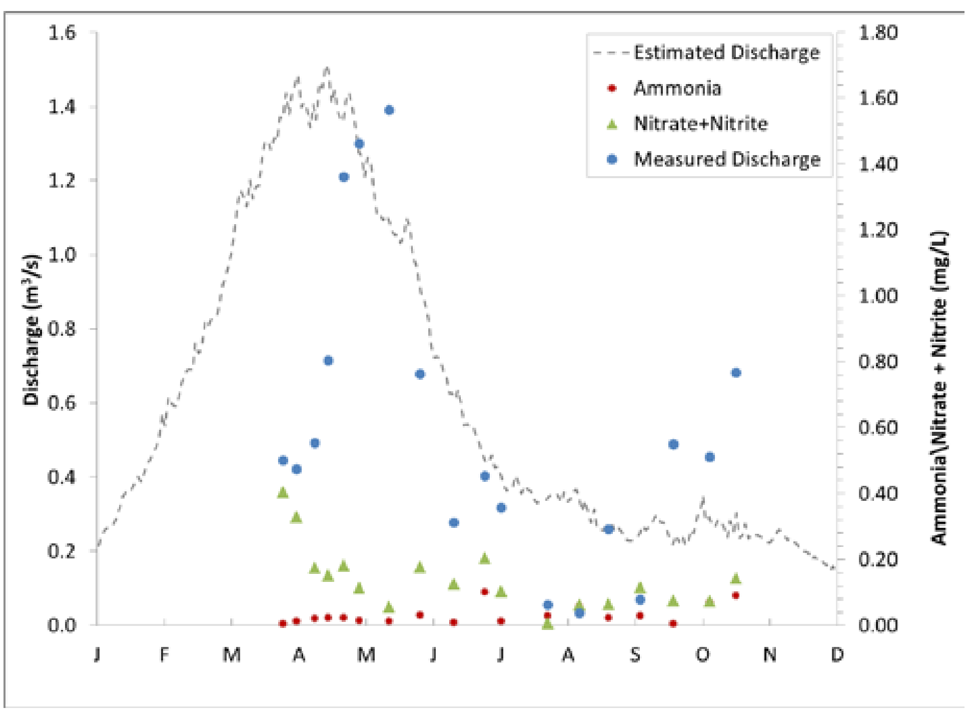


Figure 5-84 Concentration of organic nitrogen and total nitrogen (mg/L) in White Creek

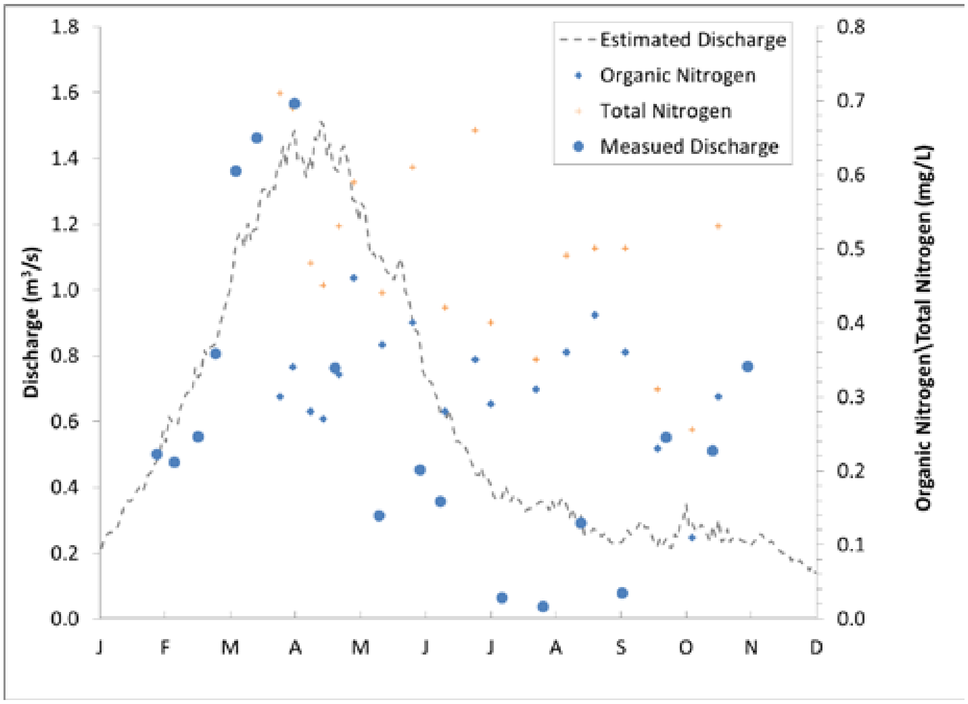


Figure 5-85 Concentration of dissolved and total organic carbon (mg/L) in White Creek

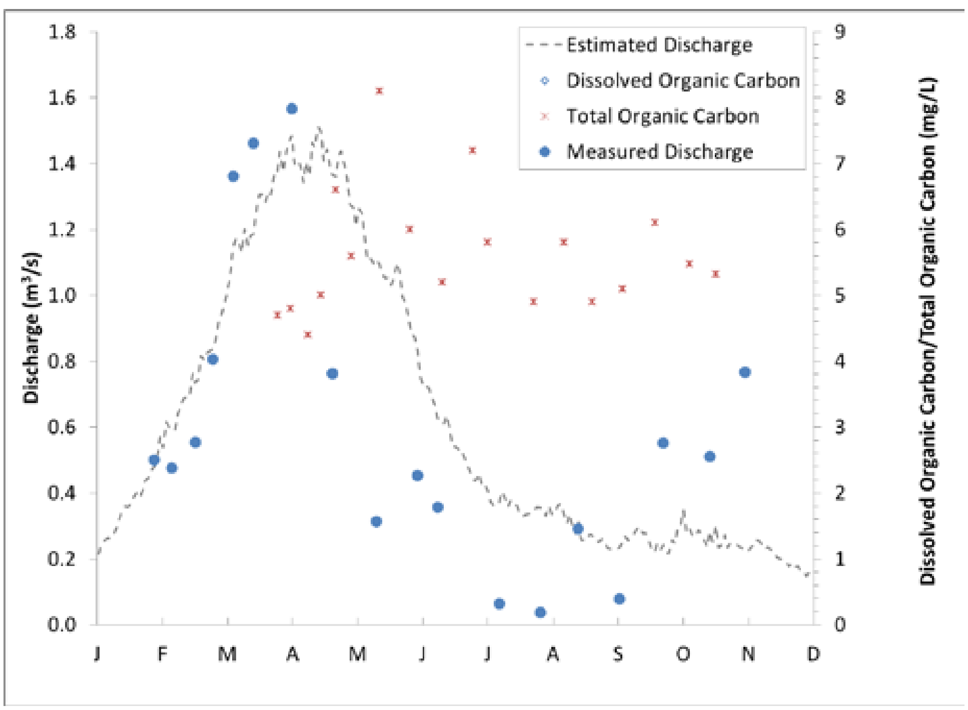


Figure 5-86 Concentration of chloride (mg/L) in White Creek

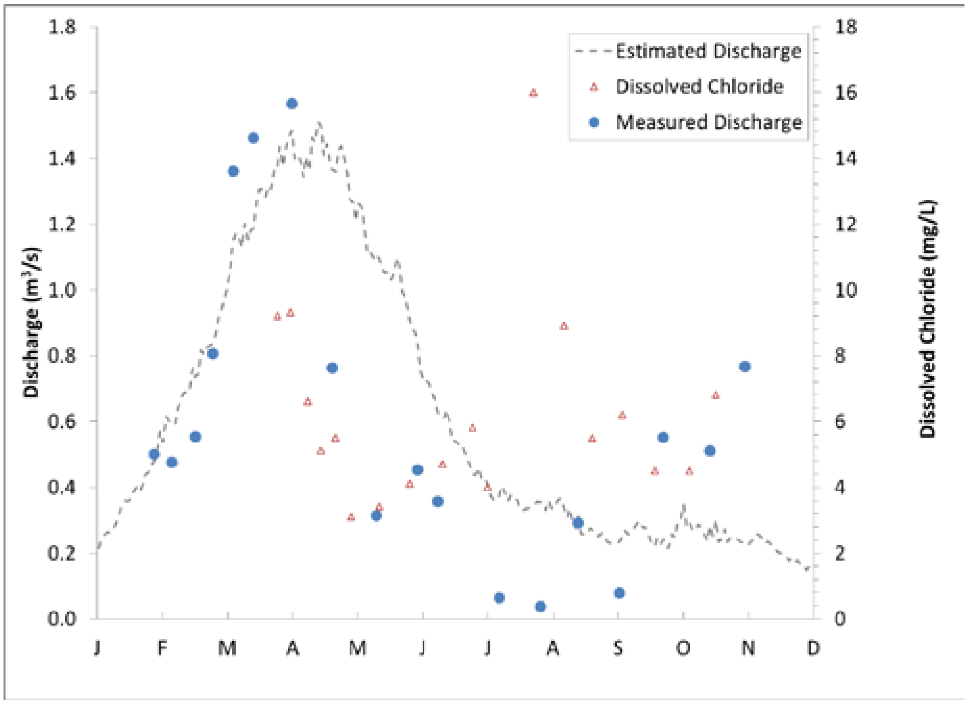


Figure 5-87 Concentration of total suspended solids (mg/L) in White Creek

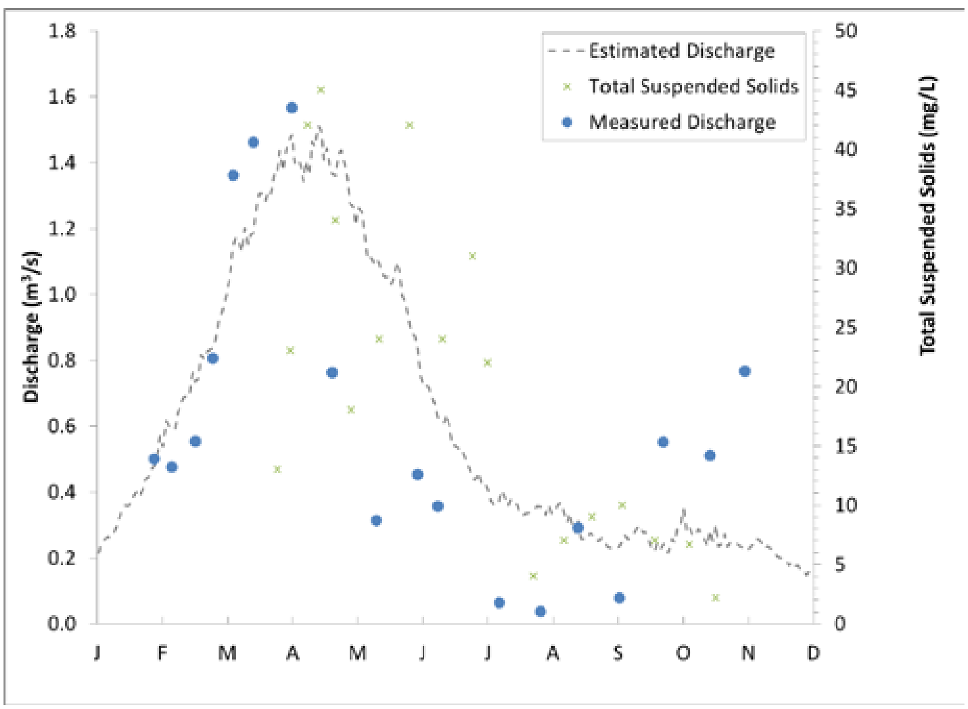


Figure 5-88 pH in White Creek

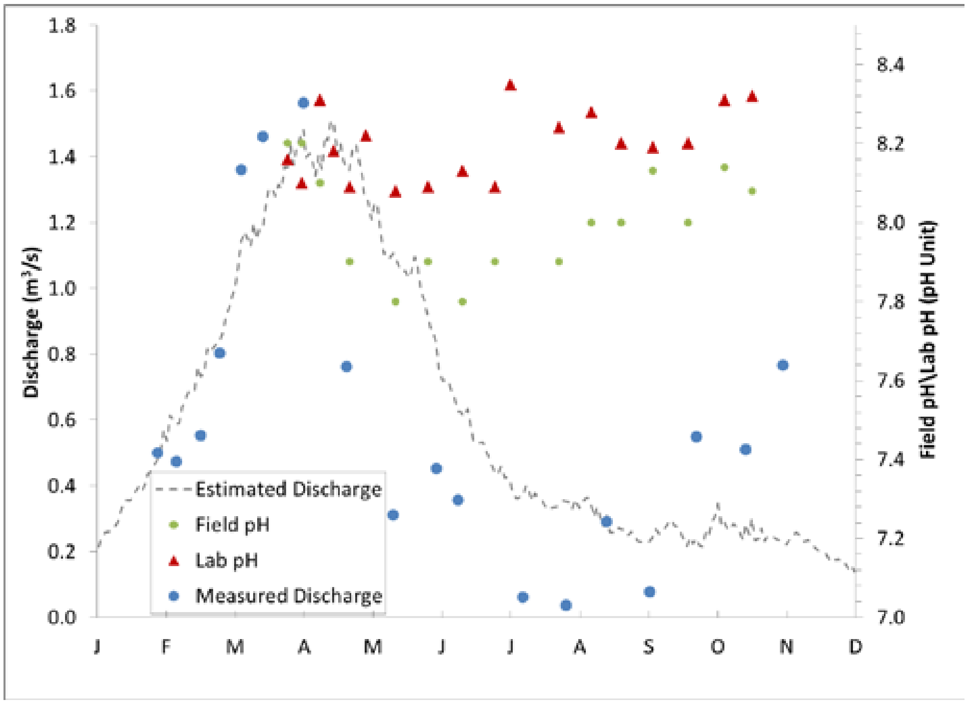
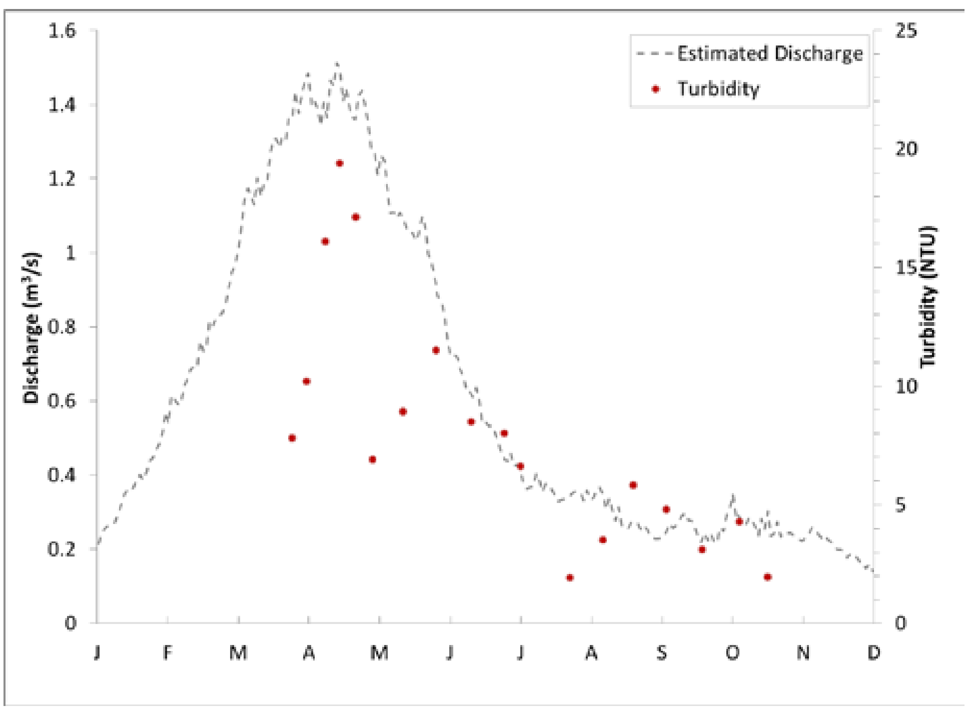


Figure 5-89 Turbidity (NTU) in White Creek



5.1.12 Shuswap River

Figure 5-90 Discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in the Shuswap River

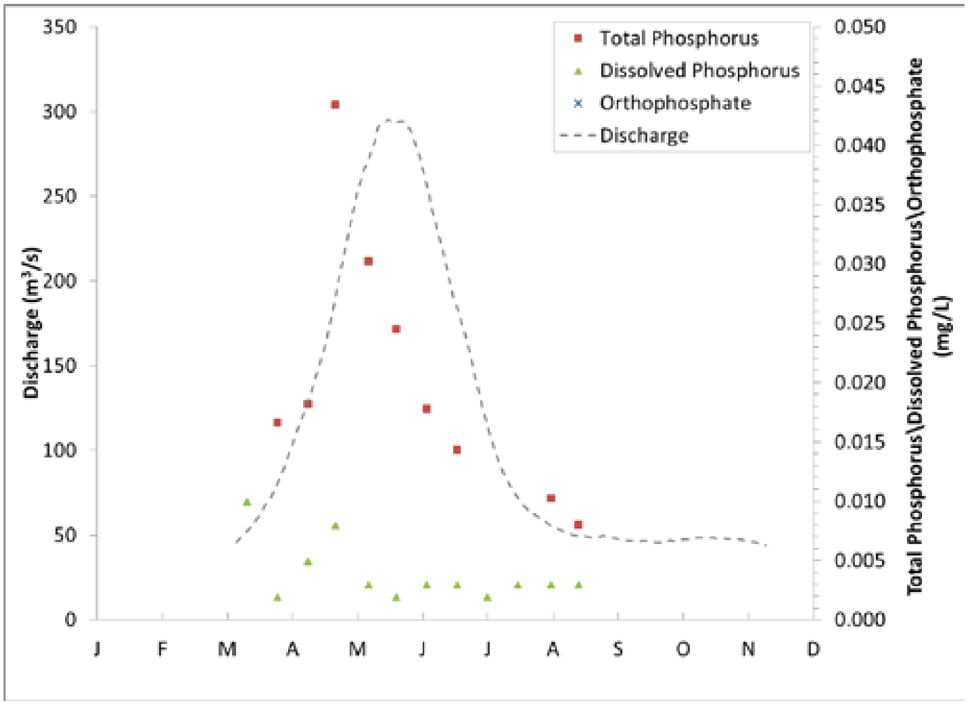


Figure 5-91 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in the Shuswap River

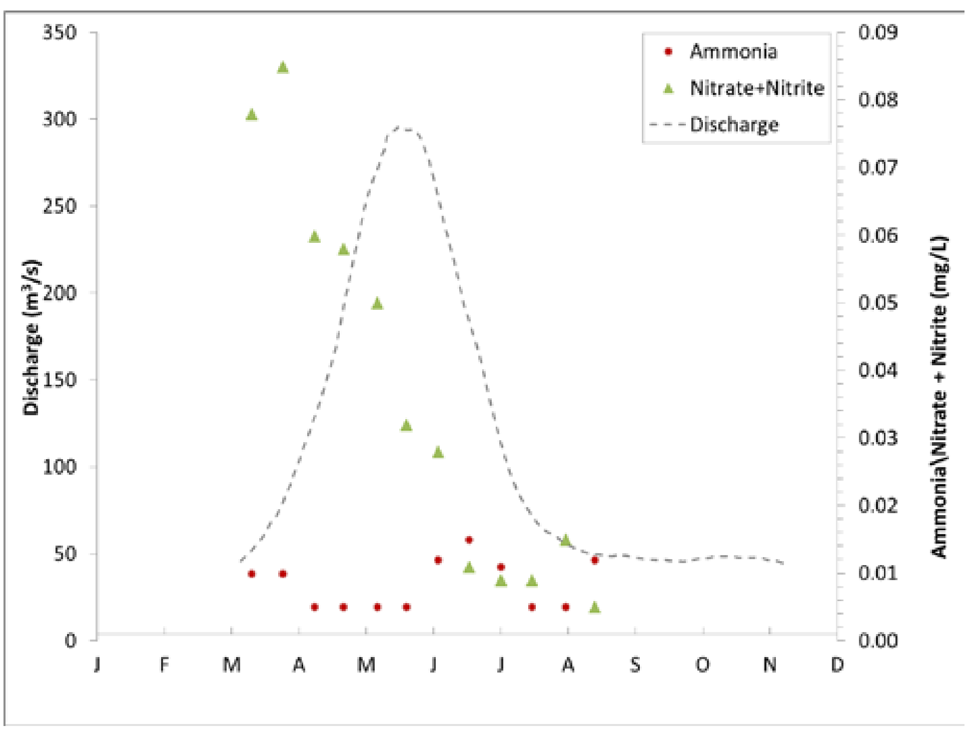


Figure 5-92 Discharge hydrograph (m^3/s) and concentration of organic nitrogen and total nitrogen (mg/L) in the Shuswap River

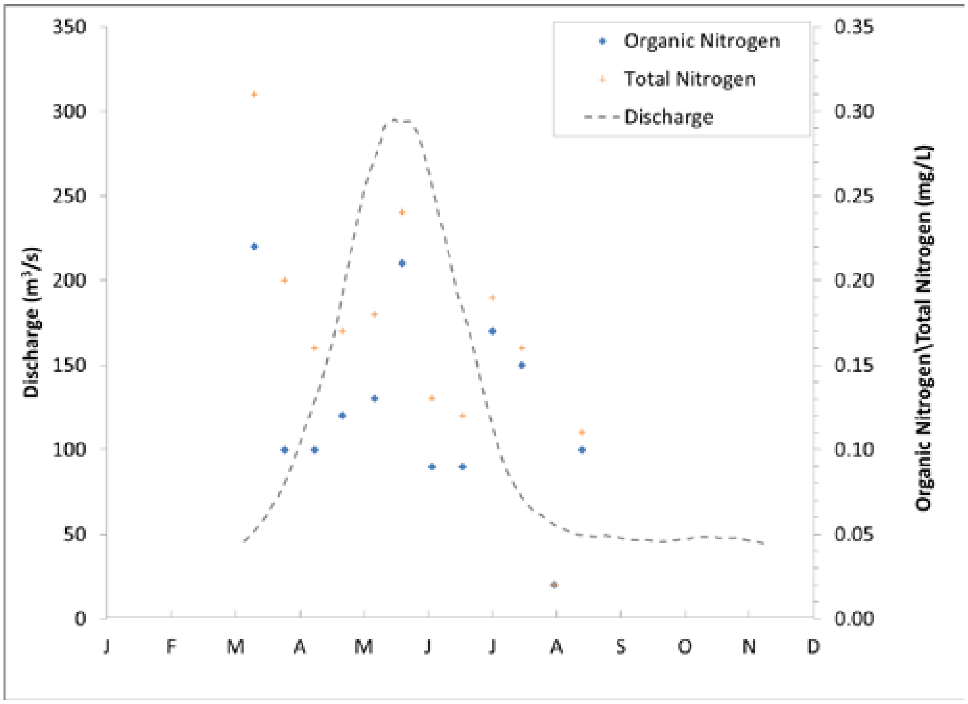


Figure 5-93 Discharge hydrograph (m^3/s) and concentration of dissolved organic carbon and total organic carbon (mg/L) in the Shuswap River

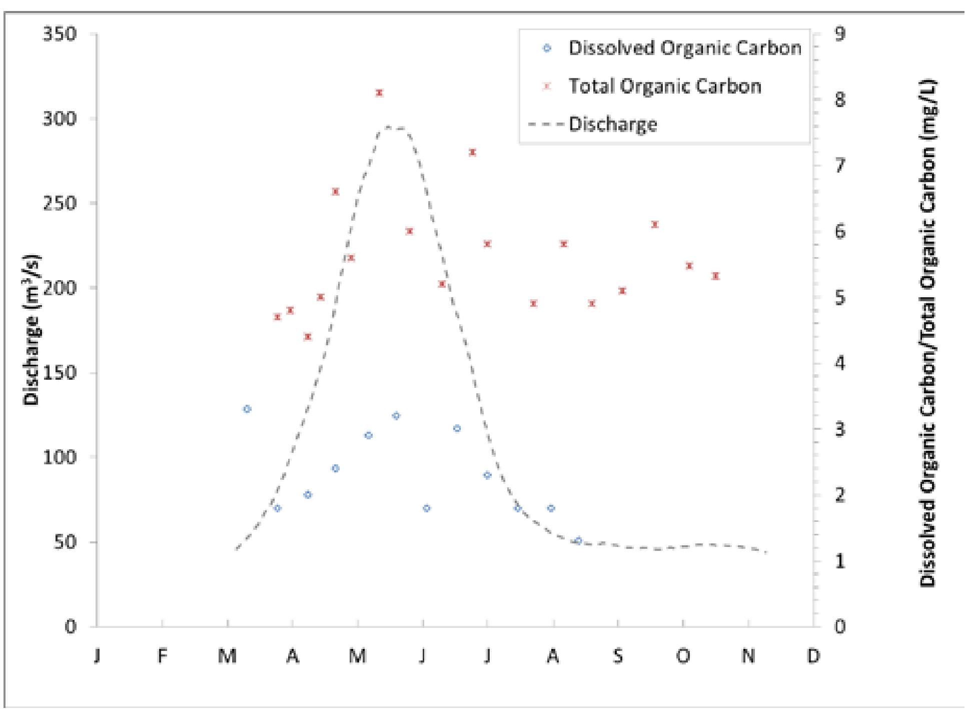


Figure 5-94 Discharge hydrograph (m^3/s) and concentration of dissolved chloride (mg/L) in the Shuswap River

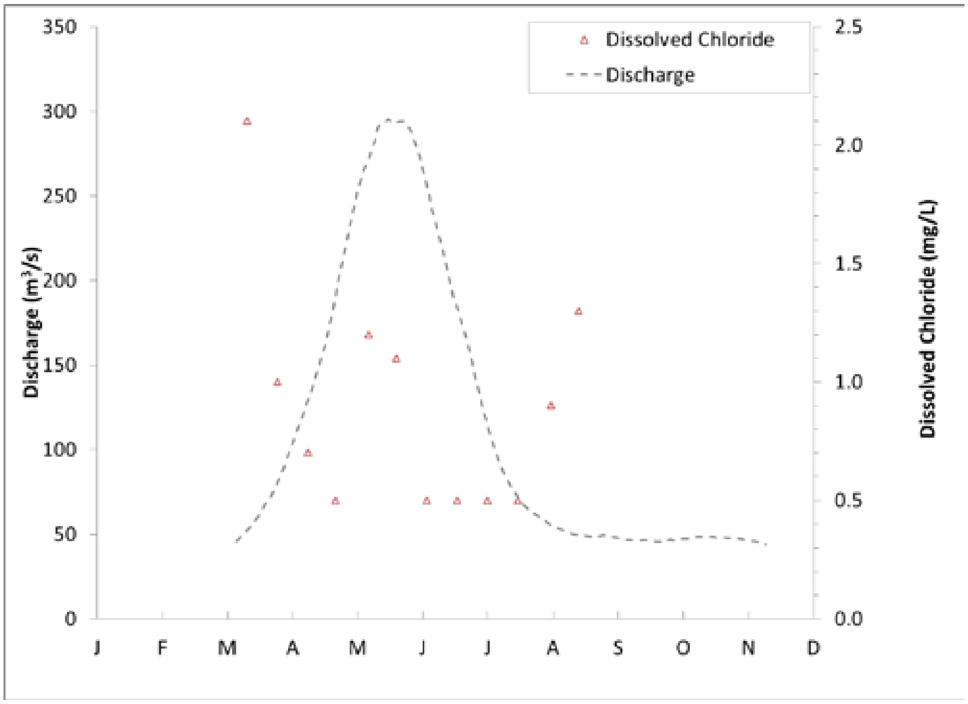


Figure 5-95 Discharge hydrograph (m^3/s) and concentration of total suspended solids (mg/L) in the Shuswap River

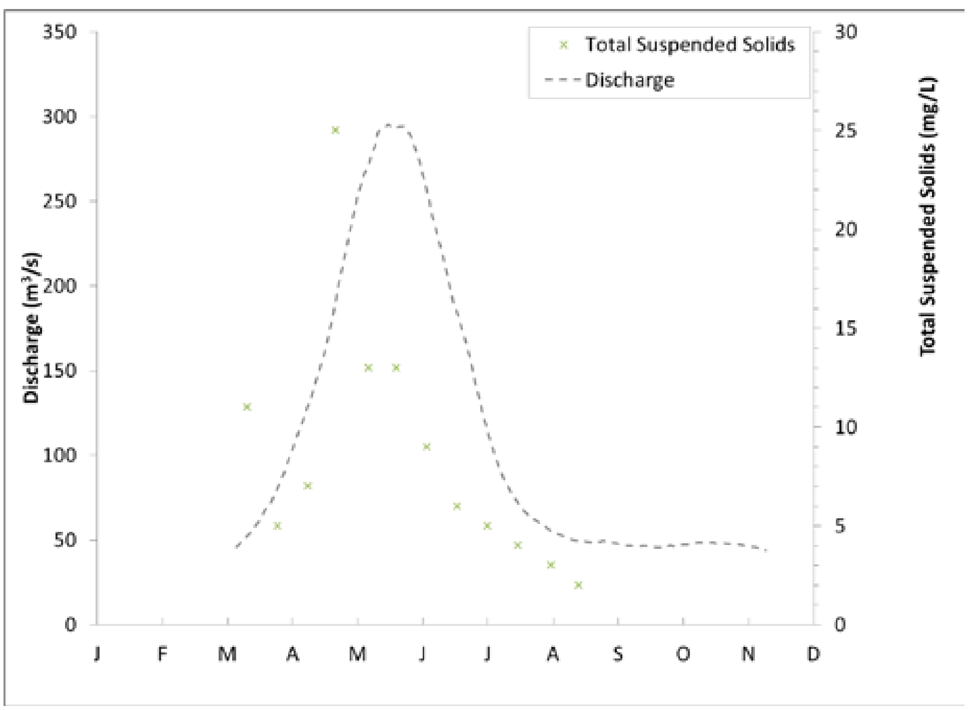


Figure 5-96 Discharge hydrograph (m^3/s) and pH in the Shuswap River

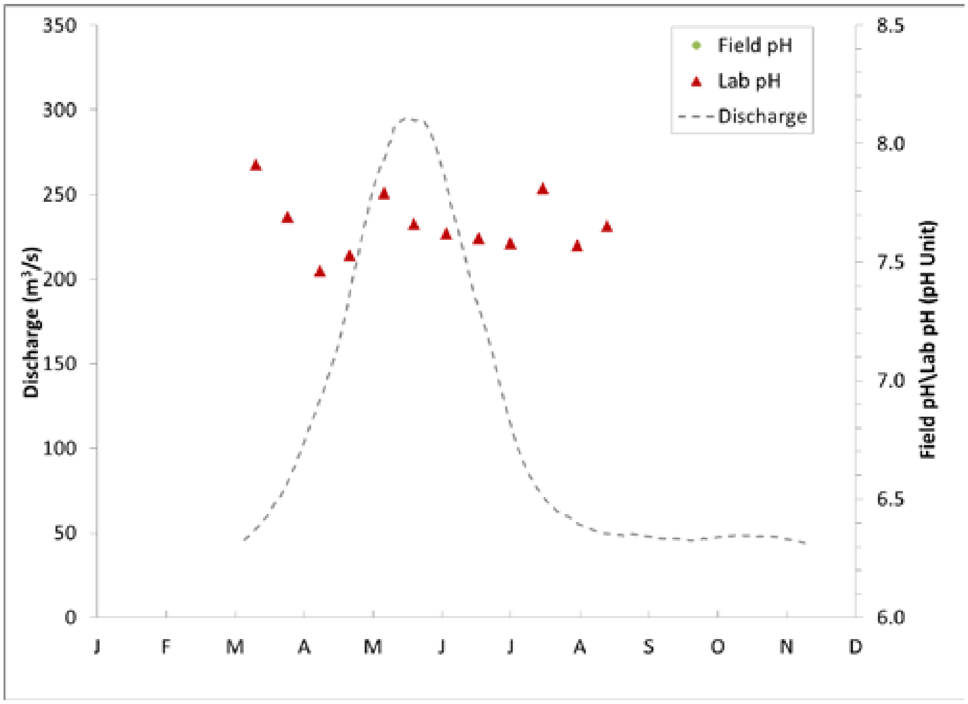
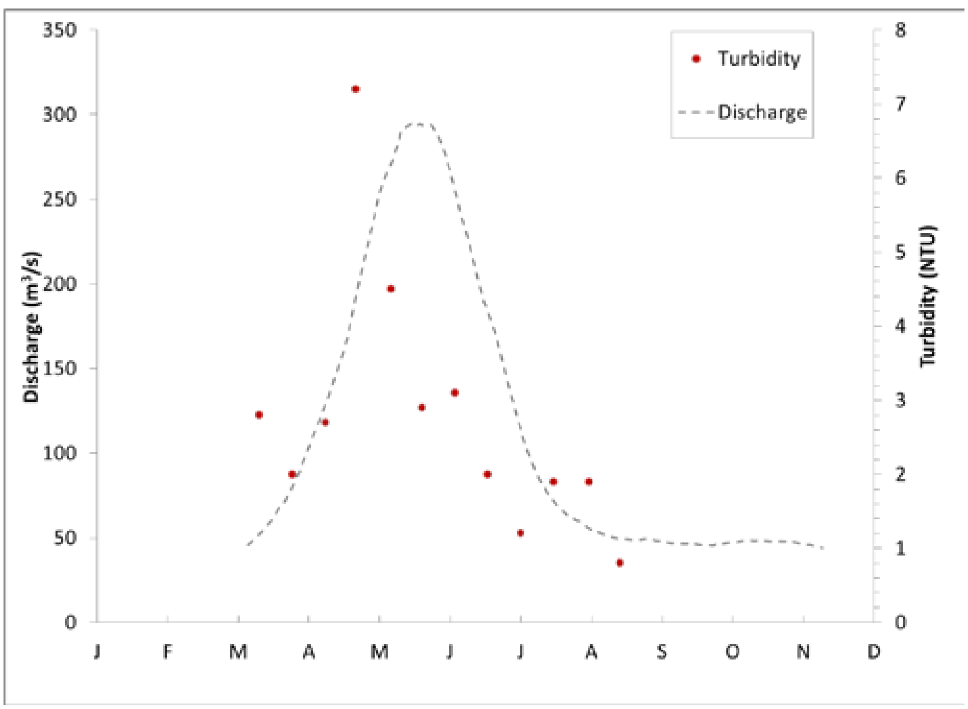


Figure 5-97 Discharge hydrograph (m^3/s) and turbidity (NTU) in the Shuswap River



5.1.13 Salmon River

Figure 5-98 Discharge hydrograph (m^3/s) and concentration of total phosphorus (Detection Limit= 0.002 mg/L), total dissolved phosphorus (Detection Limit= 0.002 mg/L) and orthophosphate (mg/L) (Detection Limit= 0.001 mg/L) in the Salmon River

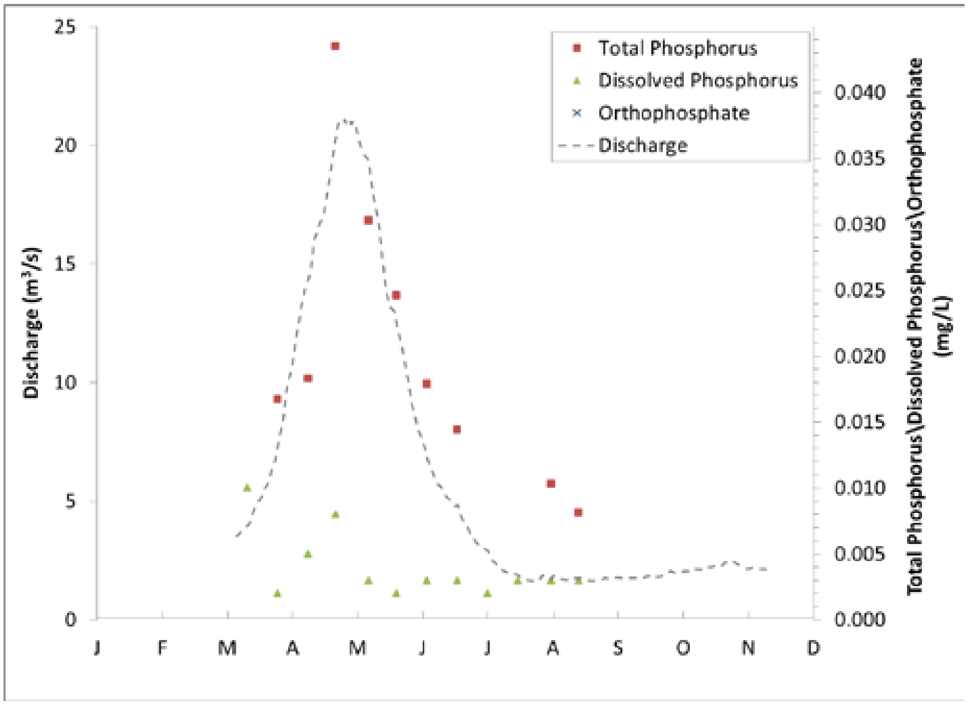


Figure 5-99 Discharge hydrograph (m^3/s) and concentration of ammonia and nitrate + nitrite (mg/L) in the Salmon River

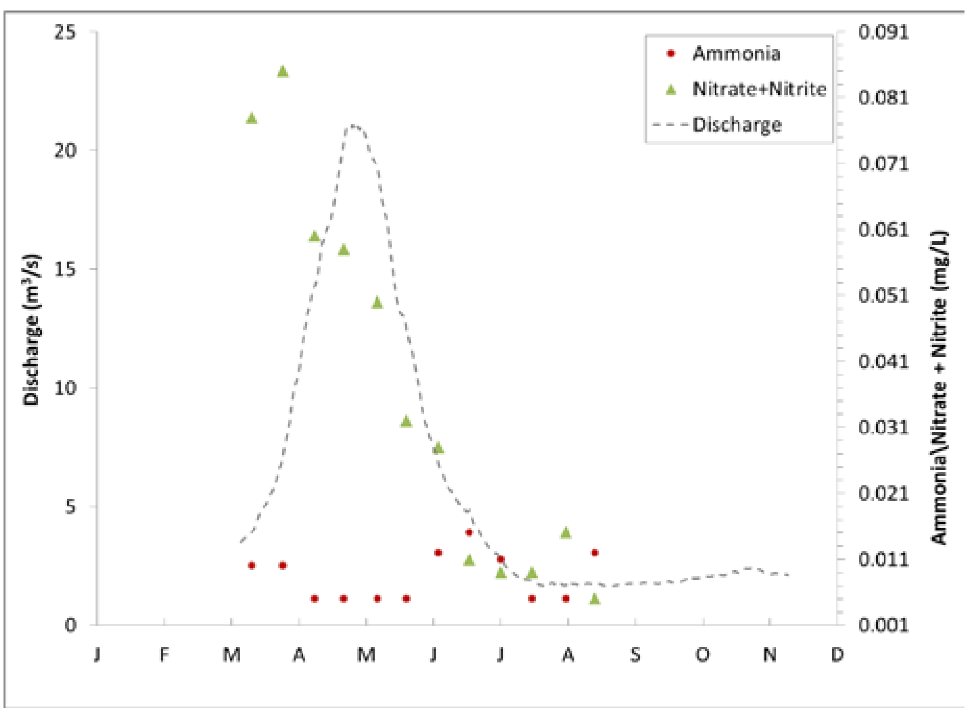


Figure 5-100 Discharge hydrograph (m^3/s) and concentration of organic nitrogen and total nitrogen (mg/L) in the Salmon River.

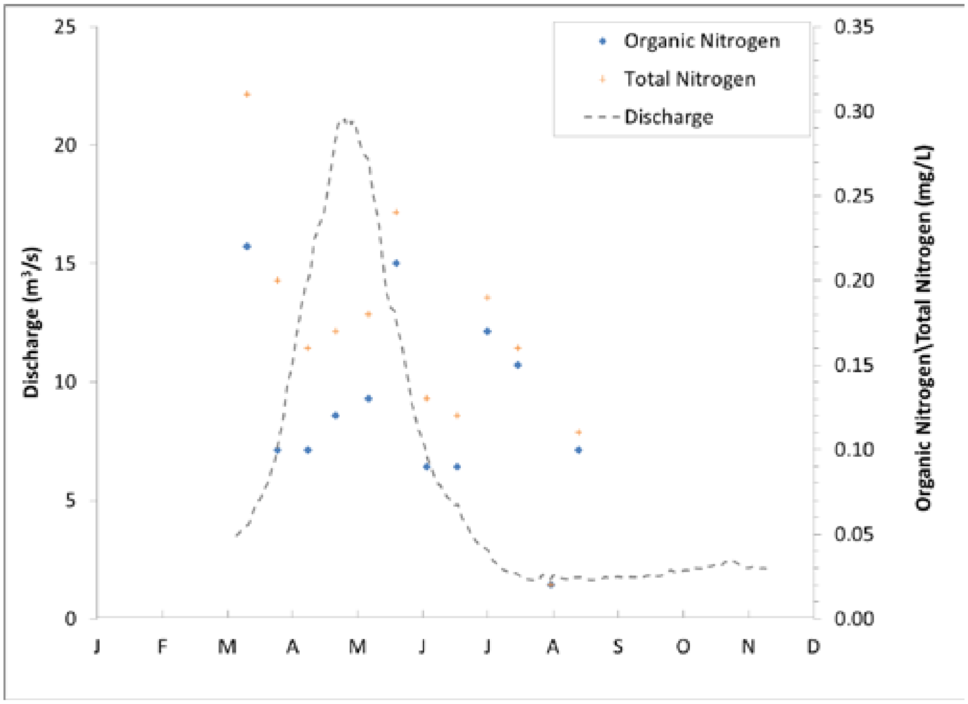


Figure 5-101 Discharge hydrograph (m^3/s) and concentration of dissolved organic carbon and total organic carbon (mg/L) in the Salmon River

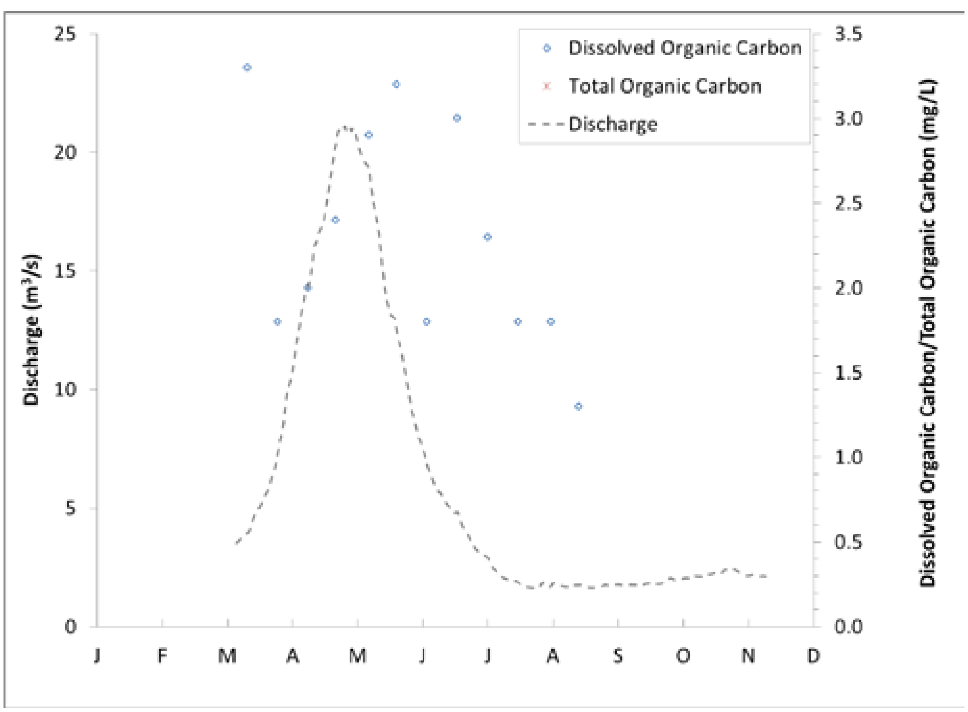


Figure 5-102 Discharge hydrograph (m^3/s) and concentration of dissolved chloride (mg/L) in the Salmon River

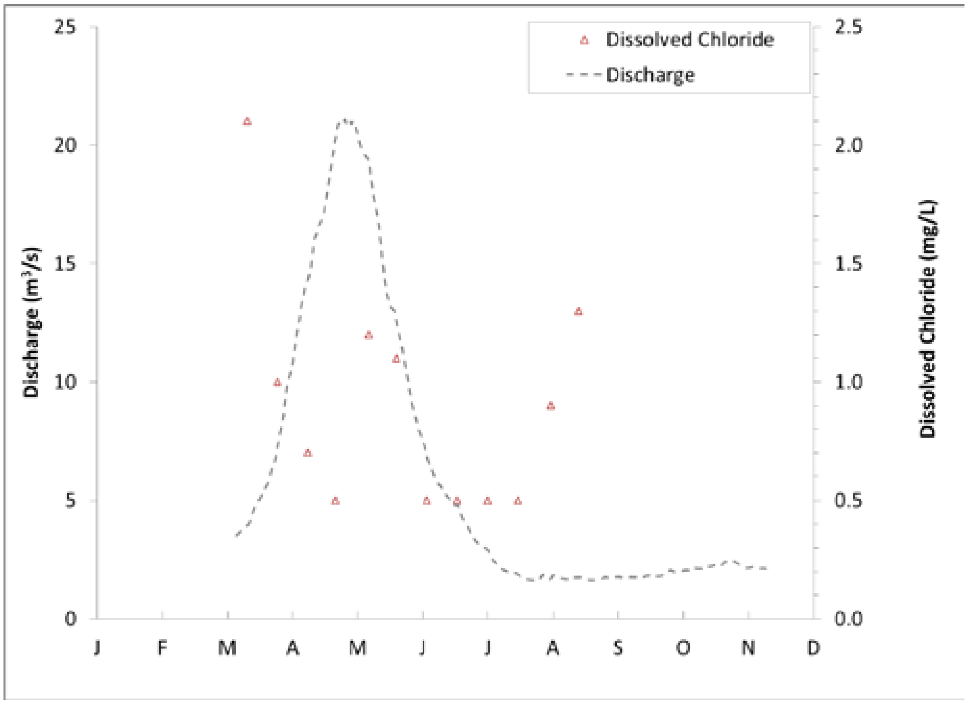


Figure 5-103 Discharge hydrograph (m^3/s) and concentration of total suspended solids (mg/L) in the Salmon River

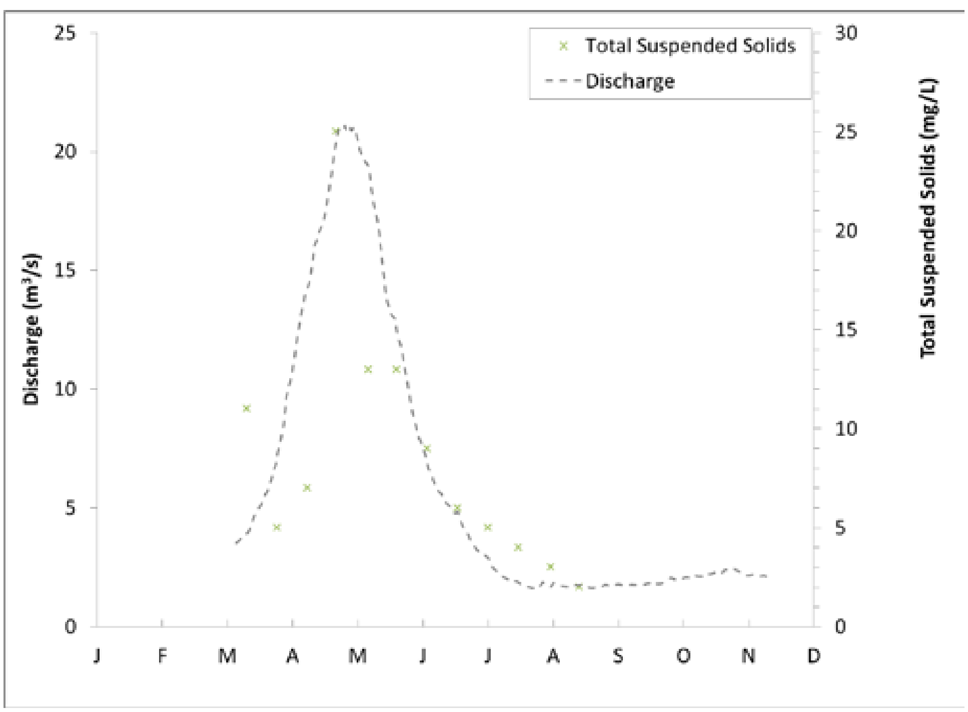


Figure 5-104 Discharge hydrograph (m^3/s) and pH in the Salmon River

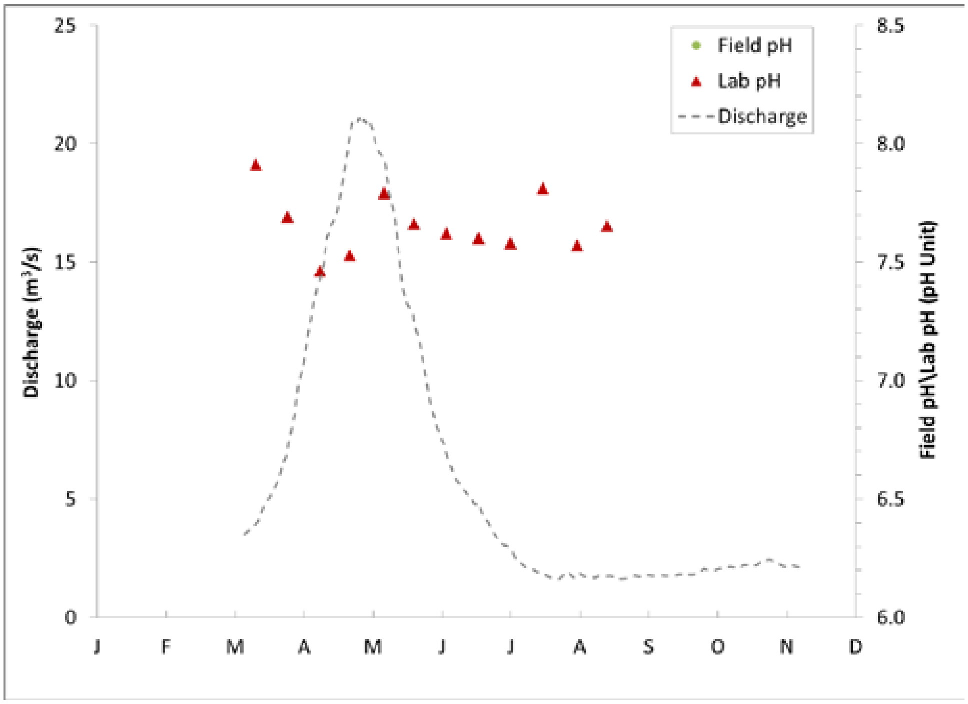
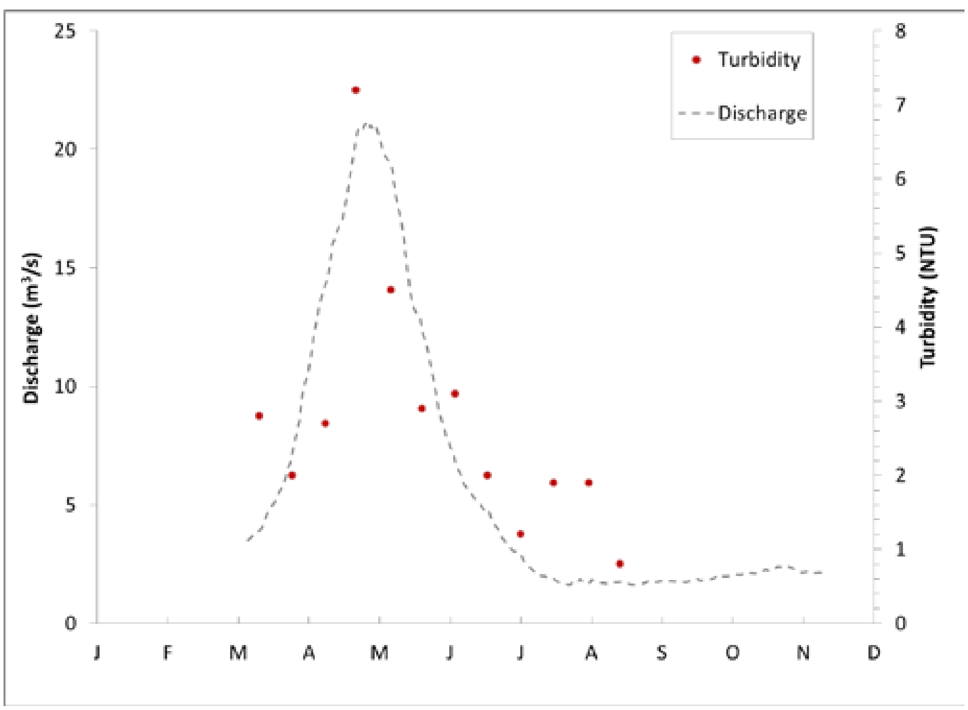


Figure 5-105 Discharge hydrograph (m^3/s) and turbidity (NTU) in the Salmon River



5.2 Seasonal Distribution of Nutrients in Shuswap and Salmon Rivers

Shuswap and Salmon Rivers were selected for a more detailed analysis of the nutrient dynamics since they have relatively high flows and there is considerable agricultural activity in these watersheds which may contribute a significant proportion of the nonpoint nutrient loadings into Shuswap Lake.

The seasonal distribution of total phosphorus and dissolved phosphorus along with their estimated discharge profiles for Shuswap and Salmon Rivers are shown in **Figure 5-101** and **Figure 5-109** respectively. Both watersheds show a similar seasonal profile for phosphorus. The total phosphorus and dissolved phosphorus concentrations rise quickly and show their peak concentrations on the rising limb of the discharge hydrograph in early April. The concentrations of total phosphorus drop off before the peak discharge in the Shuswap River but tend to follow the dropping hydrograph in the Salmon River.

The available forms of nitrogen (nitrate and ammonia) for Shuswap and the Salmon Rivers are presented in **Figure 5-102** and **Figure 5-110** respectively. Again these available forms of nitrogen follow similar seasonal patterns for both watersheds with highest nitrate concentrations just as the discharge begins to pick up in late March before phosphorus reaches its peak. Ammonia shows some of its higher values at this time as well with a second peak occurring in the summer (June and July). The early runoff at lower elevations is most likely the source of the early nitrate and ammonia peaks and probably originates from the agricultural land along the rivers.

The second peak of ammonia discharge in the summer occurs at the same time that there is a drop in the organic nitrogen concentrations in both watersheds. Apparently during the warm summer period there is a more rapid hydrolysis of the organic nitrogen in the river water with a release of ammonia. Ammonia is the most readily available form of nitrogen for phytoplankton growth.

It is interesting to determine some relative evaluation of the proportion of the phosphorus and nitrogen that are more readily available seasonally from these watersheds. Calculations of the percentage of the available nitrogen and phosphorus that were available were determined using nitrate/total N and Dissolved P/ total P ratios for the April (spring) and June/July (summer) periods (**Table 5-4**). Ammonia was not used in the calculation of this table since it usually represents less than 10% of the nitrate.

Table 5-4 Available Nitrogen and Phosphorus in the Major Shuswap Tributaries

Watershed	Month	Nitrate/Total N	Dissolved P/Total P
Shuswap	April	27	43
	June/July	4	18
Salmon	April	25	35
	June/July	4	20

All values expressed as a percentage.

Both the Shuswap and Salmon Rivers show a similar response in terms of the seasonal ratios of available nitrogen and phosphorus. Not only are the concentrations of N and P much higher in the early spring on the rising discharge hydrograph, but the proportion of both the available N and P are also higher. As the discharge decreases into the summer period, the relative proportion of available nitrogen decreases by a factor of 6 and the ratio of available P decreases by a factor of only 1.7-2.3 times. A smaller relative decrease in the ratio of available P in the summer could have some influence on the phytoplankton community structure in Shuswap Lake in areas influenced by discharges from these two watersheds.

Water Quality Guidelines and regulations for nutrients are usually established to prevent eutrophic conditions from developing. However, ammonia can be toxic to fish if concentrations are high enough. Most of the ammonia concentrations were very low even in the streams where there are environmental concerns for microorganisms and other contaminants. This is the usual finding in most well aerated streams and rivers since nitrification (ammonia oxidation to nitrate) is fairly rapid if the water temperature is not too cold.

Table 5-5 shows the highest two ammonia values recorded during 2011 for comparison to known toxic concentrations in selected watersheds of Shuswap Lake. No values were recorded above 0.100 mg/L ammonia-N. There should be no toxicity caused by ammonia since the toxicity threshold for ammonia at pH values between 6 and 8 and at moderate temperatures is over 1.0 mg/L (Nagpal *et al*. 1995) and all of the ammonia concentrations were an order of magnitude lower.

Table 5-5 Two Highest Ammonia Concentrations recorded in 2011 in Selected Shuswap Systems

Tributary	Ammonia 1	Ammonia 2
Canoe	0.052	0.018
Newsome	0.059	0.042
Tappen	0.088	0.049
Salmon	0.064	0.046
Shuswap	0.092	0.069
White	0.092	0.069

All values in mg/L ammonia-N.

The major nutrient that regulates phytoplankton production in most BC lakes is usually phosphorus. For British Columbia lakes, it is recommended to keep the total phosphorus levels below 10 µg/L P to prevent excessive phytoplankton growth. The total phosphorus concentrations in several of the rivers and streams discharging to Shuswap Lake have total phosphorus levels that exceed 10 µg/L P especially in the early spring when the discharge is increasing due to spring runoff (**Table 5-6**).

From this summary table it is evident that two larger rivers (Shuswap and Salmon) and three smaller streams (Canoe, Newsome and White Creeks) are potential sources of nonpoint phosphorus and could contribute to ongoing eutrophication in Shuswap Lake.

These nutrient data are not normally distributed due to the higher transport of nutrients during the higher discharge periods in spring. Therefore non-parametric statistics would be appropriate for the statistical analysis of the tributary seasonal nutrient concentrations. This allows median values, percentiles and outliers to be calculated. A diagrammatic plot of this type of statistics is shown in Appendix A. Additional discharge data and calculation of total annual loading rates and expected sources is critical in determining overall contributions and potential source controls.

Table 5-6 Total Phosphorus Discharge by Shuswap Lake Tributaries

Tributary	Sample Number	Total P (highest value, µg/L)	No. of Values > 10 µg/L
Celesta Creek	21	8	0
Adams River	18	4	0
Canoe Creek	17	78	17 (100%)
Eagle River	19	10	1
Hummingbird Creek	19	7	0
Newsome Creek	21	491	21 (100%)
Scotch Creek	`18	26	1
Seymour Creek	18	7	0
Sicamous Creek	19	7	0
Tappen Creek	19	21	3
W. Anstey Creek	14	10	1
White Creek	18	138	18 (100%)
Salmon River	12	185	12 (100%)
Shuswap River	15	37	10 (66%)

Total P values in micrograms/L P.

Where data were available, the seasonal total phosphorus loadings (**Figure 5-106**) and total nitrogen loadings (**Figure 5-107**) are presented for the larger rivers in the Shuswap basin, namely Shuswap, Salmon, Adams and Seymour. These nutrient loadings (TP and TN) follow fairly close to the discharge hydrographs with peak nutrient loadings occurring in May and June. The Shuswap and Adams River watersheds show higher nutrient loadings into July which may be attributable to higher elevations with later snow melt and a major lake in their watersheds which can affect seasonal discharge and sedimentation of particle associated contaminants.

Phosphorus is most often the limiting nutrient for phytoplankton growth in freshwater lakes. Monthly phosphorus loadings (**Table 5-6**) were calculated for the higher discharge months (March to August) for two major rivers (Shuswap and Salmon) and for four small creeks (Canoe, Newsome, Tappen and White) which appear to be affected by human impacts as indicated by their higher *E. coli* concentrations.

Shuswap River is the largest source of total phosphorus to Shuswap Lake with a peak May/June loading approximately 1.5 times higher than the Salmon River. The Salmon River has twice the peak May loading of total phosphorus as the combined 4 contaminated creeks. The discharge of the Salmon River and Canoe, Tappen and White Creeks into Salmon Arm are certainly important contributors to nutrient enrichment conditions that have been measured in this arm of Shuswap Lake.

Some selected sewage treatment plant (Salmon Arm) and houseboat greywater total phosphorus loadings are also in **Table 5-6** for comparison the tributary loadings. These anthropogenic sources of total phosphorus are similar to some of the peak seasonal loadings from the small creeks (Newsome and White) but are a couple of orders of magnitude lower than the peak monthly total phosphorus discharged from the Shuswap and Salmon Rivers.

Figure 5-106 Seasonal Total Phosphorus Loadings for Four Shuswap Lake Tributaries

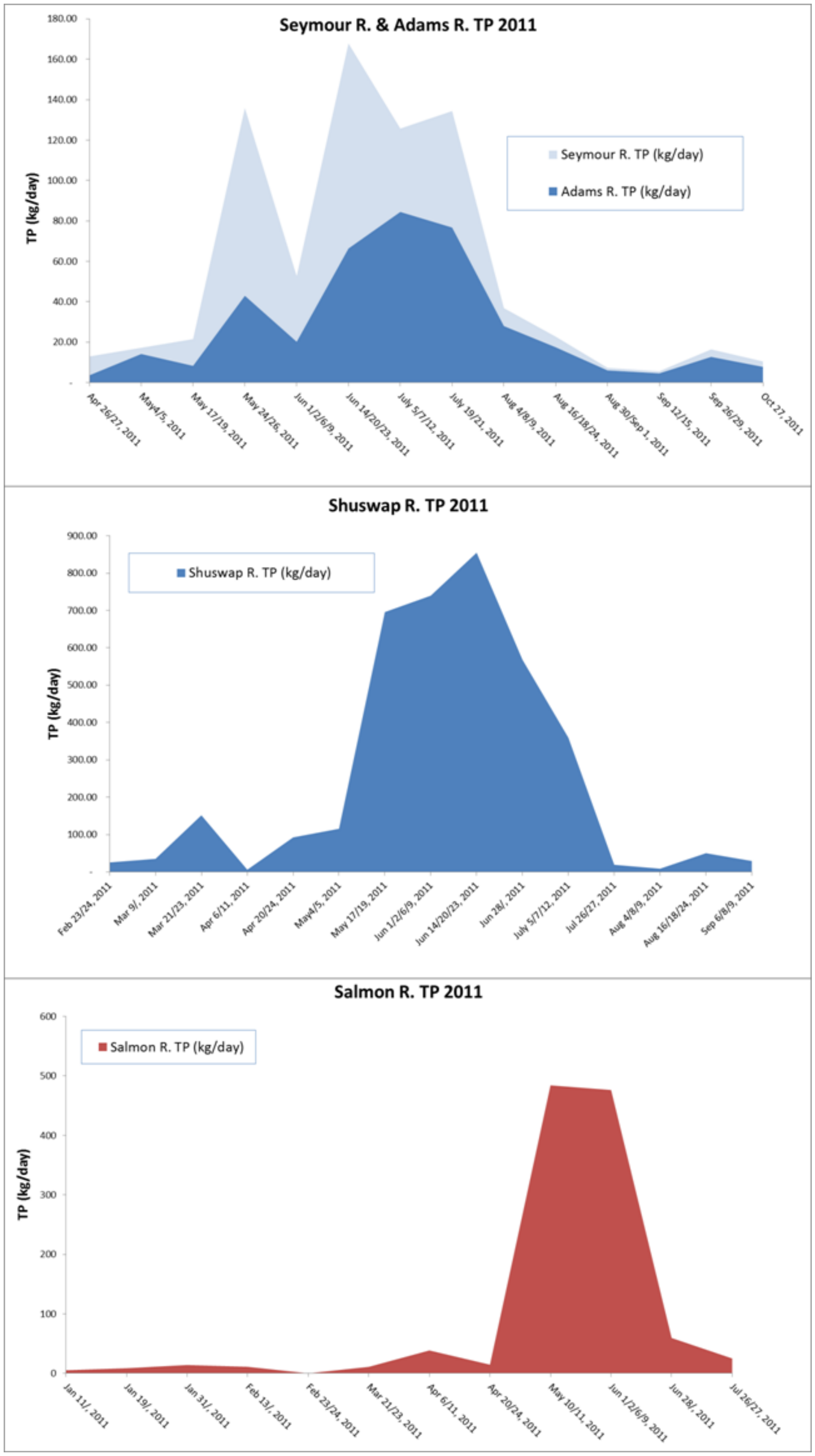
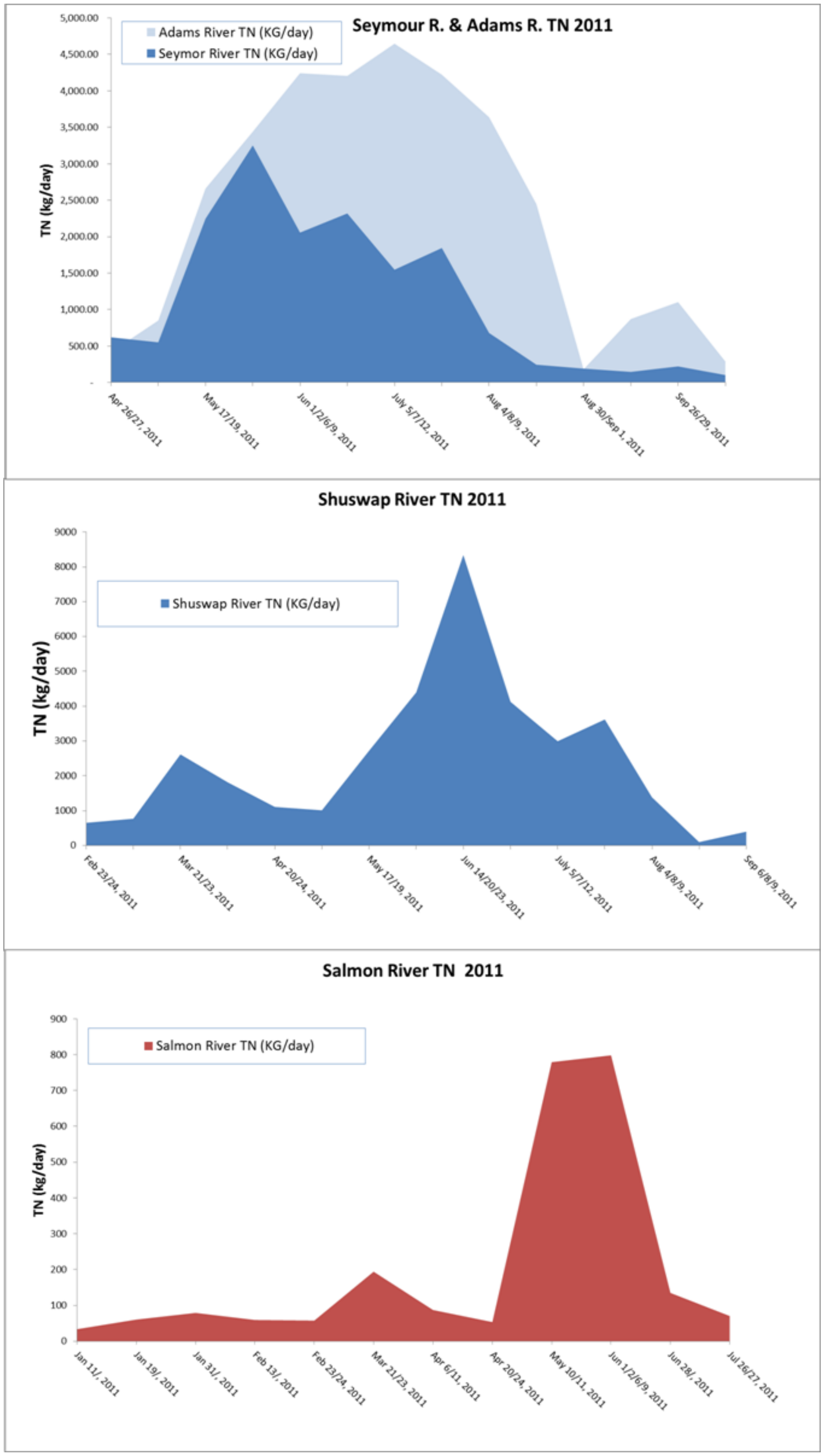


Figure 5-107 Seasonal Total Nitrogen Loadings for Four Shuswap Lake Tributaries



5.3 Trace Metals in Tributary Runoff

Water samples were analyzed for a total of twenty-nine (29) metals by ICPMS (inductively-coupled plasma mass spectrometry) . For many metals, concentrations were below the detection level. For this report, 7 trace metals (namely Al, Cu, Fe, Pb, Mn, Ni, and Zn) were selected for consideration since they are present above detection levels and some of them can be toxic to aquatic life.

For most of the minor tributaries only 2 to 5 water samples were collected, so their analysis would not be very useful given the kind of seasonal flow variations observed in these tributaries. However, the range of concentrations observed for these seven (7) metals is presented along with the number of water samples collected in **Table 5-8**. A more complete trace metal seasonal data set were collected from the Salmon and Shuswap Rivers and are presented along with available flow data (**Table 5-9**).

Since the dissolved and particulate materials transported by a river can influence trace metal transport behaviour, the seasonal distribution of specific conductivity (a measure of dissolved solids) and turbidity (a proxy measure of particulate material transport) in the Salmon and Shuswap Rivers are presented in **Table 5-10**. These data are plotted in **Figure 5-108** (Salmon) and **Figure 5-109** (Shuswap) to observe the seasonal trends and relationship to water quality (dissolved solids and suspended solids) and flow. The trace metals are plotted as semi-log plots to deal with the large differences in metal concentrations.

In the Salmon River (**Figure 5-108**) the concentrations of Al, Fe, Mn, Cu and Zn were all highest during the peak discharge as dissolved solids (specific conductivity) was decreasing and suspended solids (turbidity) was just starting to increase. Concentrations of trace metals are lower during the late fall and early winter along with low turbidity.

Trace metal concentrations in the Shuswap River show two peaks (early April and mid-late May) for all metals in **Figure 5-109** which also mirrors the peaks in turbidity indicating that they are associated with the transport of suspended solids. The metal concentrations in May reach peak values just as the turbidity starts to increase on the early part of the rising hydrograph.

Any problems from metal toxicity related to tributaries would occur in the spring months. However, since most of the metals appear to be particle-associated, they would likely settle out in the lake sediments where they will provide a historical record of this contamination.

Toxicity guidelines for these trace metals have been provided by both the provincial (BCMOE 2006) and federal (CCME 2007) governments (**Table 5-11**). Toxicity of many trace metals can be affected by the dissolved or particle associated forms, the water pH and water hardness. All values measured for trace metals in the Shuswap tributaries were for total metals which includes both the dissolved and particulate forms.

The pH range for the Shuswap tributaries was always above 6.5 where metals like Al are less toxic with a higher guideline value. The higher levels for aluminum measured in several tributaries (**Table 5-8**) and in both the Salmon and Shuswap Rivers (**Table 5-9**) during the high flow periods exceeded the dissolved guideline values. However, the measured values were for total Al which makes a toxicity concern for Al difficult to interpret.

In the Salmon River, copper exceeded the guideline during the highest discharge period and both rivers (Salmon and Shuswap) were close to the 2 µg/L guideline on a couple of high flow occasions. In the other tributaries only Newsome Creek showed a value (3 µg/L) which exceeded the quality guideline.

Iron also exceeded the both guidelines for total iron during the spring peak flow periods in the Salmon and Shuswap Rivers (Table 33). No iron concentration data were measured for the other tributaries.

Lead at 1.9 µg/L in the Salmon River was only close to the guideline of 2 µg/L at high flow in early May with the rest of the lead values less than 1 µg/L for all other tributaries. All manganese, nickel and zinc concentrations measured were well below the guidelines in the Salmon and Shuswap Rivers and other tributaries.

The highest nickel and zinc concentrations were 10 and 20 µg/L respectively and were measured in the Salmon River during the highest flow period in May.

These trace metal quality guidelines to protect aquatic life only consider toxicity effects on the basis of individual metals. Cumulative effects of being subjected to several metals at higher than baseline concentrations at the same time have not been considered by the regulatory authorities.

Figure 5-108 Seasonal Distribution of Selected Trace Metals (Al, Fe, Mn, Cu, Pb, Zn) with, Specific Conductivity, Turbidity and Flow in the Shuswap River

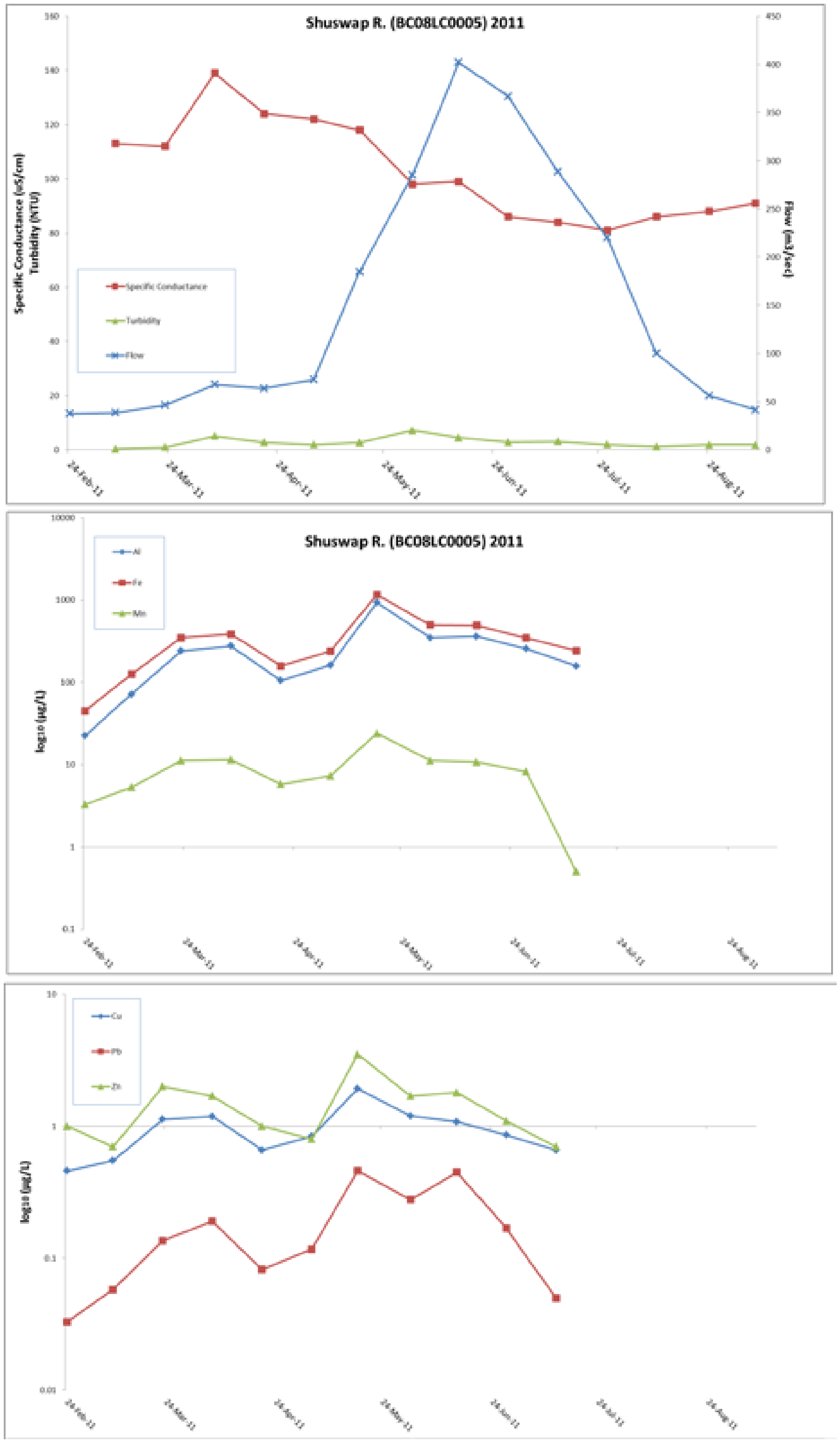


Figure 5-109 Seasonal Distribution of Selected Trace Metals (Al, Fe, Mn, Cu, Pb, Zn) with Flow, Specific Conductivity and Turbidity in the Salmon River

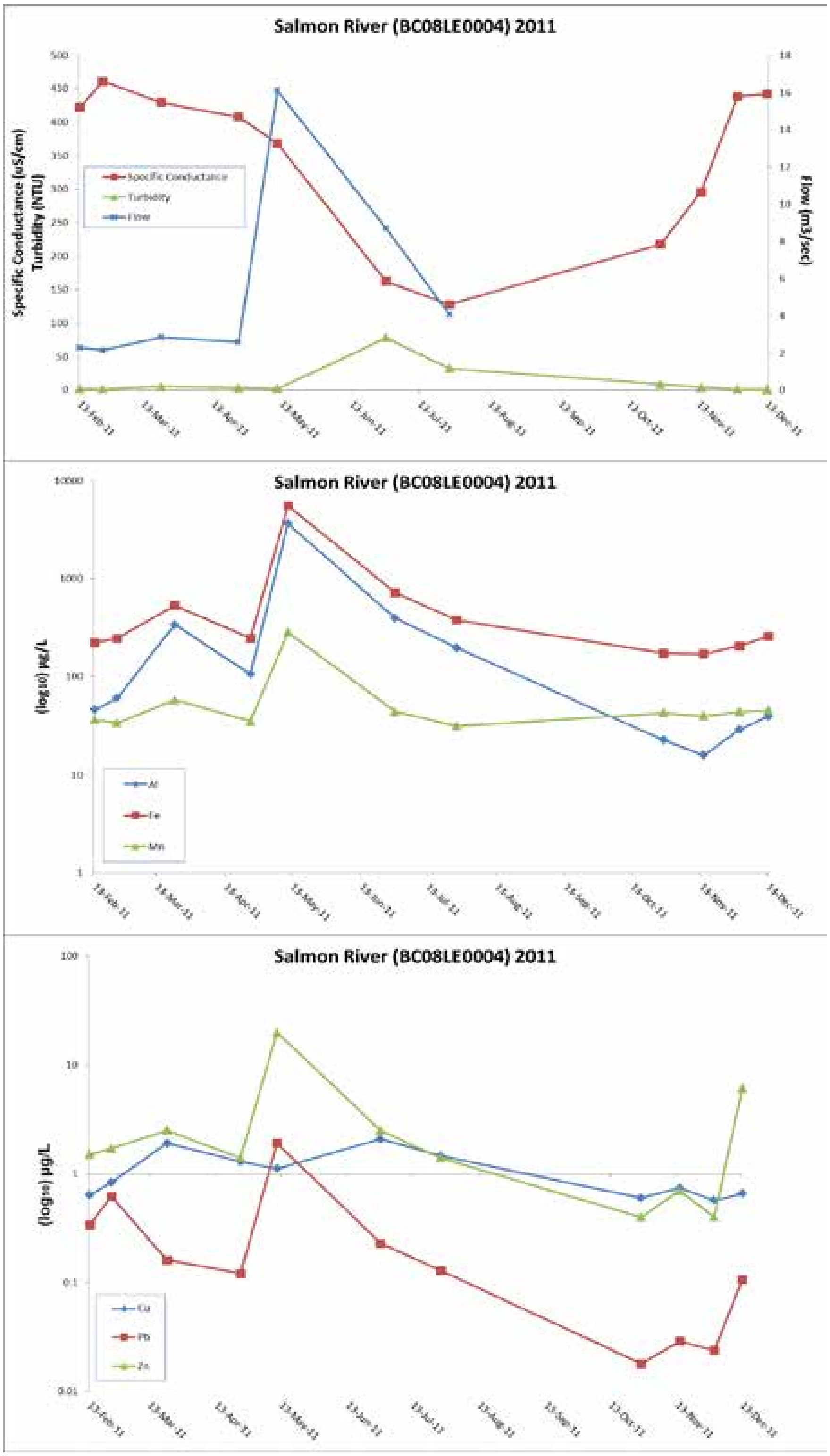


Table 5-7 Total Phosphorus Loadings from Shuswap Tributaries and Comparison to other Sources

Month (2011)	Shuswap River	Salmon River	Canoe Creek	Newsome Creek	Tappen Creek	White Creek	Salmon Arm WWTP	Houseboat Greywater
March	1550	310	1.5	6.4	ND	21.1	ND	ND
April	1500	600	10.4	44	4.2	45.3	ND	ND
May	12400	13640	66	439	4.2	205	ND	ND
June	21900	7500	39	101	5.4	65.6	24.6	21
July	9300	1500	28.5	51.8	4.8	23.9	182	155
August	930	ND	4.9	23	10.8	30.3	116	155
September	ND	ND	ND	ND	ND	ND	85	21

All data in kg/month of total phosphorus, except for Greywater and STP only for half month in June and Sept. when houseboats operating (Northwest Hydraulics Consultants 2010- see Tables 31 and 32). ND for no data.

Table 5-8 Selected Trace Metals in Shuswap Lake Tributaries in 2011

Tributary	Site No.	Sample No.	Al	Cu	Pb	Mn	Ni	Zn
Celesta Creek	500014	2	18.1-40.1	0.27-0.37	0.031-0.052	1.83-4.7	0.15-0.25	0.4-1.0
Adams River	500001	3	9.2-19.3	0.3-0.35	0.012-0.024	0.89-1.88	0.25	0.4-0.4
Canoe Creek	207640	3	12-57.6	0.4-1.96	0.15-0.22	42-98	0.62-1.0	1.5-5
Eagle Creek	E275709	5	24-46	0.29-0.8	0.023-0.075	2.3-10	0.14-0.15	0.4-0.5
Hummingbird Creek	E224166	3	38-69	0.5-0.7	<0.2-<0.2	<1-<1	<1-<1	<5-<5
Newsome Creek	500047	7	18-277	0.6-3.0	0.09-.135	8-30	1-2	1.6-6
Scotch Creek	500064	3	10-19.4	0.21-0.37	0.032-0.051	0.8-1.8	0.13-0.19	0.3-0.4
Seymour Creek	E206964	3	52-117	0.22-0.45	0.032-0.065	3.1-5.0	0.21-0.28	0.3-0.6
Sicamous Creek	E206452	5	37-236	0.36-1.0	0.046-<0.2	0.79-2.0	0.55-1.0	0.5-<5
Tappen Creek	600246	5	37-236	0.36-1.0	0.05-0.4	4.9-14	0.4-0.8	0.8-1.4
West Anstey River	500005	4	28-127	0.3-1.8	0.13-0.23	1.6-4.6	0.2-0.39	1.4-1.9
White Creek	500098	4	80-210	0.7-0.88	0.096-<.2	14.9-25	0.35-0.92	1.2-<5

Tributary	Site No.	Sample No.	Al	Cu	Pb	Mn	Ni	Zn
Salmon River	BC08LE0004	11	15-3660	0.57-11.1	0.018-1.9	31-283	0.54-10.1	0.4-19.9
Shuswap River	BC08LC0005	11	22.4-935	0.66-1.92	0.033-0.46	3.3-24	0.35-2.0	0.7-3.5

All values in micrograms/liter.

Table 5-9 Seasonal Variation in Selected Trace Metals in Two Tributaries of Shuswap Lake

River	Site No.	Date (2011)	Flow (m^3/s)	Al	Cu	Fe	Pb	Mn	Ni	Zn
Salmon River (Highway 1 Bridge)	BC08LE0004	2/13	2.29	45.9	0.64	222	0.34	36.3	0.55	1.5
		2/23	2.15	60.3	0.83	246	0.62	33.7	0.66	1.7
		3/21	2.84	339	1.9	532	0.161	57.7	1.41	2.5
		4/24	2.57	106	1.29	246	0.121	35.3	0.84	1.4
		5/11	16.1	3660	11.1	5560	1.91	283	10.1	19.9
		6/28	8.68	393	2,08	721	0.23	44.1	1.84	2.5
		7/26	4.07	197	1.46	377	0.129	31.3	1.19	1.4
		10/27	ND	22.4	0.6	174	0.018	42.7	0.54	0.4
		11/14	ND	15.7	0.74	171	0.029	39.7	0.54	0.7
		11/30	ND	28.7	0.57	206	0.024	43.7	0.55	0.4
		12/13	ND	39.5	0.66	256	0.106	45.4	0.62	6.1
Shuswap River (upstream of Mara Lake)	BC08LC0005	2/24	37.69	22.4	0.46	44.9	0.033	3.3	0.35	1.0
		3/9	38.68	71.8	0.55	125	0.058	5.3	0.43	0.7
		3/23	46.5	240	1.13	348	0.136	11.2	1.01	2.0
		4/6	67.8	276	1.19	384	0.191	11.5	1.02	1.7
		4/20	64	105	0.66	158	0.082	5.8	0.56	1.0
		5/4	73	162	0.84	239	0.117	7.3	0.68	0.8
		5/17	185	935	1.92	1160	0.46	24	2.02	3.5
		6/1	285.5	349	1.20	498	0.278	11.2	1.23	1.7
		6/14	402	361	1.08	492	0.449	10.8	1.07	1.8

River	Site No.	Date (2011)	Flow (m^3/s)	Al	Cu	Fe	Pb	Mn	Ni	Zn
		6/28	367	256	0.86	347	0.169	8.2	0.9	1.1
		7/12	288.8	158	0.66	242	0.05	0.5	0.66	0.7
		7/26	220							
		8/9	100							
		8/24	56.3							
		9/6	41.7							

All trace metal values in micrograms/liter. ND for no data.

Table 5-10 Seasonal Variation in Dissolved and Particulate Substances in Two Tributaries of Shuswap Lake

Tributary	Site No.	Date (2011)	Flow	Specific Conductivity (µS/cm)	Turbidity (NTU)
Salmon River (Highway 1 Bridge)	BC08LE0004	2/13	2.29	422	1.5
		2/23	2.15	461	1.2
		3/21	2.84	429	5.5
		4/24	2.57	408	3.0
		5/11	16.10	368	1.8
		6/28	8.68	162	78
		7/26	4.07	128	32.6
		10/27	ND	218	8.5
		11/14	ND	296	4
		11/30	ND	438	0.95
		12/13	ND	442	0.68
Shuswap River(upstream of Mara Lake)	BC08LC0005	2/24	37.7	113	0.4
		3/9	38.68	112	1.0
		3/23	46.5	139	5.1
		4/6	67.8	124	2.8
		4/20	64	122	2.0
		5/4	73	118	2.7
		5/17	185	98	7.2
		6/1	285.5	99	4.5

Tributary	Site No.	Date (2011)	Flow	Specific Conductivity (µS/cm)	Turbidity (NTU)
		6/14	402	86	2.9
		6/28	367	84	3.1
		7/12	288.8	81	2.0
		7/26	220	86	1.2
		8/9	100	88	1.9
		8/24	56.3	91	1.9
		9/6	41.7	92	0.8

ND for no data.

Table 5-11 Trace Metal Water Quality Guidelines for the Protection of Aquatic Life

Metal	BC Guideline	CCME Guideline
Aluminum	Dissolved concentration at pH 6.3=66 at pH 6.4=74 at pH 6.5 =100	pH<6.5 =5 pH>6.5=100
Copper	Varies with hardness For Shuswap area 3-8 µg/L	Varies with hardness Shuswap area 2 µg/L
Iron	Total Fe conc. 1000 Dissolved Fe 350	300
Lead	Varies with hardness 9-45	Varies with hardness Hardness 0-60, 1.0 µg/L Hardness 60-120, 2.0 µg/L
Manganese	Varies with hardness For Shuswap area 700-1200 µg/L	No guideline
Nickel	Varies with hardness Hardness 0-60, 25 µg/L Hardness 60-120, 65 µg/L	Varies with hardness Hardness 0-60, 25 µg/L Hardness 60-120, 65 µg/L
Zinc	Varies with hardness For Shuswap area 30 µg/L	30 µg/L

All metal values in µg/L, Hardness as mg/L $CaCO_3$

References: BC MOE 2006, CCME 2007.

6 Recommendations

The SLIPP water quality monitoring program should be continued as per the SLIPP Strategic Plan (BCMOE *et al*., 2008) that recommended development and implementation of a long-term inter-agency lake, foreshore and tributary water quality monitoring program on Shuswap Lake and Mara Lake to establish their current trophic status, relate this to past trophic states and identify trends in water quality. Continuance of this program should include an annual process for setting monitoring priorities and allocating the resources of SLIPP participating agencies to ensure inter-agency coordination and improve integration of existing information, monitoring activities and resources.

As the initial reporting of data from the program, the 2011 report required a significant amount of time to prepare due to a variety of factors. These include collection and parsing of the data, setting up standard reporting templates and charting. One critical issue is the inability of all agencies involved in the monitoring program to directly upload their data into the Provincial EMS data base. While it may not be feasible for all federal agencies to participate in this process, all of the agencies under Provincial jurisdiction should ensure their staff and contractors have the necessary training to upload their respective data files directly to the centralized EMS data base. Although this may incur additional costs at the front end of the monitoring program, it will substantially reduce future reporting costs and ensure the data is properly archived.

Additional SLIPP water quality monitoring program recommendations are as follows:

1. Restore and expand the public Secchi Disk monitoring program to include Adams Lake, Little Shuswap, Mabel, Shuswap Lake, Sugar and Mara Lake;
2. Develop partnerships with local universities to explore the feasibility of cost-effective monitoring of emerging contaminants;
3. Specifically engage the agricultural community in the Shuswap watershed to understand the rationale for, and participate in land-based nutrient containment/reduction activities where required, with support from Federal and Provincial environmental farm plan initiatives.

The value of a well-designed and properly implemented long-term water quality monitoring program cannot be overstated, especially given potential climate change issues emerging, and the high degree of concern for Shuswap Lake sockeye stocks during the recently completed Cohen Commission hearings. Large lakes, such as the Shuswap lakes are not immune to water quality degradation, as was clearly demonstrated in Shuswap Lake in June 2008 and Mara Lake in May 2010. Data and information are required to answer both long-term and acute water quality issues. However, these data collection programs are increasingly being pressured to reduce scope and resources.

The SLIPP program provides an approach that shares values and costs and provides an agent for communication and delivery of data to the public in accost-effective manner. It is the responsibility of the SLIPP participating agencies, participating NGOs and the public to ensure that they collaboratively 'stay the course', despite the pressures to reduce the program scope and resourcing. Such reductions would result in delivery of a fragmented and dysfunctional water quality monitoring program, and an inability to look at emerging issues and long term trends in lake water quality that drive environmental health in the region.

It's unlikely that the Shuswap Lake ecosystem can be adequately protected over the long term unless a comprehensive monitoring program continues, followed by action plans to reduce nutrient and contaminant loadings when and where required. A repeated lesson has been demonstrated in other water quality issues worldwide: it is safer, far less expensive, and less environmentally and socially-disruptive to prevent a water quality problem from developing than remedial or restoration actions after the problem has developed.

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7.1 Land-Use Maps

Figure 7-1 **Land use activities in Shuswap Lake watershed**

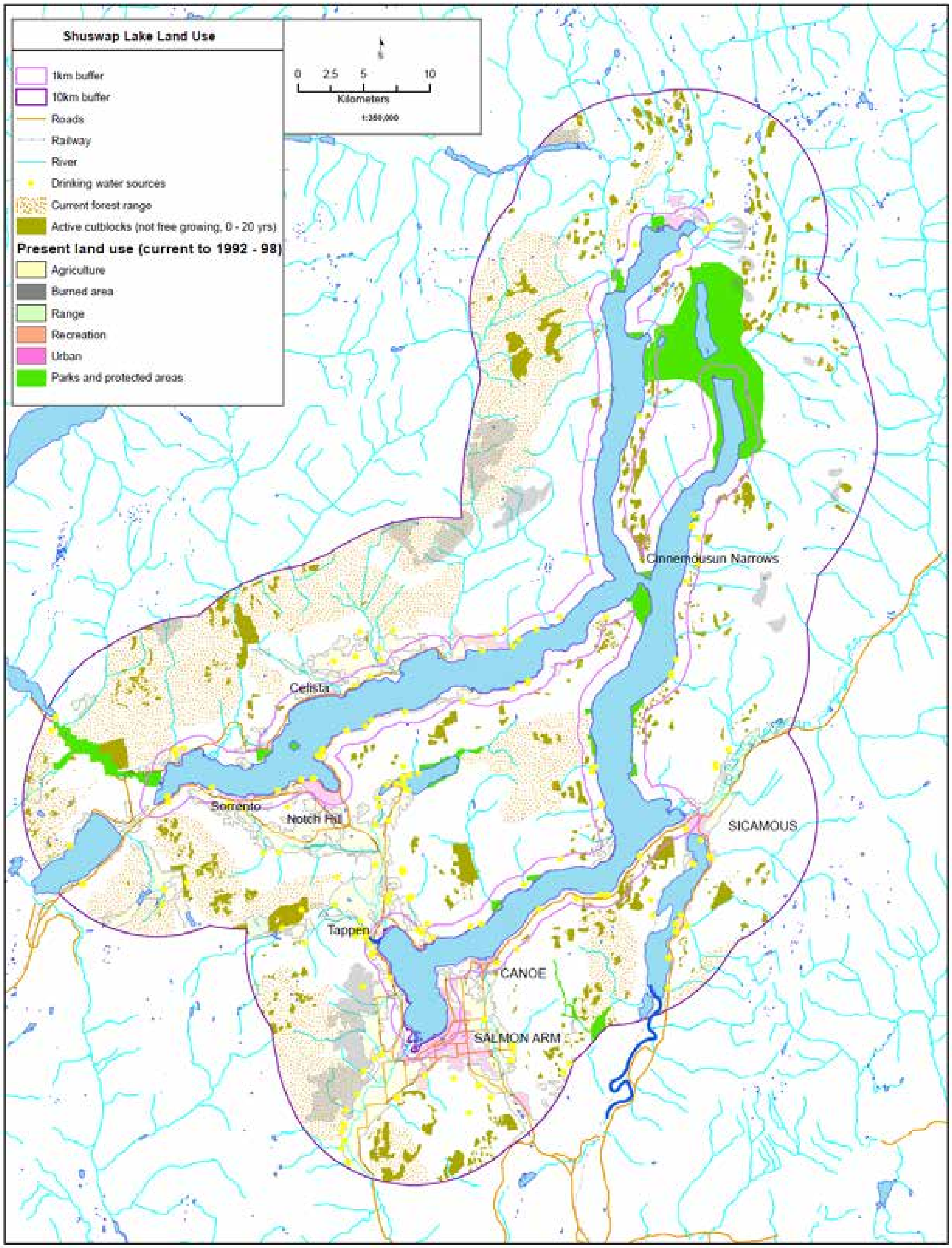


Figure 7-2 Land use activities in Adams River watershed

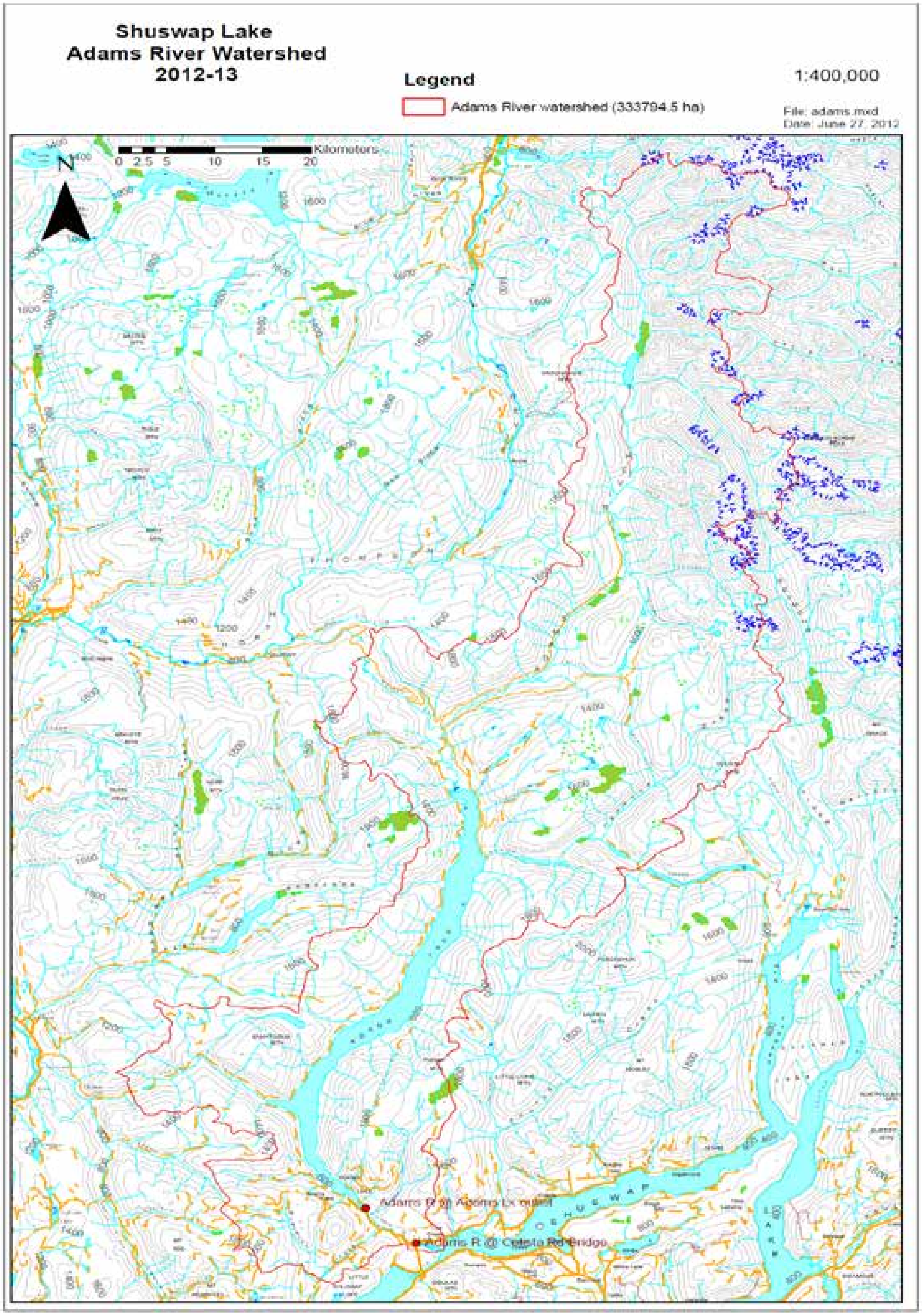


Figure 7-3 Land use activities in Seymour River and Celista Creek watersheds

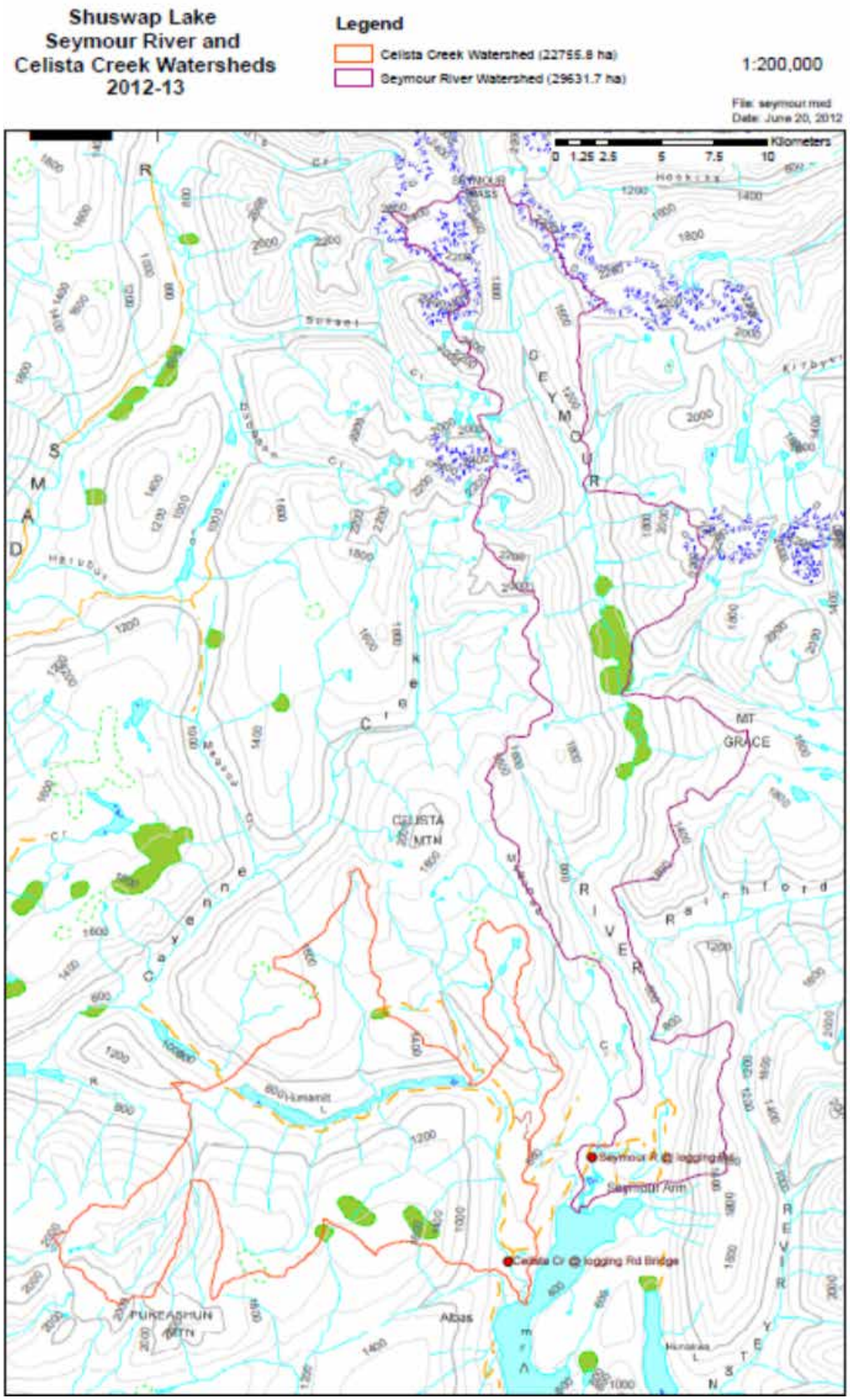


Figure 7-4 Land use activities in Canoe Creek watershed

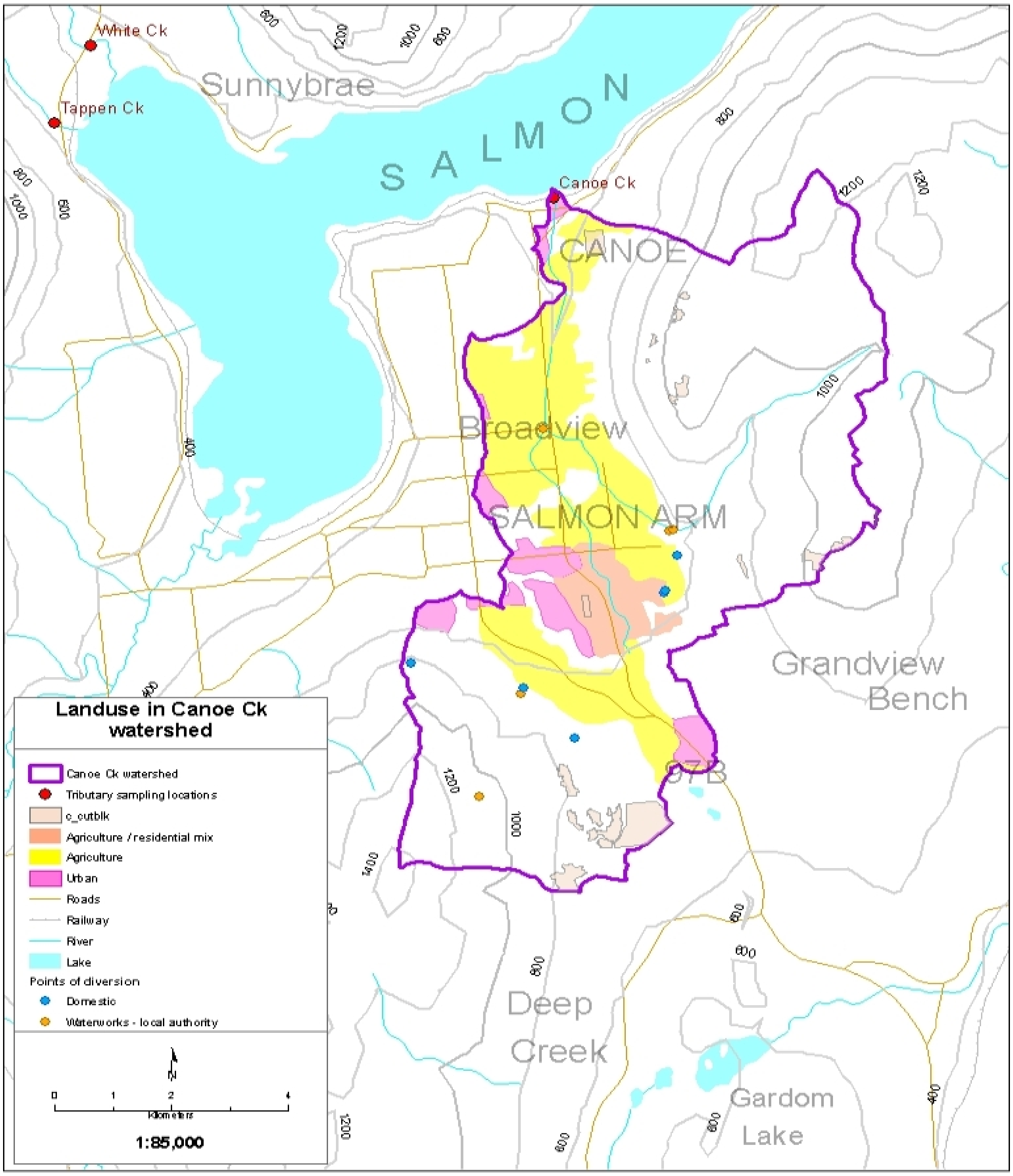


Figure 7-5 Land use activities in Eagle Creek watershed

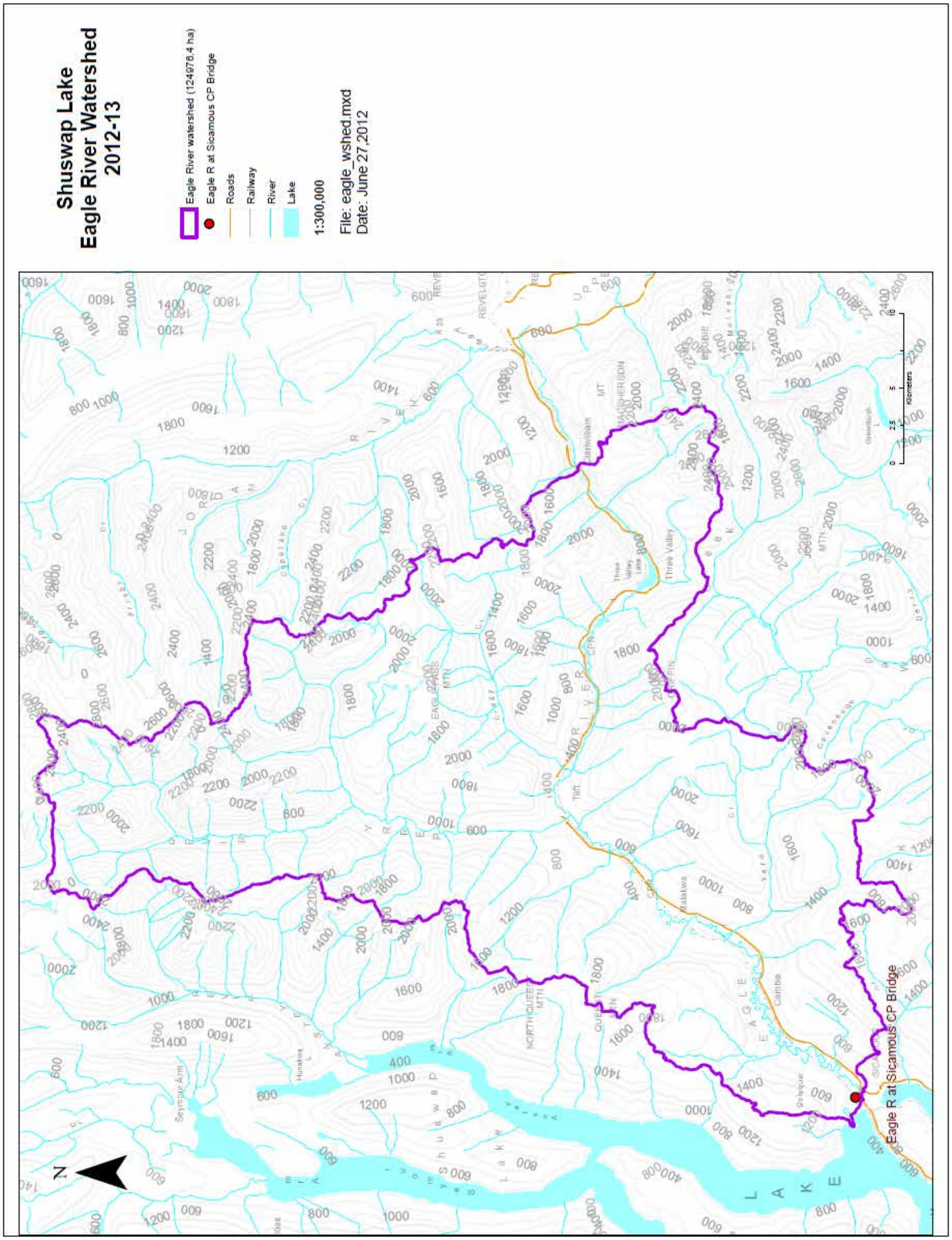


Figure 7-6 Land use activities in Sicamous and Hummingbird Creek watersheds

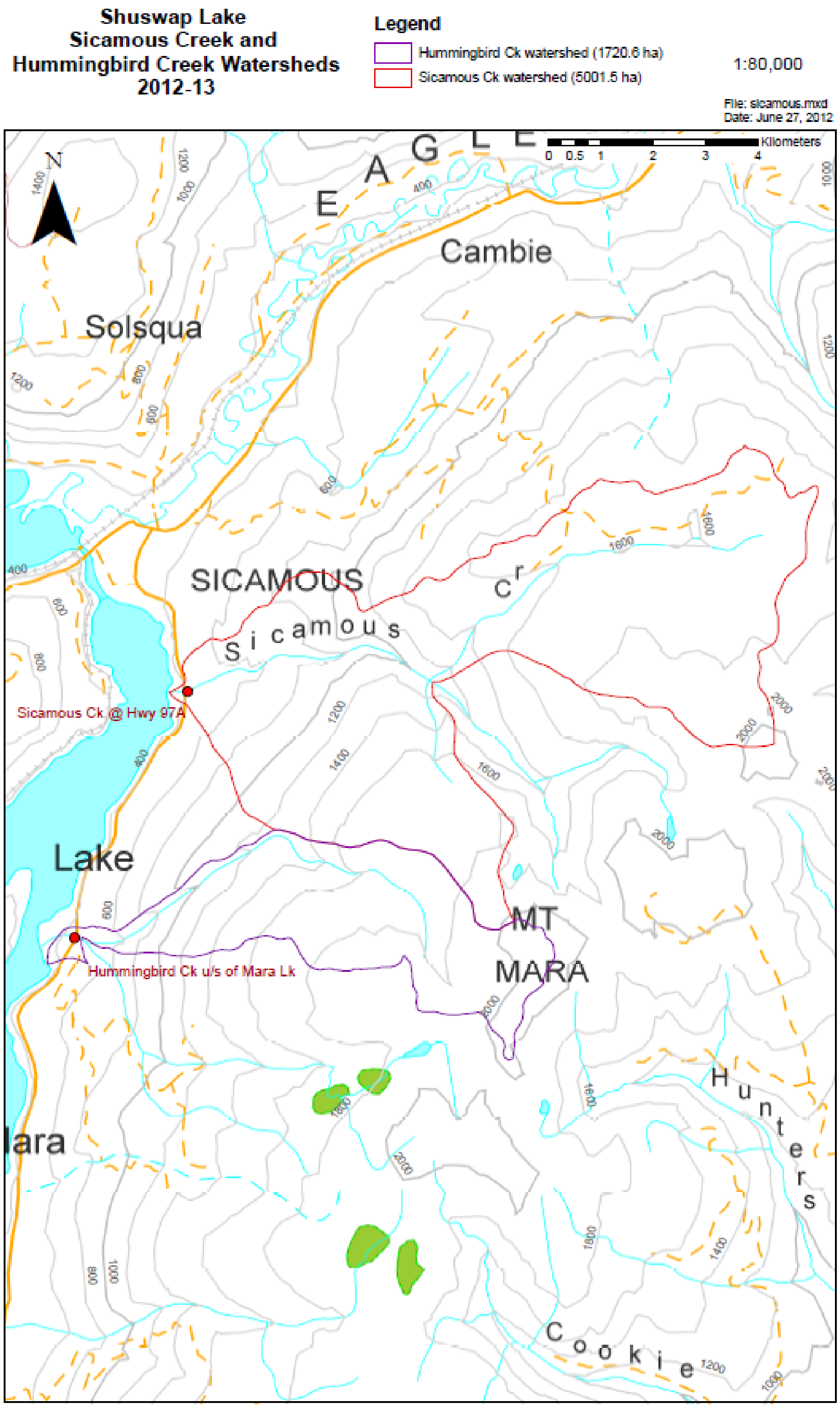


Figure 7-7 Land use activities in Newsome Creek watershed

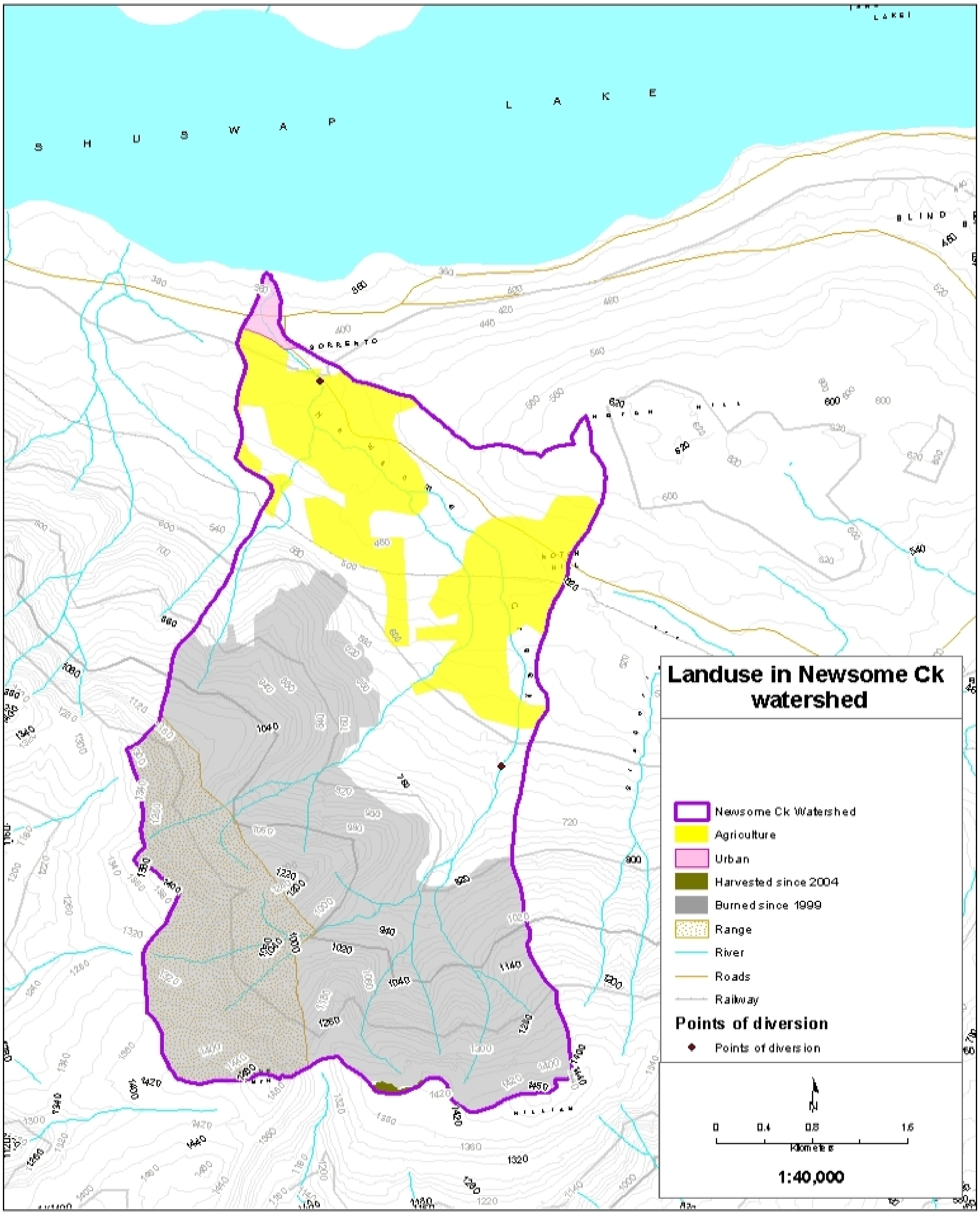


Figure 7-8 Land use activities in Scotch Creek watershed

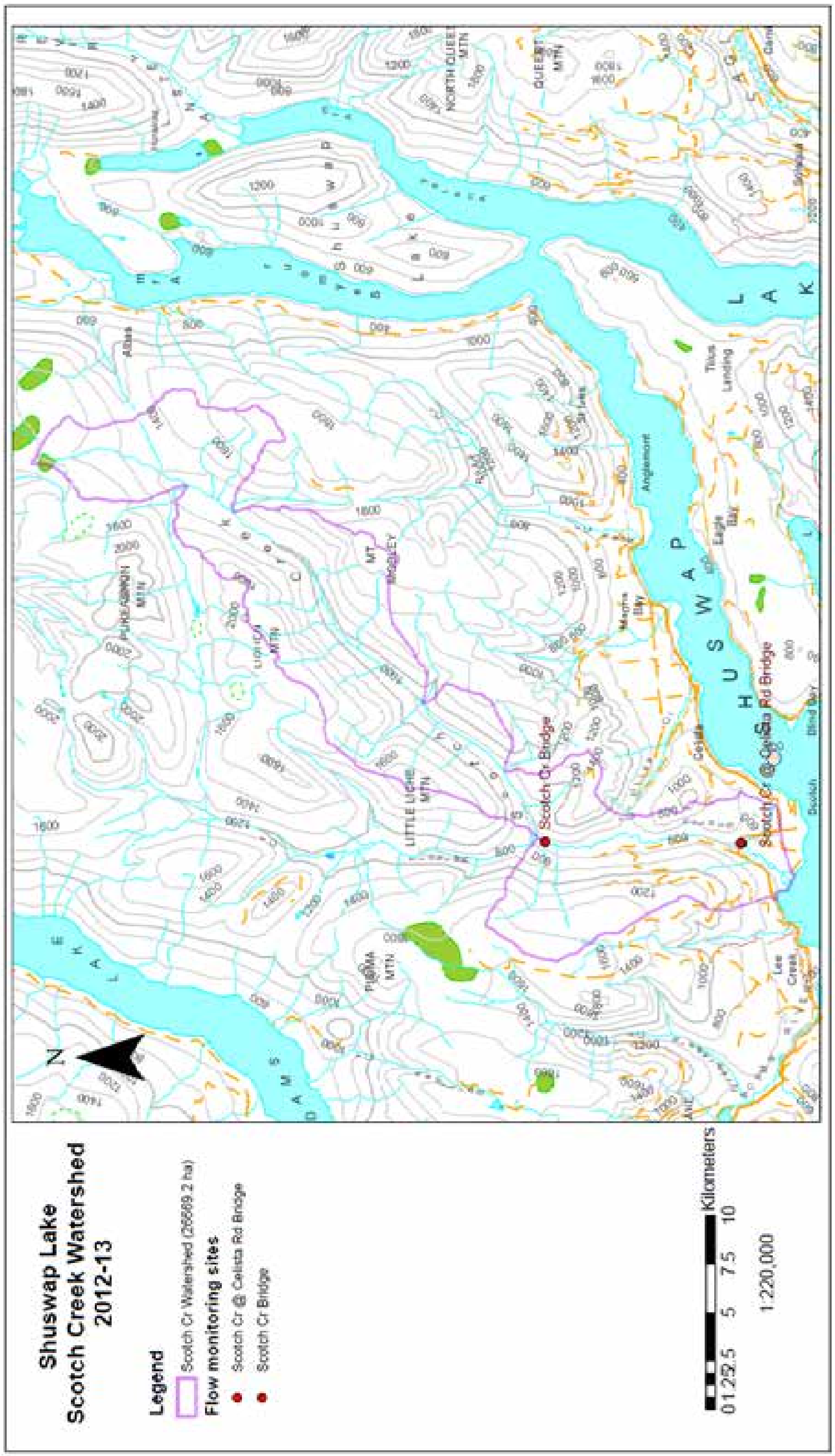


Figure 7-9 Land use activities in Salmon River watershed

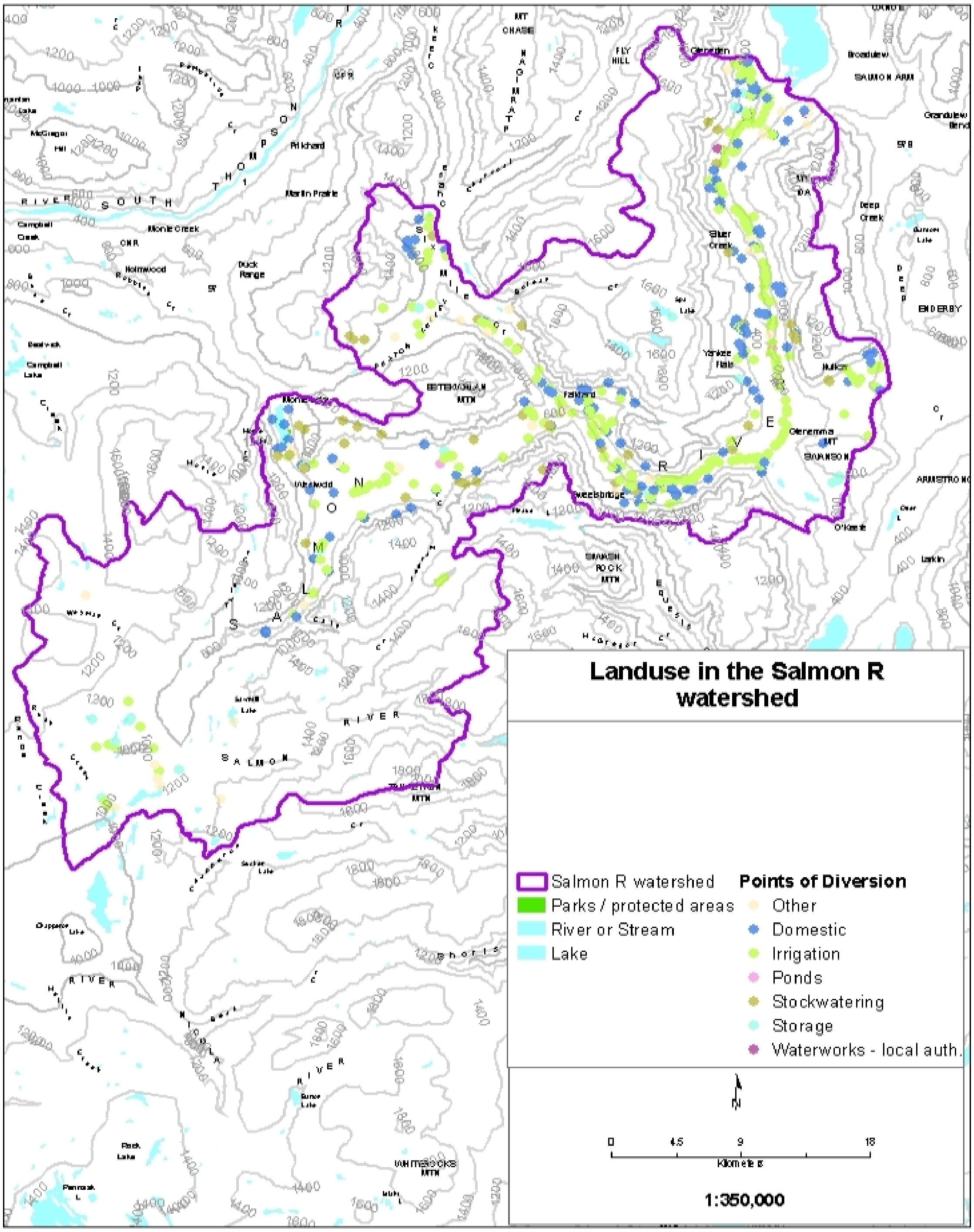


Figure 7-10 Land use activities in Tappen Creek watershed

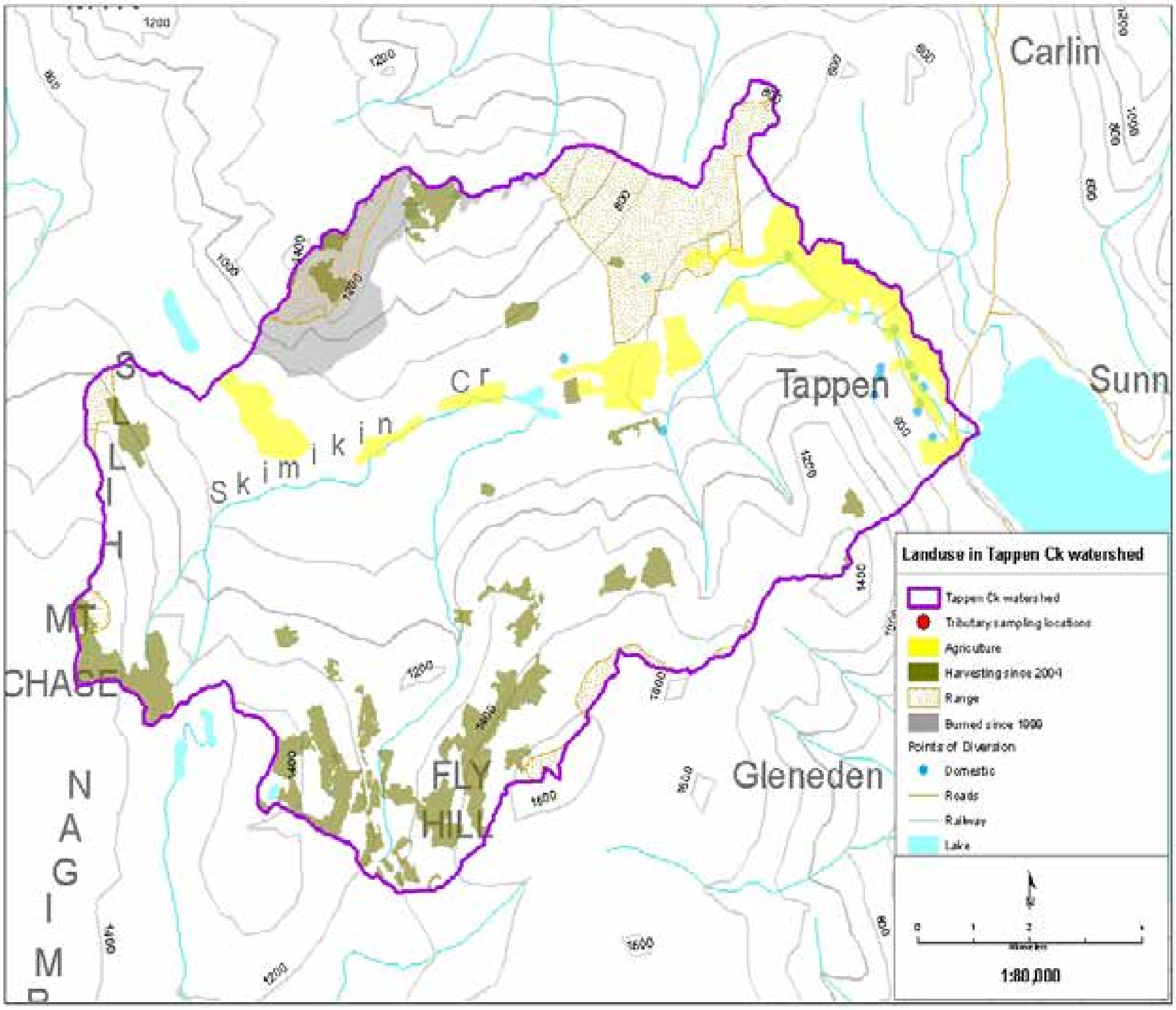
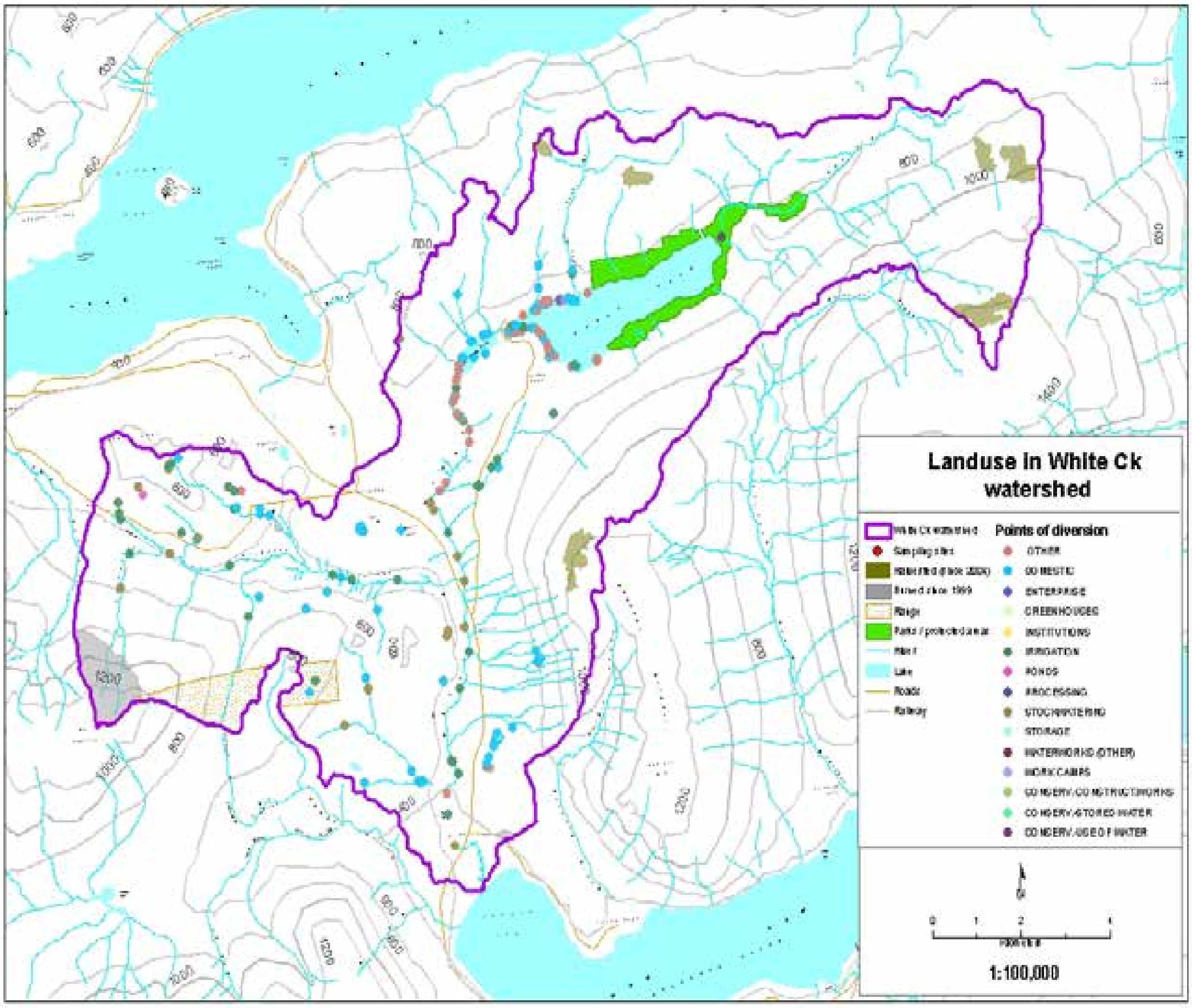


Figure 7-11 Land use activities in White Creek watershed



Appendix A Assessment of Primary Productivity in Shuswap and Mara Lakes

Introduction

The Shuswap watershed is an increasingly prized recreational destination that has experienced unprecedented development, densification, and recreational use in recent years (SLIPP 2008). Shuswap and Mara lakes provide critical rearing habitat for juvenile sockeye salmon (*Oncorhynchus nerka*), producing a cyclical, but often large number of adult salmon returning to the Fraser River. The rapid development within the Shuswap has led to significant concerns over water quality and aquatic habitat degradation, highlighting the trade-offs between unsustainable watershed development and use and the ability of the ecosystem to function as quality habitat for aquatic organisms including fish (SLIPP 2008).

In response to these concerns, the Shuswap Lakes Integrated Planning Process (SLIPP), an alternative governance model involving communities, First Nations, governments and public agencies, was initiated in 2006, with the intention of ensuring 1) development that respects the environment as well as economic and social interests; 2) water quality that supports public and environmental health; and 3) desirable recreation experiences that are safe and sustainable (SLIPP 2008).

As a member of the SLIPP water quality technical team, Fisheries and Oceans Canada's Lakes Research Program engaged in limnological research on Shuswap and Mara Lakes in 2011, to explore water quality and habitat changes for sockeye since a previous study conducted in the late-1980's and early-1990's (Nidle and Shortreed 1996; Morton and Shortreed 1996). Here, the primary productivity results (photosynthetic rates as measured by ^{14}C uptake experiments) are presented and discussed for Shuswap and Mara Lakes.

Methods

Shuswap and Mara lakes (50056' N, 119006' W) are located in the southeastern Fraser River drainage. The two systems are hydrologically-connected, with Mara Lake flowing into Shuswap Lake, which then empties to the South Thompson River via Little Shuswap Lake (**Figure A-1**). The lakes lie at an elevation of 347 m above sea level, occupying a combined surface area of 314 km^2, and are relatively shallow, with a mean depth of 58 m. With a relatively large watershed area of 15,335 km^2, Shuswap Lake is a fjordal system, comprised of multiple arms (Main Arm, Salmon Arm, Anstey Arm, Seymour Arm) that are limnologically quite distinct.

The Shuswap system has a relatively short water residence time for its area, averaging 2.1 years, likely owing to its relatively shallow depth and large watershed area and inflows. Much of eastern portion of the watershed is located within the Interior Western Hemlock biogeoclimatic zone, receiving 600 to 1,450 mm precipitation annually. By contrast, the western portion of the catchment lies in the Interior Douglas Fir biogeoclimatic zone, which experiences considerably less precipitation (350 to 600 mm/y; Farley 1979; Nidle and Shortreed 1996). The watershed experiences a variety of mixed land uses ranging from agriculture and light industry to substantial recreational and residential development that likely have varied effects on water quality within the lake.

Primary Productivity Estimation using 14C

In situ phytoplankton photosynthetic rates (PR) were estimated using a standard ^{14}C uptake technique (see Nidle and Shortreed 1996) at all stations and sampling dates from April to November. For each station, PR was measured at 7 depths from the lake surface to below the euphotic zone, which was estimated using a Licor data logger (Li250A) equipped with a spherical sensor (Li-92S). At each depth, glass bottles (two clear and one opaque) were filled with water collected at depth by Van Dorn sampler, and inoculated with a ^{14}C-radiolabelled bicarbonate (HCO_3^-) stock solution. All samples were incubated for 1.5-2 h at the original sampling depth/light climate. Throughout the study, incubations commenced between 0900 and 1100 h (Pacific Standard Time). On each sampling date, inoculant radioactivity was determined from 3 vials containing known quantities of the ^{14}C-bicarbonate solution mixed with 0.5 mL of 0.2N NaOH.

Following each incubation, bottles were placed in light-proof boxes and transported to the field laboratory, where samples were filtered at <2 h after the incubations were stopped (<20 cm Hg pressure). Known volumes of all samples were filtered through 25 mm diameter filters to estimate total PR at all stations (0.3 µm glass fiber filters) and size-fractionated PR at Stations 1,4,6 (0.3 µm glass fiber, 2 µm polycarbonate, and 20 µm Nitex filters). All filters were placed in scintillation vials containing 0.5 N HCl and the vial lids were left off for 6-8 h to evolve any unincorporated ^{14}C as CO_2.

Before counting, 10 mL of Scintiverse II (Fisher Scientific) was added to each scintillation vial. The radioactivity in each vial was determined using a Beckman Coulter LS6500 liquid scintillation counter. Quench series composed of the same scintillation cocktail and filters used for the samples were generated, and used to determine counting efficiency. The equation of Strickland and Parsons (1972) was used to calculate hourly PR. Daily PR (mg C/m^2/d) was estimated using sunlight data collected with Li-Cor LI-1000 data loggers and Li-Cor 190SA quantum sensors.

Seasonal averages of PR data from each station were calculated as time-weighted means of data obtained from April to November, assuming PR was negligible on May 1 and October 31. Whole-lake PR averages for Shuswap Lake were calculated by spatially weighting the value for each arm by the proportion of the lake it represented. Whole Lake PR for Mara Lake was estimated from the data gathered at Station 10.

For comparative purposes, historical PR data were included from an earlier study in the 1980's and 1990's, which employed similar methods. Refer to Nidle and Shortreed (1996) for further methodological detail on the earlier study.

Results and Discussion

Seasonal mean photosynthetic rates (PR) in Shuswap and Mara lakes demonstrated substantial spatial variation ranging from 162.3 - 245.4 mg C/m^2/d amongst the various arms and across lakes (**Figure A-2**). Seasonal mean PR was highest in Salmon Arm, followed in descending order by the Main Arm, Mara Lake, Anstey Arm and Seymour Arm. Variation in the magnitude of 2011 seasonal mean PR values were generally consistent with variability in trophic status between the arms (DFO unpublished data; Nidle and Shortreed 1996).

In relation to historical sampling, both the spatial and temporal patterns in seasonal mean PR were consistent with the suspected cultural eutrophication of Shuswap and Mara lakes since the late-1980's to early 1990's. The overall seasonal mean PR of Shuswap and Mara lakes appears to have increased substantially over historical levels, with the most notable increases in seasonal mean PR observed in the Main Arm and Mara Lake (**Figure A-3**). By contrast, Salmon, Seymour, and Anstey arms, exhibited seasonal mean PR within the range of historical variability (**Figure A-3**).

The lack of a clear temporal trend in seasonal mean PR in these arms may reflect the relatively undeveloped status of Seymour and Anstey arms, and the long-term historical development history of Salmon Arm.

Daily photosynthetic rates in Shuswap and Mara lakes in June 2011 were strongly correlated with spatial variation in the 2010 sockeye salmon spawner densities ($r = 0.90$, $p = 0.038$, $n = 5$), suggesting a potential salmon-derived nutrient (SDN) fertilization on primary productivity. This relationship, however, should be considered within the context of spatial variation in other land-use activities affecting PR in lakes (i.e. development, agriculture, sewage outfalls) to determine if SDN are a principal driver of primary productivity in Shuswap and Mara lakes.

Within the 2011 growing season, daily PR exhibited substantial spatial and temporal variation (**Figure A-4**). Peak daily PR was recorded in August in all arms except in the Main Arm and in Mara Lake, which demonstrated the highest daily PR in May and April respectively (**Figure A-4**). Elevated spring PR may reflect pronounced spring blooming of phytoplankton in the Main Arm of Shuswap Lake and Mara Lake. All sampling locations demonstrated relatively high daily PR throughout the growing season relative to lakes of similar size in the Fraser drainage (Shortreed *et al*. 2001).

Elevated daily PR was inclusive of April and November, when primary productivity is typically lower in lake ecosystems. An overall trend towards declining PR at the end of the growing season was evident in the more productive arms (Salmon, Main (Station 6)) and Mara Lake (Figure 194A,B,F), which may reflect seasonal nutrient limitation of phytoplankton under strong thermal stratification. Commensurate trends were not evident in the less biologically-productive arms (Anstey, Seymour; **Figure A-4**).

Daily PR fractionated by algal size class demonstrated disparate trends across Salmon, Main (Stn 6) and Seymour arms (**Figure A-5**). Picoplankton (algae < 2µm), nanoplankton (algae > 2µm < 20µm), and microplankton (algae > 20 µm) contributed to overall production throughout the growing season, but distinct seasonal trends were observed. Microplankton PR contributions to daily PR increased across all arms in late-May, with the most pronounced response in Salmon Arm, contributing 85% to overall productivity (**Figure A-5**). Less pronounced spring microplankton production increases were evident in Seymour and Main Arms (Figure 195B, C). The relative importance of picoplankton to daily PR increased throughout the growing season at all sites, with modest fall declines in Seymour and Main arms (**Figure A-5**).

Summary

Photosynthetic rates in Shuswap and Mara lakes have increased over historical measurements taken in the late-1980's and early-1990's, with the principal increases in primary productivity having occurred in the Main Arm and Mara Lake. The extent to which increased primary productivity in Shuswap and Mara lakes has resulted from changes in nutrient loading from land use activities versus carcass-loading from the elevated sockeye salmon return in 2010 remains difficult to resolve with a single year of data. PR data from subsequent years should help to highlight the relative importance of these nutrient loadings on biological productivity in Shuswap and Mara lakes.

Figure A-1 Fisheries and Oceans Canada's 201114C incubation stations in Shuswap and Mara lakes during 2011.

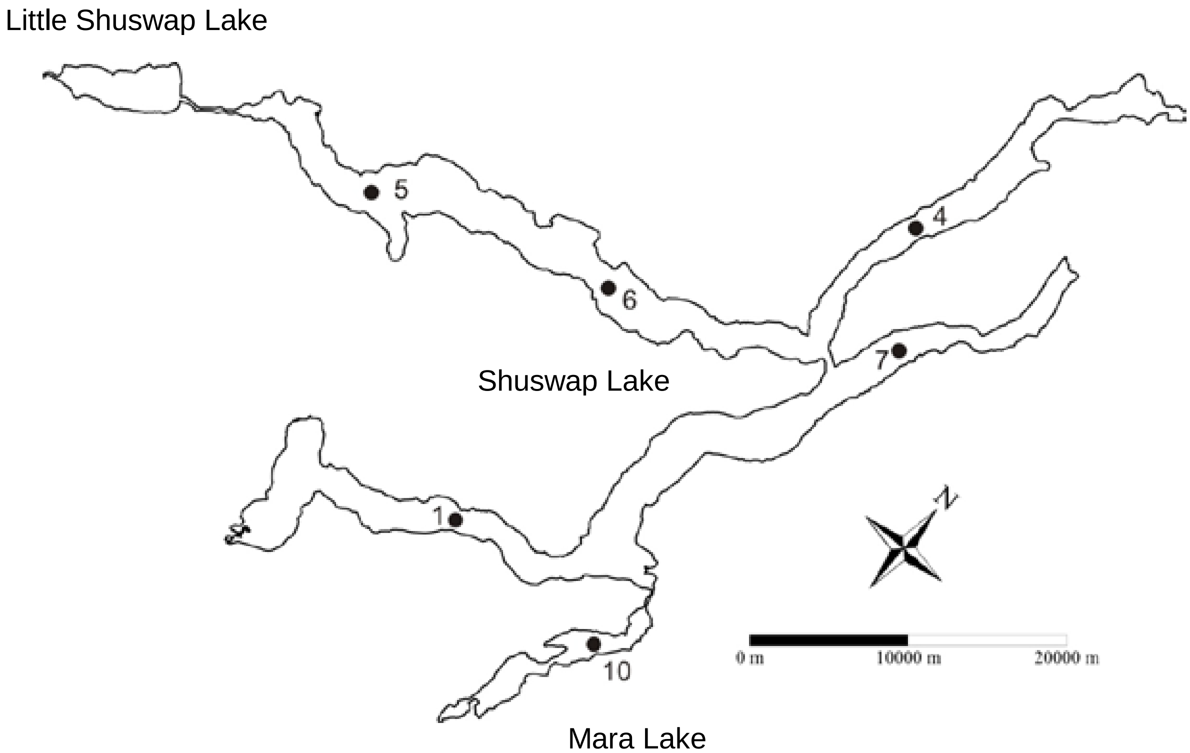


Figure A-2 2011 Seasonal mean photosynthetic rates (red bars) for A) Shuswap Lake (All Stns), B) Salmon Arm (Stn 1), C) Seymour Arm (Stn 4), D) Anstey Arm (Stn 7), E) Main Arm (Stn 6) in Shuswap and F) Mara Lake. Historical data are presented for reference (grey bars).

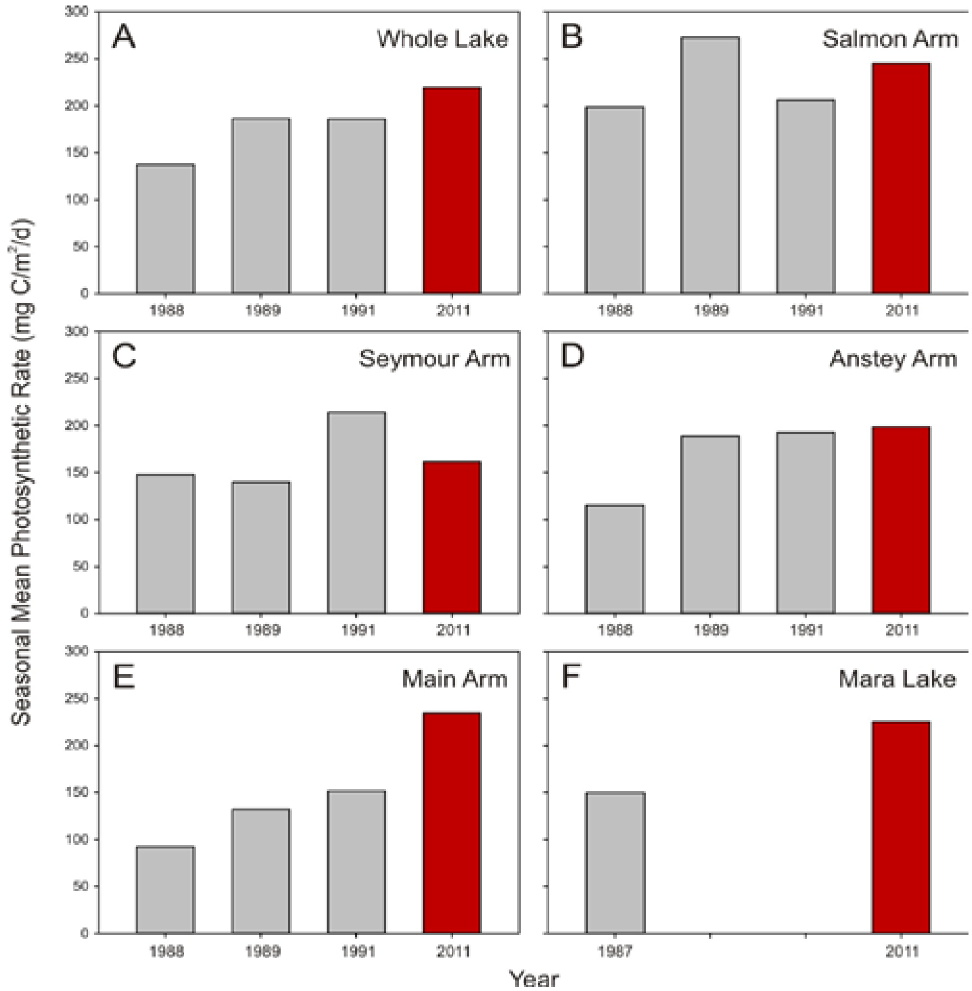


Figure A-3 2011 daily photosynthetic rates for A) Salmon Arm (Stn 1), B) Main Arm (Stn 6), C) Seymour Arm (Stn 4), D) Anstey Arm (Stn 7), and E) Main Arm (Stn 5) in Shuswap and F) Mara lakes (Stn 10), BC.

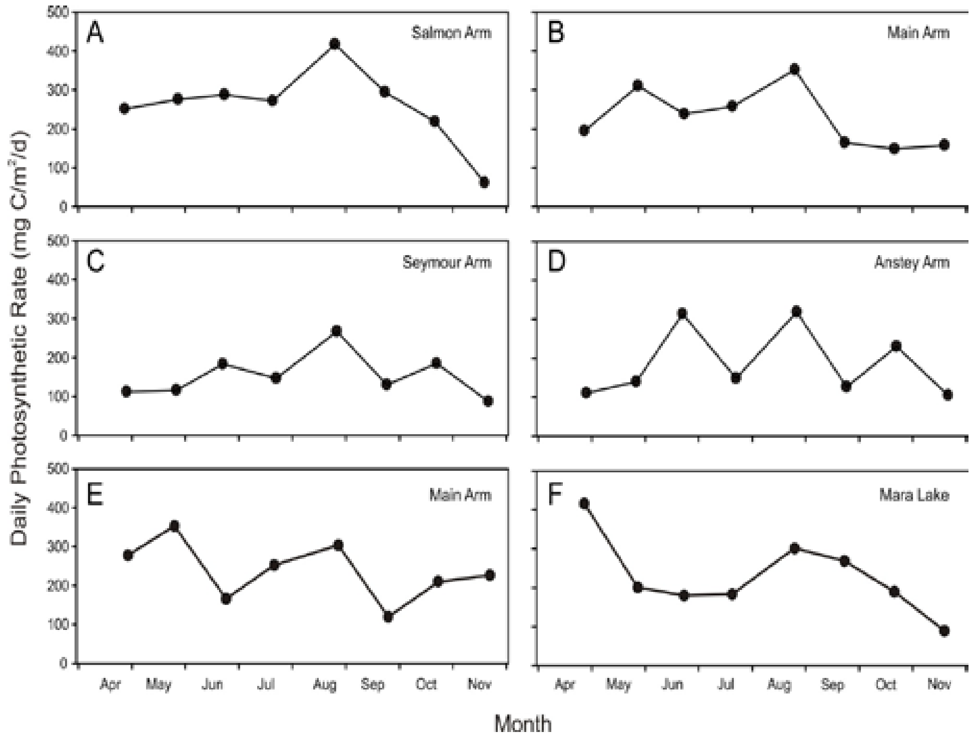
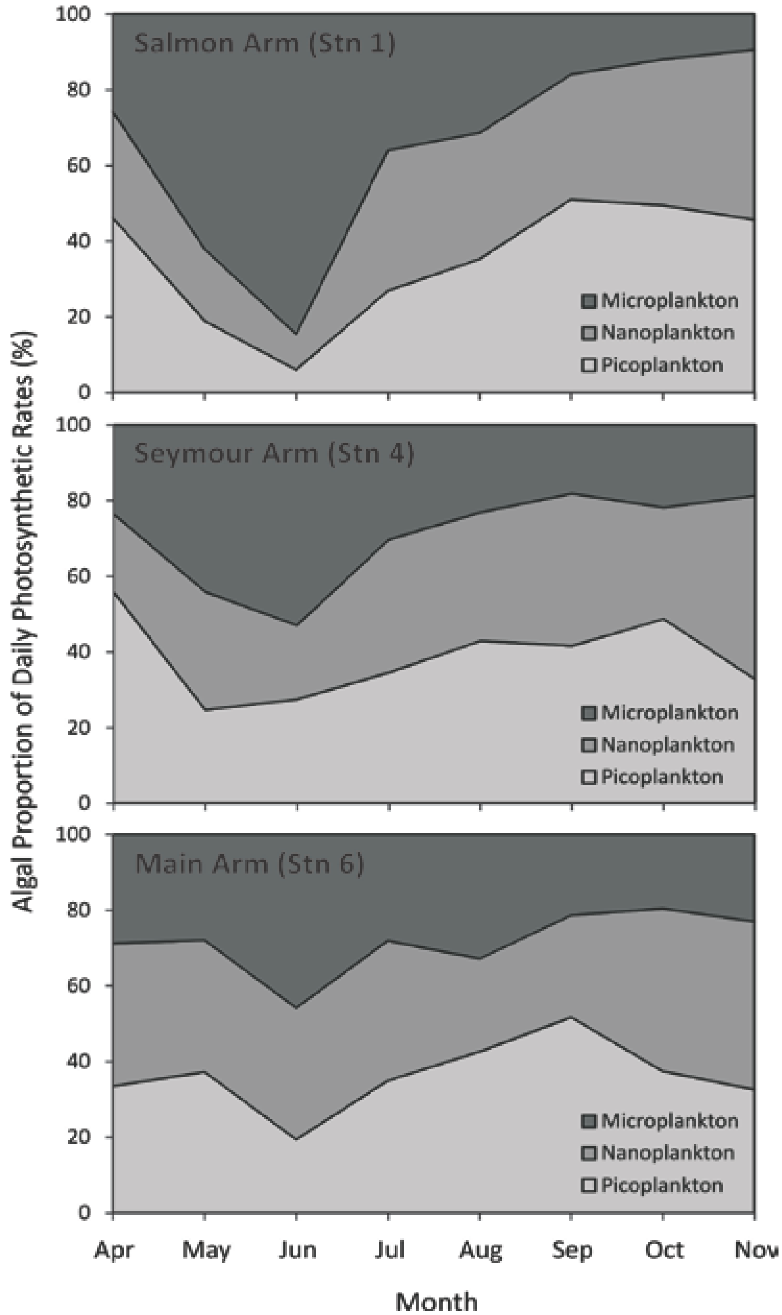


Figure A-4 2011 growing season contributions of algal size classes (microplankton >20 µm; nanoplankton (2-20 µm; picoplankton <2µm) to total daily photosynthetic rates in A) Salmon Arm (Stn 1), B) Seymour Arm (Stn 4) and C) Main Arm (Stn 6) in Shuswap Lake, BC.


Salmon Arm (Stn 1)
Seymour Arm (Stn 4)
Main Arm (Stn 6)
Microplankton
Nanoplankton
Picoplankton
Algal Proportion of Daily Photosynthetic Rates (%)
0
20
40
60
80
100
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Month

Appendix B Shuswap and Mara Lakes Phytoplankton Assessment

Background And Study Purpose

Mara Lake and contiguous sectors in 2008 and 2010 experienced spring mini-blooms of micro-flagellates dominated mainly by the 'golden' algae *Ochromonas spp.* (**Photo B-1**). These spring surface blooms have caused concern among local residents, municipalities and regional district that they may portend a possible growing trend nutrient enrichment or eutrophication of the southeastern sectors of Shuswap Lake, i.e. Salmon Arm and Mara Lake (**Figure B-1**).

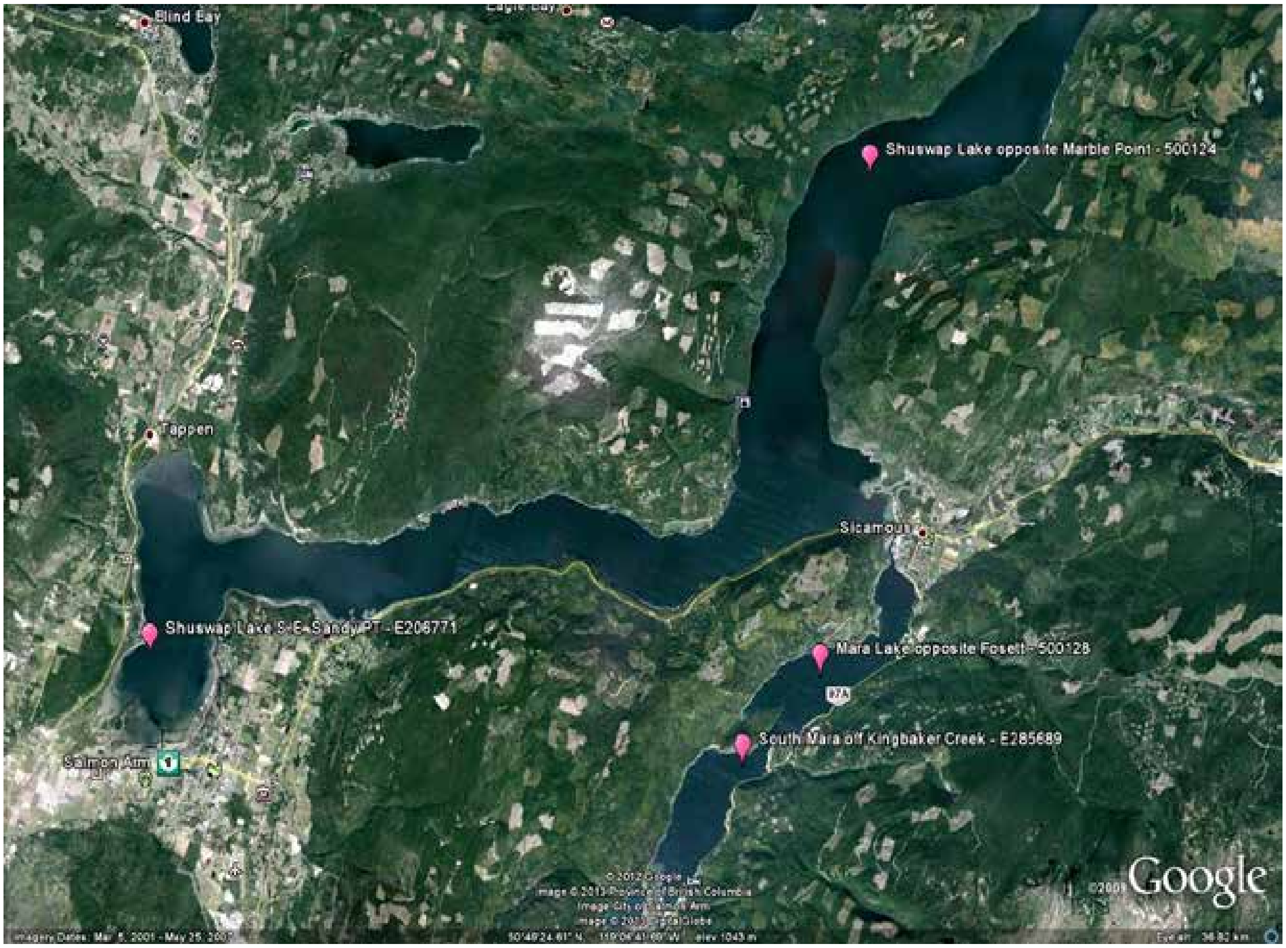
Adverse publicity prompted calls for increased monitoring and further lake studies to better understand causes, consequences and potential impacts on tourism, recreational and related activities. Municipal and regional districts and BCMOE approved a monitoring plan to further elucidate possible causes of the prevailing Mara Lake spring bloom condition. Increased monitoring of the lake and adjoining sectors began in 2010 and continued in 2011 and 2012 to enable more accurate measures of current' trophic state and identify causes of 'bloom' inception in Mara in spring of 2008 and 2010.

Earlier studies of Shuswap Lake and adjoining Sicamous Arm (Mara Lake) in the 80's and 90's classified the lake, with the exception of Salmon Arm, as a multi-basin interior *oligotrophic* lake; with characteristic low nutrient concentrations, low chlorophyll and plankton biomass with moderate to low fish production (Holmes 1987). However by early 2000 signs of change were to a more nutrient enriched condition were apparent, particularly in southeastern sectors like Salmon and Sicamous Arms that included Mara Lake.

This brief report examines the present trophic state of Mara Lake in 2011, identifies some of the factors causing spring flagellate blooms, and provides some answers to questions of water quality change in Mara Lake.

PhotoB-1 Flagellate bloom (streaks) Mara Lake, June 2010 (Photo by MOE, Fisheries Branch, Kamloops, BC)

Figure B-1 Sampling Sites in Mara and Shuswap lakes



Study Limitations

There were 4 stations sampled at a monthly and often bimonthly frequency, hence they provide only a series of 'snapshots' through the 2011-year of ambient nutrient concentrations, chlorophyll, and picoplankton and phytoplankton population abundance and biomass. Hence , this short report should not be considered as a comprehensive 'synthesis' of current state of Mara lake, rather a first glimpse of one year's seasonal change in Mara Lake, with anticipation of more yearly science-based reviews of Shuswap Lake and its major basins, including Mara Lake.

This report has attempted to interpret each of many of many factors that can affect the magnitude and/or duration of spring flagellate blooms in Mara Lake. This has in some cases had to be done without the support of additional data, e.g. primary production, periphyton distribution, some chemical variables, zooplankton, etc. Therefore discussions and conclusions are based on what present data, albeit limited, are telling us over a 1 year period – 2011; therefore conclusions must remain preliminary and may be viewed as tentative pending results of long term sampling and analyses.

Sampling Methods

There were 4 stations sampled; data from which were used in this Mara Lake review: **Stn. 1** - Shuswap Lake opposite Marble Pt. (124); **Stn. 2** - Mara Lake opposite Fosett (128); **Stn. 3** - South Mara off King-Baker Creek (689); the station closest to the Shuswap River inflow, and **Stn. 4**, Shuswap Lake SE. Sandy Pt. (771) at the head of Salmon Arm. At this station (**Stn. 4**), only phytoplankton were collected, no picoplankton or nutrient data.

Plankton sampling of Mara Lake began in February, was most intensive from March to June, a period of increasing light intensity, warming temperatures and high ambient nutrient levels, conditions that precede the annual spring plankton increase in north temperate lakes. Samples collected were limited to a single composite sample, from 0 to 15 m, a depth range that usually was well within the epilimnion.

Photo B-2 Shuswap River inflow to Mara Lake in June 2010, with noticeable flagellate bloom lower left corner, (Photo by MOE, Fisheries Branch, Kamloops, BC)

Phytoplankton

Lugol's (acidic iodine) preserved samples were gently shaken for 60 seconds and then poured into 25 mL settling chambers and allowed to settle for a minimum of 4 hrs. Quantitative counts were done on a Carl Zeiss inverted phase-contrast plankton microscope at a high power of 1,560X with and a low power scan of 700X to confirm uniform sample settlement of the bottom plate (Utermohl 1958) (**Figure B-2**).

In total, from 250 to 300 cells were enumerated in each sample to ensure statistical accuracy (Lund et al. 1958). The compendia of Prescott (1978), Canter-Lund and Lund (1995) and Wehr and Sheath (2003) were used as taxonomic references. All interpretations of seasonal plankton population trends reported herein are based principally on two key variables: cell density (cells/mL) and biovolume or biomass (mm^3/L).

Figure B-2 Epi-fluorescence microscopy with digital photomicrography and computer assist field magnification (A) and Inverted phase-contrast microscopy (B)

A **B**

Picoplankton

Minute (0.2-2.0 µ) picoplankton includes two major groups: 1. free-living Heterotrophic bacteria) and 2. Photosynthetic or Autotrophic pico-cyanobacteria, and these were sampled from the same composite depths and time intervals as phytoplankton, but only at the 3 major sampling sites, not Stn 4. Picoplankton samples were processed using techniques described by MacIsaac and Stockner (1981, 1993), and enumerated using dark-field epi-fluorescence microscopy (Figure 24 A).

Nutrients

All data examined for this review were assembled from data files of BCMOE Environmental Quality Unit in Kamloops, BC. Methods utilized in current and past monitor programs can be obtained from the MOE office upon request. Most nutrient data presented here comes from the epilimnion (0 to 15 or 20 m) or from within photic zone. The primary nutrients for plankton growth are phosphorus (P) in total dissolved -filtered (TDP) and particulate – unfiltered form (TP) and nitrogen (N) in dissolved (NH_3, NO_3, + DON [organic N]) and particulate forms (Kjeldahl). Patterns of nutrient concentration and distribution in 2011 season are shown in Figures 25-29, with the exception of Kjeldahl - N values that are not shown. No nutrient data were received from BCMOE from Salmon Arm. Stn. 771.

Results

Seasonal Pattern of Nutrients

A common seasonal pattern throughout most Shuswap Lake Arms and sub-basins is characterized by lower TP and TDP, higher NO_3, DIN and Chlorophyll values followed by gradually declining NO_3 through the summer period reaching lowest values in late-summer and early fall (Table B-1, **Figure B-3;A-C**), caused by phytoplankton uptake of NO_3 DIN within the epilimnion with little mixing of richer hypolimnetic water through the stable metalimnion. The TN: TP ratio falls below the Redfield ratio concurrent with the summer decline, signalling co-limitation by both N and P at this period (Figure B-3:B).

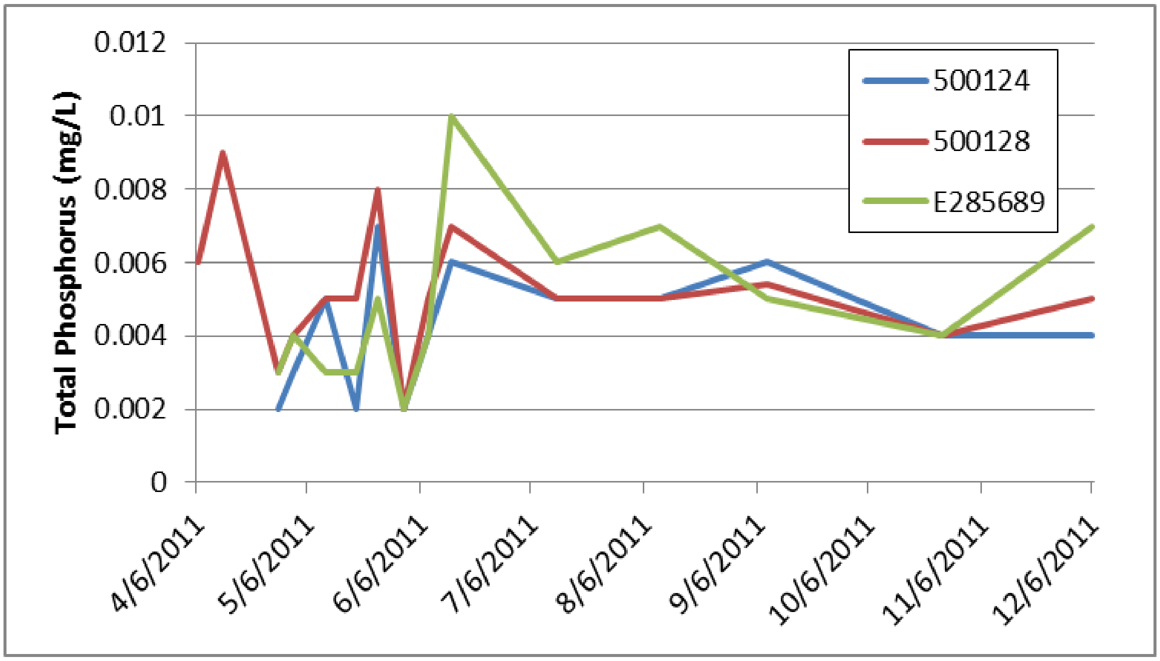
Table B-1 Nutrient concentrations at 2 study stations in Mara and 1off Marble Pt., upper Shuswap Lake 2011

Station	Season	Total Nitrogen (mg/L)	Total Inorganic Nitrogen (mg/L)	Total Phosphorus (mg/L)	Ortho-Phosphate (mg/L)	Chl a (µg/L)
Shuswap Lk opposite Marble Pt. (500124)	Spring	0.20	0.06	0.004	0.001 (62%<RL)	2.48
	Summer/Fall	0.10	0.03	0.005	0.0018 (60%<RL)	1.98
Mara Lake opposite Fosett (500128)	Spring	0.21	0.06	0.004	0.001 (75%<RL)	4.50
	Summer/Fall	0.12	0.04	0.006	0.002 (60%<RL)	2.61
South Mara off King-Baker Creek (E285689)	Spring	0.20	0.05	0.005	0.0013 (70%<RL)	4.95
	Summer/Fall	0.10	0.03	0.005	0.0016 (60%<RL)	2.00

Seasonal changes in DIN and DON at each of the 3 stations sampled in this review show an interesting pattern of change in DON abundant through the growing season in Mara's Stn. 128 and 689, but declining in a pattern similar to DIN-NO_3 at Marble Pt., Shuswap Lake (Figure B-3:C). It is interesting that the highest values of DON are at the Stn. 128 closest to the Shuswap River inflow, likely the major source of DON and DIN in Mara Lake.

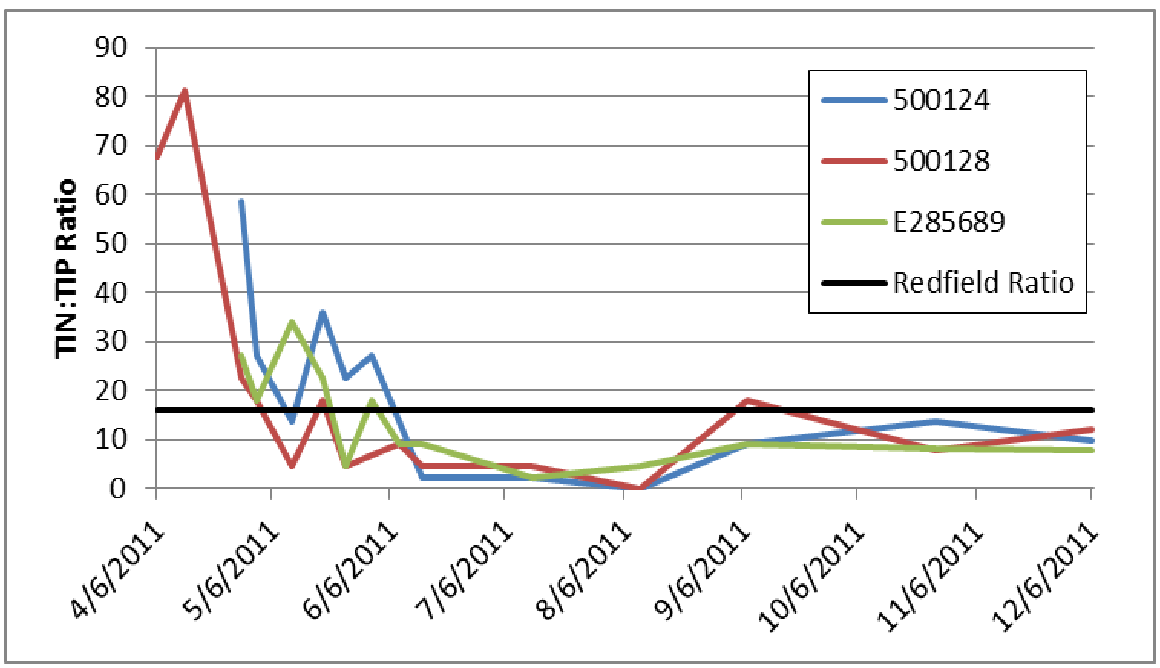
Figure B-3 Seasonal pattern of TP (A), TN: TP ratio (B) and Total Chlorophyll (C) concentrations at stations 124 Marble Pt.; 128 Mara off Fosett; and 689 Mara off King-Baker Creek

A



0.012
0.01
0.008
0.006
0.004
0.002
0
Total Phosphorus (mg/L)
4/6/2011
5/6/2011
6/6/2011
7/6/2011
8/6/2011
9/6/2011
10/6/2011
11/6/2011
12/6/2011
500124
500128
E285689

B



90
80
70
60
50
40
30
20
10
0
TIN:TIP Ratio
4/6/2011
5/6/2011
6/6/2011
7/6/2011
8/6/2011
9/6/2011
10/6/2011
11/6/2011
12/6/2011
500124
500128
E285689
Redfield Ratio

C

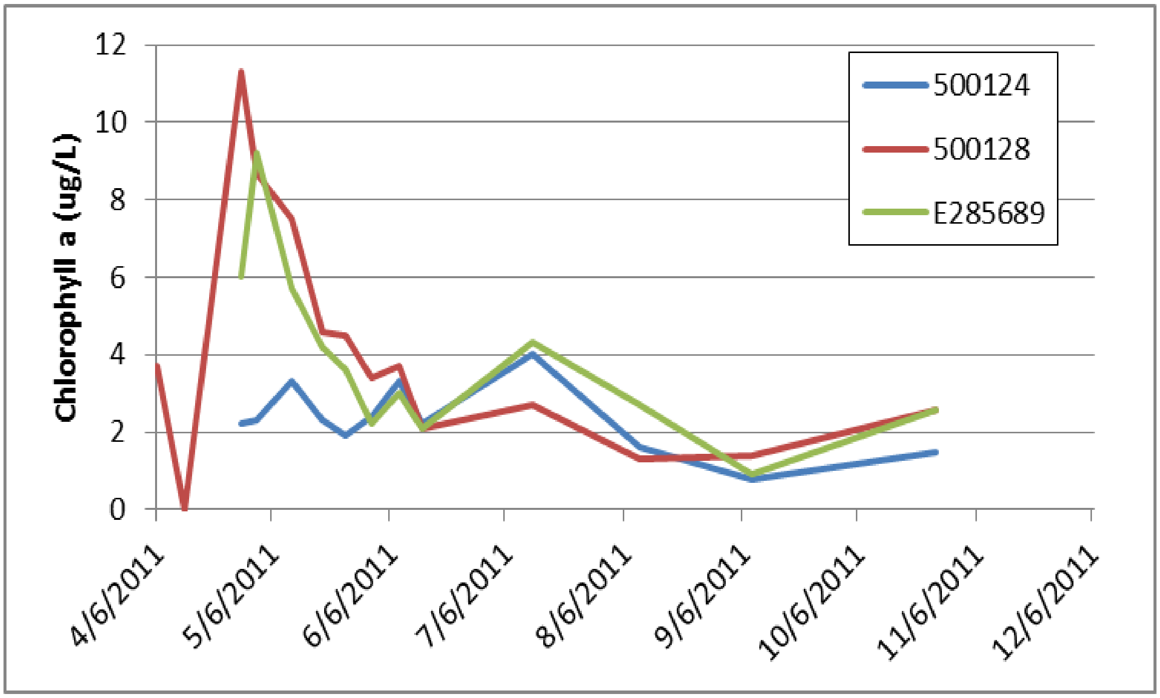
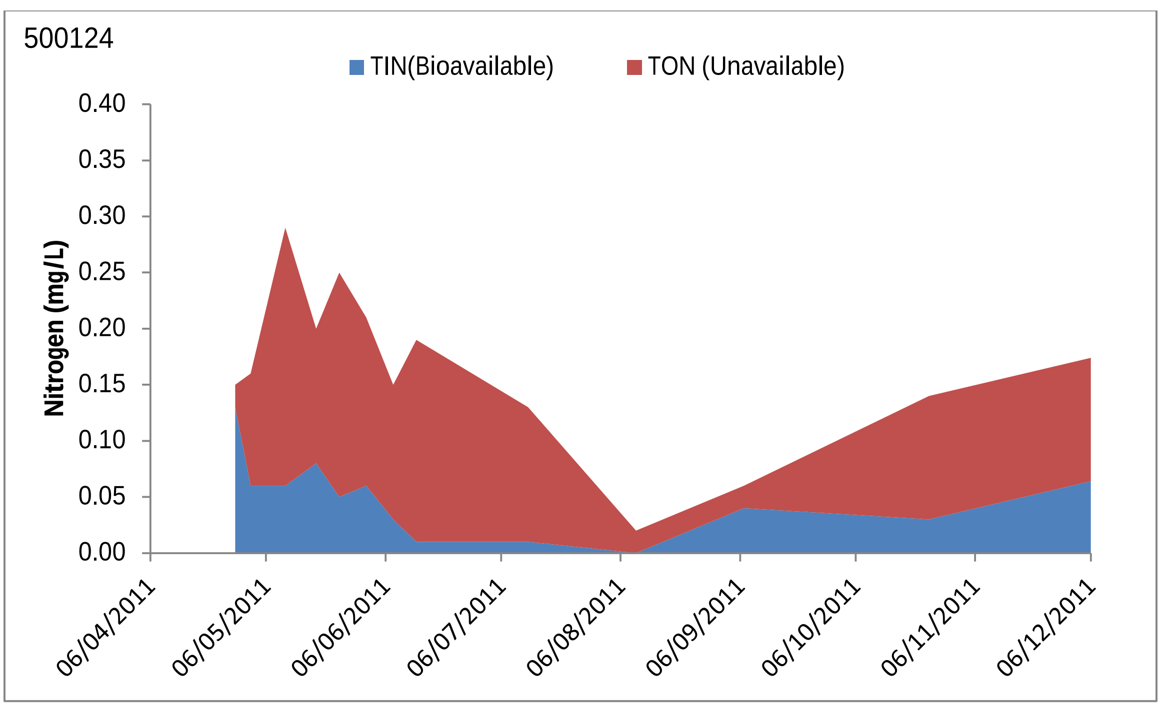
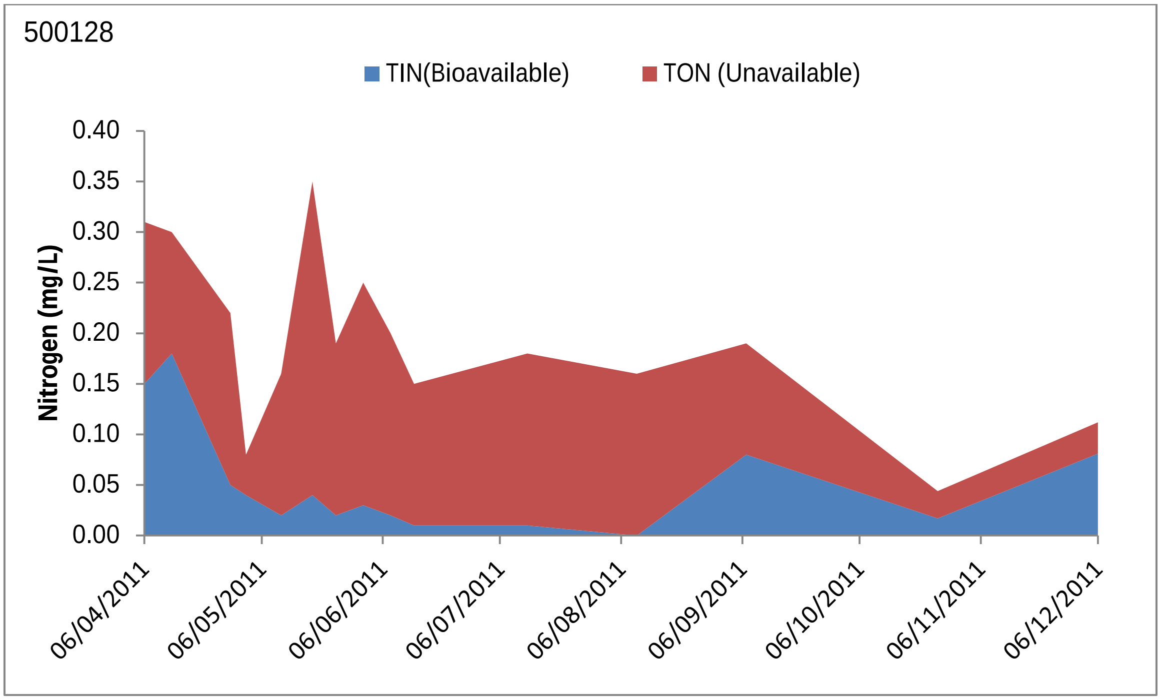


Figure B-4 Seasonal pattern of total inorganic N (TIN) and total organic N (TON) at stations 124 Marble Pt (A); 128 Mara off Fosett (B); and 689 Mara off King-Baker Cr (C)

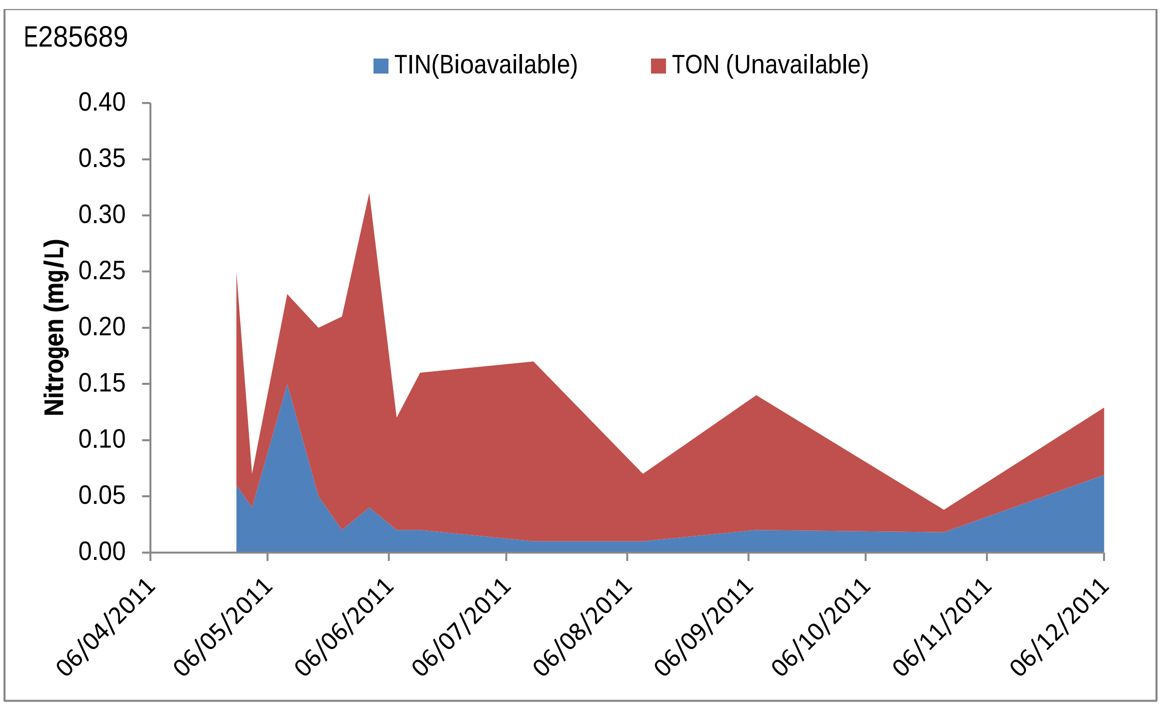
A



B


500128
TIN(Bioavailable)
TON (Unavailable)
Nitrogen (mg/L)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
06/04/2011
06/05/2011
06/06/2011
06/07/2011
06/08/2011
06/09/2011
06/10/2011
06/11/2011
06/12/2011

C

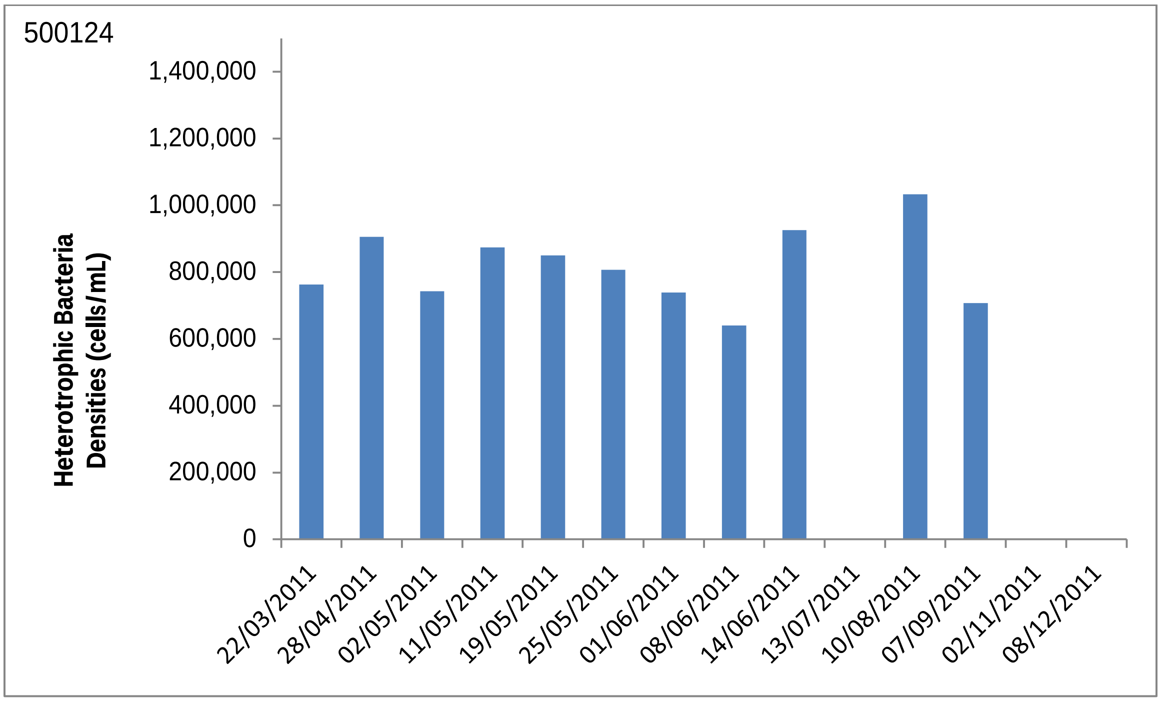

E285689
TIN(Bioavailable)
TON (Unavailable)
Nitrogen (mg/L)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
06/04/2011
06/05/2011
06/06/2011
06/07/2011
06/08/2011
06/09/2011
06/10/2011
06/11/2011
06/12/2011

Picoplankton - Bacteria

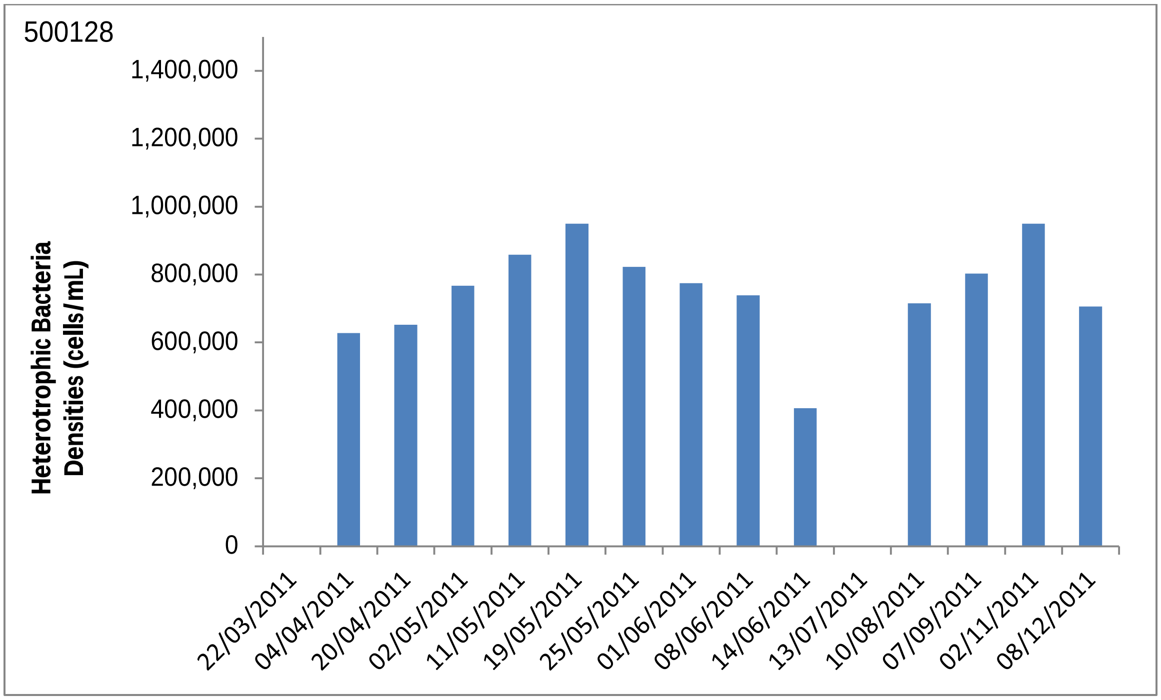
The population densities of free-living bacteria did not show major differences among stations or seasons (March to September), with an annual average density of about 750,000 cells/mL and ranging from a low of 400,000 in mid-June at Stn. 128 to a highs of over a 1,000,000 cells/mL in mid-May at Mara stations and in August in Shuswap Lake Stn. at Marble Pt. (**Figure B-5:A-C**) At Mara stations populations declined to about 600,000 to 700,000 cells/mL in mid-summer and rose again to close to a 1,000,000 in October – November Mara Lake overturn, i.e. winter mixing period.

Figure B-5 Seasonal patterns of free-living bacteria population growth at stations 124 Marble Pt (A); 128 Mara off Fosett (B); and 689 Mara off King-Baker Cr (C)

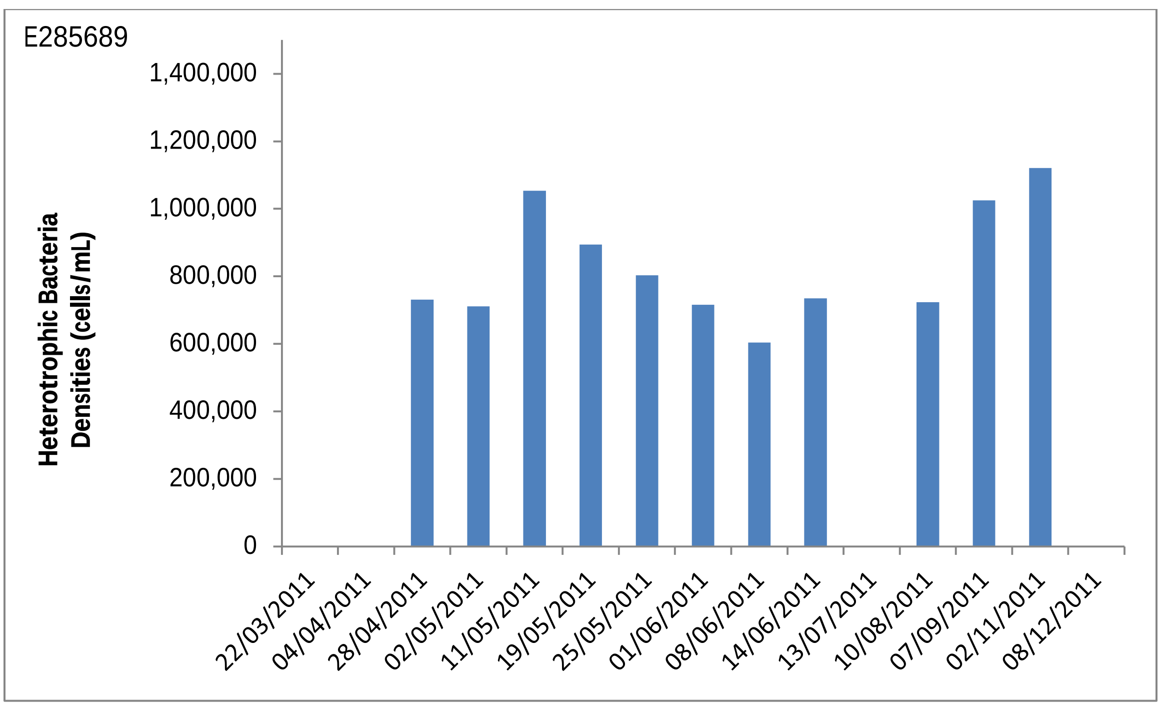
A



B


500128
Heterotrophic Bacteria Densities (cells/mL)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
22/03/2011
04/04/2011
20/04/2011
02/05/2011
11/05/2011
19/05/2011
25/05/2011
01/06/2011
08/06/2011
14/06/2011
13/07/2011
10/08/2011
07/09/2011
02/11/2011
08/12/2011

C


E285689
Heterotrophic Bacteria Densities (cells/mL)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
22/03/2011
04/04/2011
28/04/2011
02/05/2011
11/05/2011
19/05/2011
25/05/2011
01/06/2011
08/06/2011
14/06/2011
13/07/2011
10/08/2011
07/09/2011
02/11/2011
08/12/2011

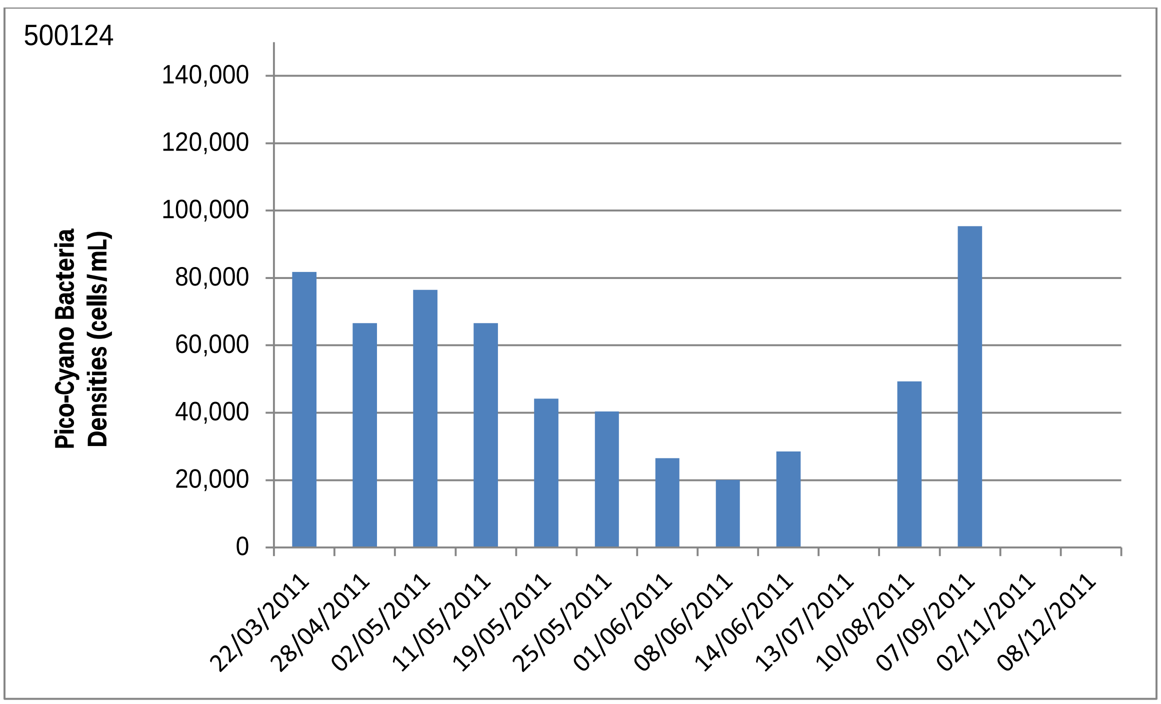
Photosynthetic Pico-Cyanobacteria

The Major pico-cyanobacterial species in Mara and Shuswap were *Synechococcus* and *Synechocystis*, both species with dimensions of <2 µm and possessing a very low biovolume (Stockner 1991). Populations of pico-cyanobacteria were largest from March to May 50,000 to 75,000 cells/mL at Shuswap Marble Pt. – Shuswap Lake, declining to lower levels (20,000 to 30,000 cells/mL) through the summer early fall period, and increasing to over 90,000 cells/mL in August and September (**Figure B-6:A**).

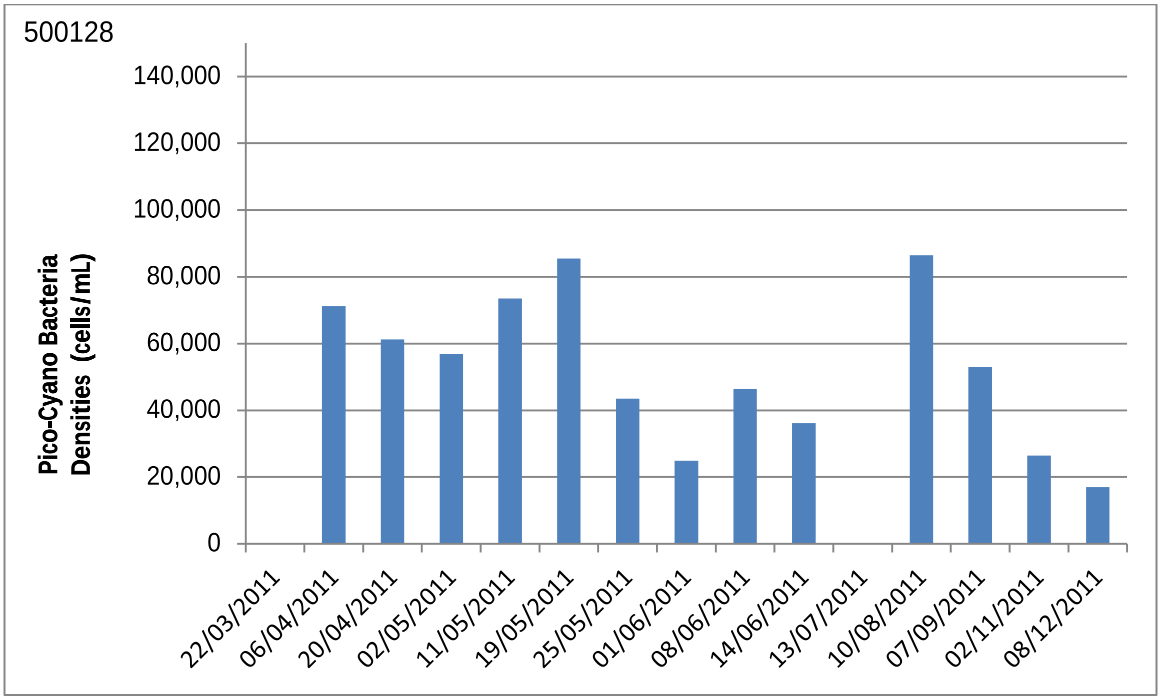
A similar pattern occurred at Mara Lake-Fosett Stn. 128 but average values were higher than in Marble Pt. and peaked in mid-May at 85,000 cells/mL, showed a summer decline then increased again in August to peal values over 90,000 cells/mL and tailed off to < 40,000 cells/mL by Oct and further declined to values less than 20,000 cells/mL by November (**Figure B-6:B**). At Mara King-Baker Creek Stn. 689, concentrations were lower throughout the growth period showing a small peak of 75,000 cells/mL in May then showed a marked decline through the summer with another small peak of 60,000 cells/mL in September (**Figure B-6:C**).

Figure B-6 Seasonal patterns of pico-cyanobacteria population growth at stations 124 Marble Pt (A); 128 Mara off Fosett (B); and 689 Mara off King-Baker Cr (C)

A



B



C

[Figure missing from draft report]

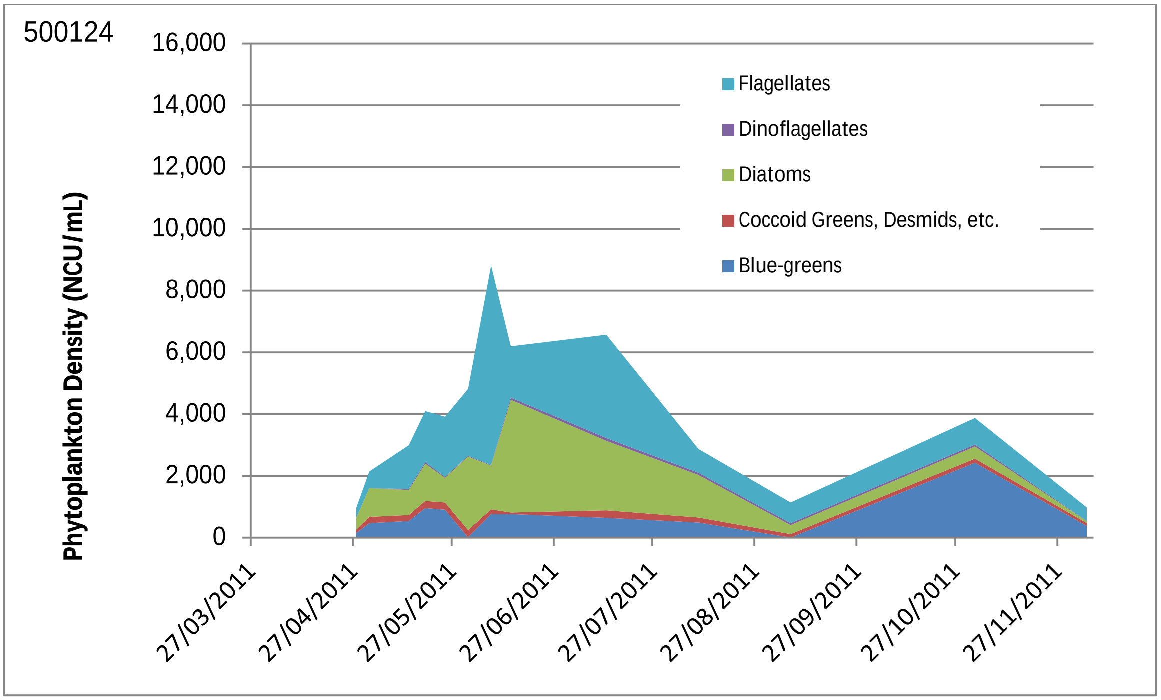
Phytoplankton

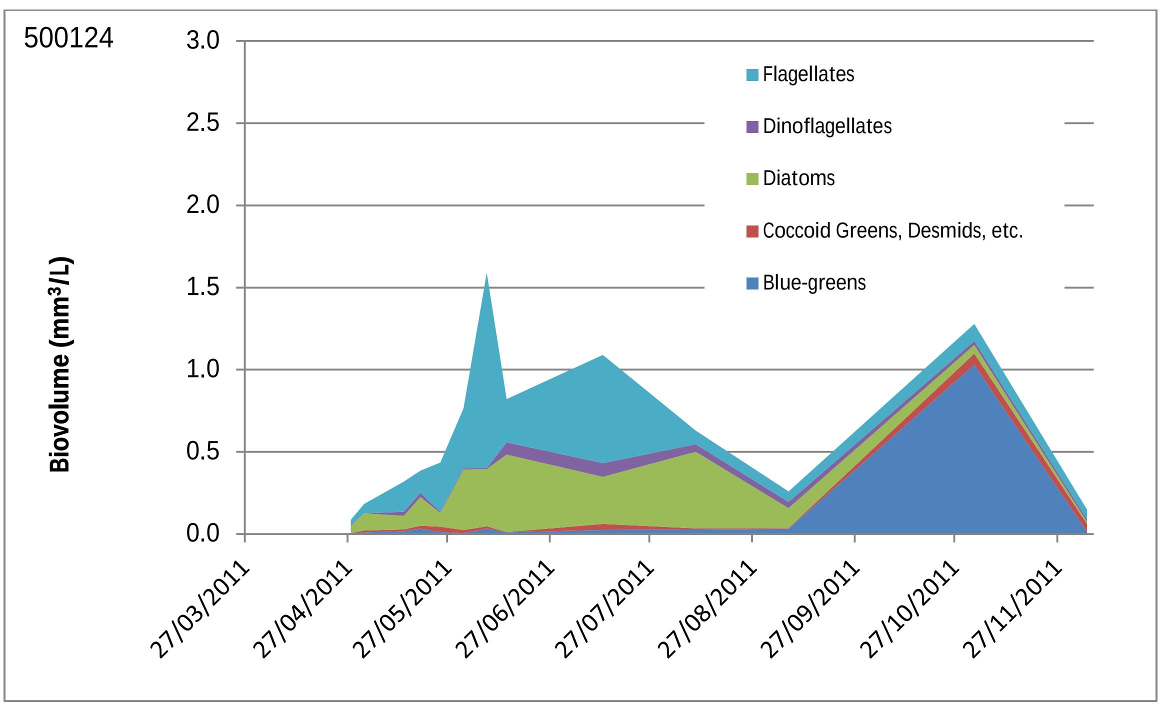
The phytoplankton assemblages at both Mara Lake stations showed greater densities and biomass than populations off Marble Pt. in Shuswap Lake (**Figure B-7:A-D**). Not surprisingly, total phytoplankton populations in Mara Lake peaked in May and early June and were chiefly dominated by flagellates, with a considerably smaller increase in diatoms and remaining groups in late June and early July. Stn. 689 off King-Baker Creek, the Stn. closest to the Shuswap River inflow, had the largest total population peak reaching over 15,000 cells/mL in late May early June and comprised mainly of Flagellates, notably *Ochromonas* spp. (**Figure B-7:C**).

At Mara Stn. 128 off Fosett, flagellates were again dominant with total phytoplankton density of about 12,000 cells/mL peaking in late May – early June (**Figure B-7:B**). Populations at all stations tailed-off in autumn to much lower levels without notable peaks. Stn. 771 in Salmon Arm showed a less striking peak of flagellates and diatoms in late July and early August at peak densities of 12,000 cells/mL (**Figure B-7:D**).

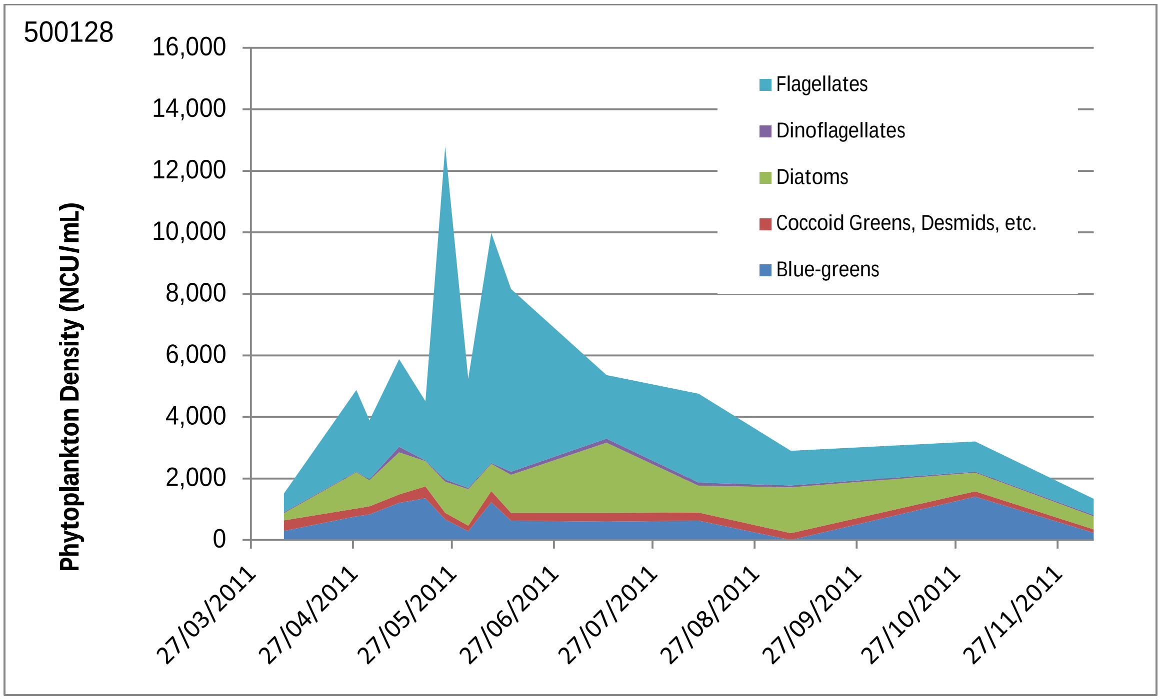
Figure B-7 Seasonal patterns of major groups of phytoplankton population density and biovolume at Stations 124 Marble Pt (A); 128 Mara off Fosett (B); and 689 Mara off King-Baker Cr (C) and 771 Shuswap Lake, off Sandy Pt (D)

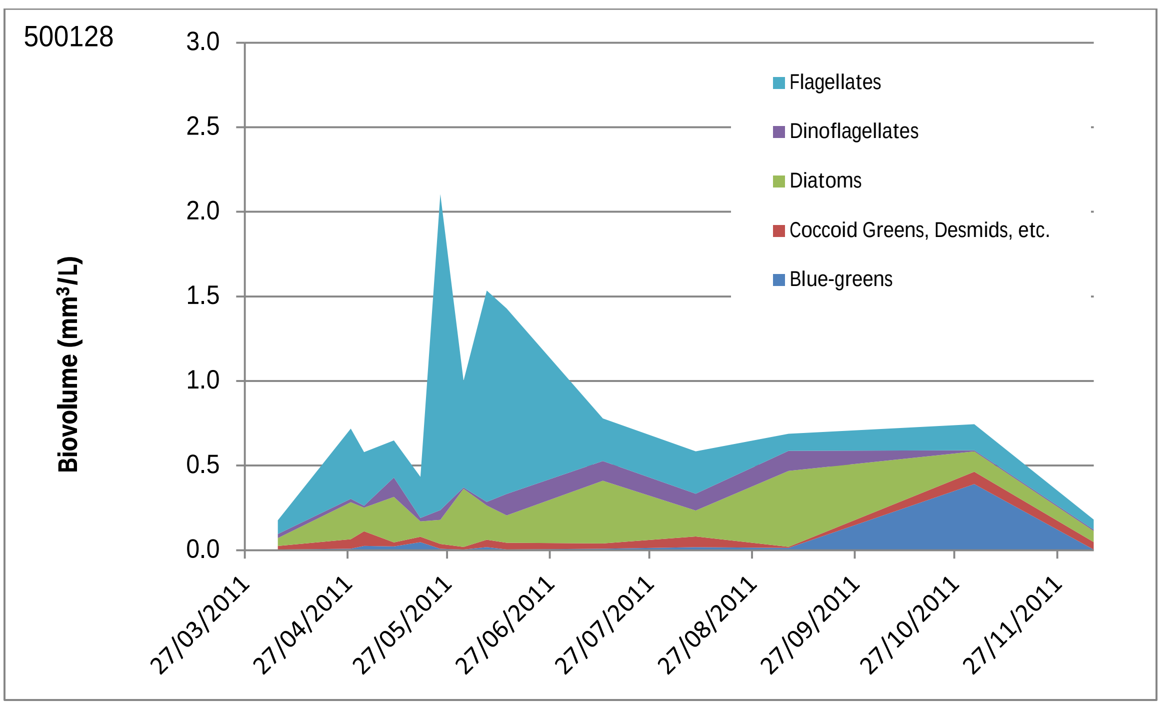
A





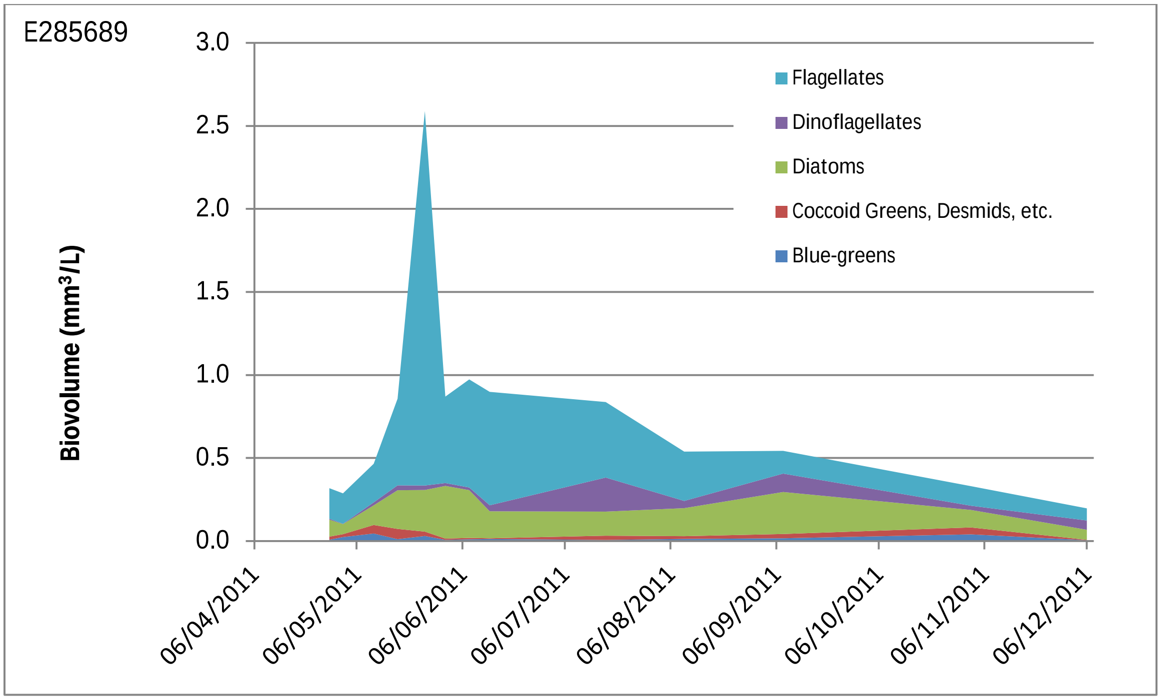
B


500128
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Phytoplankton Density (NCU/mL)
Flagellates
Dinoflagellates
Diatoms
Coccoid Greens, Desmids, etc.
Blue-greens
27/03/2011
27/04/2011
27/05/2011
27/06/2011
27/07/2011
27/08/2011
27/09/2011
27/10/2011
27/11/2011


500128
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Biovolume (mm³/L)
Flagellates
Dinoflagellates
Diatoms
Coccoid Greens, Desmids, etc.
Blue-greens
27/03/2011
27/04/2011
27/05/2011
27/06/2011
27/07/2011
27/08/2011
27/09/2011
27/10/2011
27/11/2011

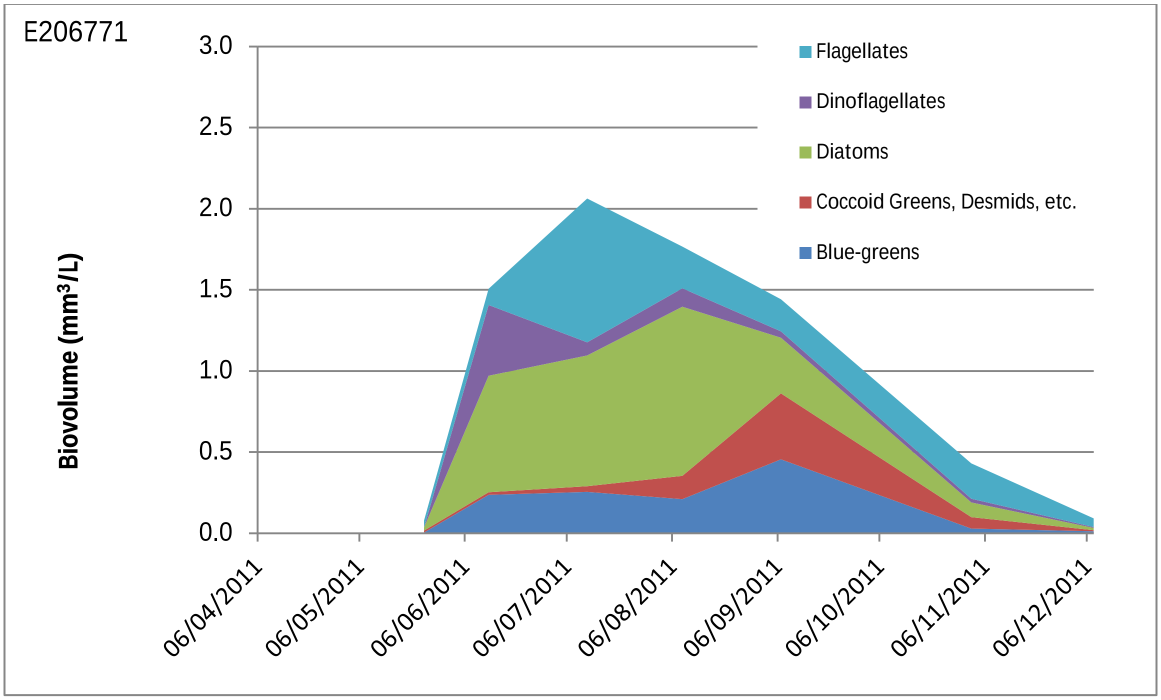
C

[Chart not included in original report]



D

[Chart not included in original report]



Mara Lake flagellate blooms

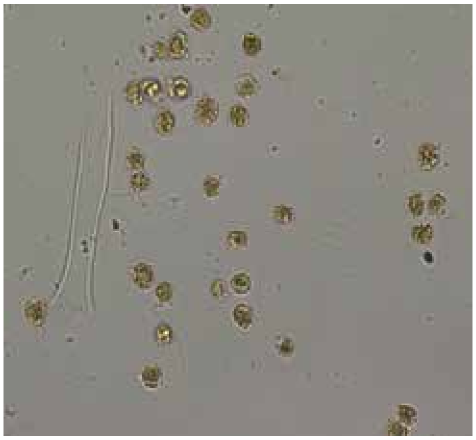
The Mara Lake bloom was comprised mainly of *Ochromonas* spp. as seen by 600x microscopy (A) by aerial photography (B) and by sketch from electron microscopy (C). These blooms first occurred in Mara Lake in 2008 with a noticeable 'streaking' golden-brown appearance on the lake surface (**Figure B-8:B**). Within visible streaks contained high concentrations of *Ochromonas* that varied in density between 300-650,000 cells/mL in both 2008 and 2010 (**Figure B-8:A**). In 2012 minor streaks appeared but to a far lesser extent (D. Einerson, *pers. comm.*).

Known to taxonomists as 'golden-brown' algae or 'Chrysomonads', *Ochromonas* and others are ubiquitous in lakes and ponds and are always predominant in spring or early summer. They lack starch, but store lipids, and the polysaccharide chrysolaminarin or leucosin. The golden-brown color comes from the primary assessory photo-pigment – xanthophyll (**fucoxanthin**) which masks the pigments chlorophyll *a* + *c* that creates the golden brown color.

Most 'chrysomonads' are mixotrophic, that is they can utilize: a) photosynthesis; b) phagotrophy - intake of food by eating other small organics like picoplankton, or c) osmotrophy -by direct absorption of complex organic molecules. The flagella are used to concentrate picoplankton-sized particles into a feeding cup which engulfs selected particles and retracts back into the cell. This diverse feeding capability with three forms of nourishment coupled with their preference for colder water spring conditions at a time when competition from zooplankton and other grazers is slight, are likely two of the key factors for the onset of bloom conditions in Shuswap/Mara lakes. These include abundant bacteria and picocyanobacteria to graze (phagotrophy), high DOC and DON concentrations for direct osmotrophy, and ever increasing light intensity (photosynthesis).

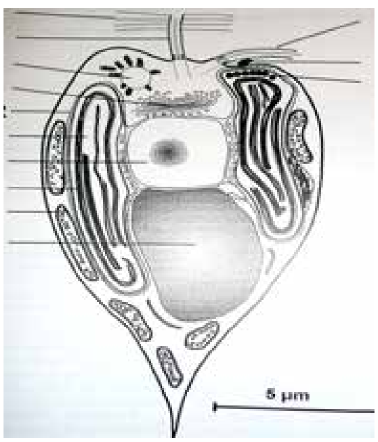
Figure B-8 Mara flagellate bloom as seen by microscopy (A), aerial photography (B) and electron microscopy (C)

A



B

C



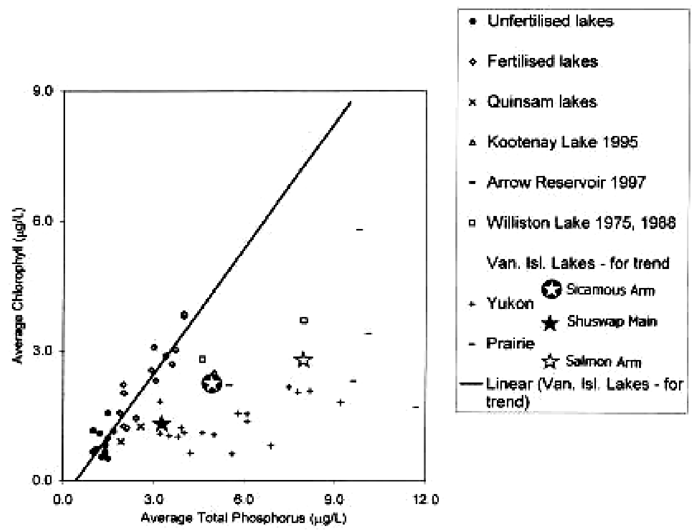
There are additional factors that help explain why chrysomonad flagellate blooms are a ‘spring’ occurrence in north temperate lakes. They are opportunistic species with an ability to rapidly adapt to and utilize 3 energy pathways as previously given photosynthesis, phagotrophy, and osmotrophy. In addition, Shuswap and Eagle river inflows draining rural, agricultural, or logged drainage basins after spring snow-melt bring higher concentrations of nutrients, especially DOC and DON.

Picoplankton, small micro-flagellates and ciliates at the base of the early spring food-web are excellent sentinels of ‘change’ to nutrient supply, especially from regenerative domains such as river inflows and wetlands. Their small size provides ability to grow rapidly (1-2 doublings/day) and provide rapid response to even small ambient changes in lakes.

With recent earlier ice-free conditions, Mara Lake in late April-early May provides increased irradiation for photosynthesis along with plentiful nutrients and abundant picoplankton population. With ideal conditions within the water column, an extended period of calm and sunny weather in late May or early June after lake overturn provides ideal conditions for a bloom

The plot of average TP concentrations of three of Shuswap Lake's more productive basins vs. average Chl-a together with values from other coastal and interior BC lakes and several is interesting in that the regression-line shown is for Vancouver Island coastal lakes (Figure **B-9**). On this plot Shuswap Main basin values lie within the oligotrophic interior BC lake range, while Sicamous Arm (Mara Lake) lies close to fertilized Kootenay Lake that is considered of to be oligo-mesotrophic production level. However Salmon Arm values fall within the range of mesotrophic Yukon lakes and meso-eutrophic Alberta lakes. The current average TP values and plankton community composition of Salmon Arm, Shuswap Lake is a close description of its current meso-eutrophic state.

Figure B-9 Average annual TP vs. Chlorophyll plot showing 3 Shuswap Lake basins Main (dark star), Sicamous (dark circled star), and Salmon Arm (open star) to compare with values from other BC coastal and interior lakes, Alberta prairie, and Yukon sub-arctic lakes



Summary

The nutrient enriched waters within the eastern most basins within Shuswap Lake - Sicamous Arm, Mara Lake, and in upper Salmon Arm - Shuswap Lake have a trophic status that ranges from oligotrophic to mesotrophic to eutrophic.

Mara Lake should be considered oligo-mesotrophic while upper Salmon Arm is shallower and richer – meso-eutrophic. Sicamous Arm receives the Shuswap River, the largest inflow and highest annual nutrient load by inflow rivers to Shuswap (Holms 1987, Stockner 1994, 2010). Salmon Arm of Shuswap is shallow and nutrient-enriched both from past discharges from the city of Salmon Arm STP and from internal loading from reductive organic sediments in the shallow basin. This basin within Shuswap Lake has the highest abundance and biomass of filamentous cyanobacteria and largest areas of aquatic macrophytes among all basins of Shuswap Lake. Mara Lake within the last few decades has likely been subjected to gradually increasing annual nutrient loads and is slowly responding to the influence of anthropogenic induced changes to the Shuswap River drainage basin, e.g. forestry, agricultural and urbanization that have collectively added more DON, DOP,TP and TN to the lake.

Without efforts to stabilize nutrient inputs from the rivers drainage basin it is very likely that Mara Lake in future years will continue to exhibit annual flagellate blooms of growing amplitude and duration, perhaps yielding to late summer-fall blue-green blooms within a few decades with would have severe implications for drinking water quality and public health issues.

Appendix C Shuswap and Mara Lakes Zooplankton Assessment

Introduction

This section of the Shuswap lakes report summarises the zooplankton data collected in 2011. The study of Shuswap and Mara Lakes macrozooplankton (length >150 µm), including their composition, abundance and biomass help to determine the current status of lakes. Samples were collected once a week from the beginning of May to mid June, and then monthly to the end of the sampling season in December, with a vertically hauled mesh Wisconsin net with a 0.5 m throat diameter. The depth of each haul was 25 m. In Shuswap Lake samples were collected at the location opposite to Marble Point, and in Mara Lake at two locations, one opposite to King-Baker and one opposite to Fosett.

Collected zooplankton samples were rinsed from the dolphin bucket and preserved in 70% ethanol. Zooplankton samples were analyzed for species density, biomass, and fecundity. Samples were re-suspended in tap water, filtered through a 74 µm mesh and sub-sampled using a four-chambered Folsom-type plankton splitter. Splits were placed in gridded plastic petri dishes and stained with Rose Bengal to facilitate viewing with a Wild M3B dissecting microscope (at up to 400X magnification). For each replicate, organisms were identified to species level and counted until up to 200 organisms of the predominant species were recorded. If 150 organisms were counted by the end of a split, a new split was not started.

The lengths of up to 30 organisms of each species were measured for use in biomass calculations, using a mouse cursor on a live television image of each organism. Lengths were converted to biomass (µg dry-weight) using empirical length-weight regression from McCauley (1984). The number of eggs carried by gravid females and the lengths of these individuals were recorded for use in fecundity estimations. Zooplankton species were identified with reference to taxonomic keys (Sandercock and Scudder 1996, Pennak 1989, Wilson 1959, Brooks 1959).

Shuswap Lake Zooplankton Species

Two calanoid copepod species have been identified in the samples from Shuswap Lake (**Table C-1**). *Leptodiaptomus ashlandi* (Marsh) was present in samples during the whole sampling season, while *Epishura nevadensis* (Lillj.) was observed rarely. One cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes) was seen in samples during the entire sampling season. Seven species of Cladocera were present in Shuswap Lake during 2011 sampling season (**Table C-1**). *Daphnia thorata* (Forbes), *Bosmina longispina* (O.F.M.), and *Leptodora kindtii* (Focke) were common, while other species such as *Scapholeberis mucronata* (O.F.M.), *Holopedium gibberum* (Zaddach), *Biapetura affinis* (Leydig), and *Diaphanosoma brachyurum* (Lievin) were observed sporadically.

Table C-1 List of zooplankton species identified in Shuswap Lake in 2011 ("+" indicates a consistently present species and "r" indicates a rarely present species)

Cladocera	Status
Biapertura affinis	r
Bosmina longispina	+
Daphnia thorata	+
Diaphanosoma brachyurum	r
Holopedium gibberum	r
Leptodora kindtii	+
Scapholeberis mucronata	r
Copepoda	**Status**
Cyclops bicuspidatus thomasi	+
Epishura nevadensis	r
Leptodiaptomus ashlandi	+

Density and Biomass

During the study period zooplankton density was numerically dominated by Copepoda, which averaged 84% in 2011. *Daphnia* comprised 13%, while cladocerans other than *Daphnia* made up 3% of total zooplankton density (**Table C-2**). During 2011 copepods were the most abundant zooplankton (**Figure C-1**). Among them *L. ashlandy* numerically prevailed during the whole sampling season, with populations peaking in mid May (**Figure C-2**). The number of *Cladocerans* other than *Daphnia* was low and did not change during the entire sampling season. The highest density was found in June with 0.89 individuals/L. *Daphnia* was present during the whole sampling season. Density of *Daphnia* increased gradually reaching its peak in mid June with 4.59 individuals/L which contributed to 36% of total zooplankton density (**Figure C-3**).

Seasonal average total zooplankton biomass in 2011 was 47.62 µg/L (Figure C-1, Table C-2). *Daphnia* had the highest proportion of the total biomass in the whole reservoir 53% with 25.39 µg/L. Copepods made up 43% with 20.58 µg/L, while Cladocerans other than *Daphnia* comprised only 4% of the total zooplankton biomass with 1.65 µg/L.

The highest total zooplankton biomass of 94.65 µg/L was found in mid June, when *Daphnia* comprised 73% of total biomass with 68.70 µg/L (Figure 33). Although *Daphnia* spp. was present in samples during the entire season, it made up a great proportion of the biomass from June through October. Zooplankton composition, density, and biomass fluctuated along a great range during the study period.

Table C-2 Seasonal average zooplankton density and biomass in Shuswap Lake in 2011 (Density is in units of individuals/L; biomass is in units of µg/L)

Density	Species	2011	%
	Copepoda	9.42	84
	Daphnia	1.49	13
	Other *Cladocera*	0.30	3
Total		**11.21**	**100**
Biomass	**Species**	**2011**	**%**
	Copepoda	20.58	43
	Daphnia	25.39	53
	Other *Cladocera*	1.65	4
Total		**47.62**	**100**

In 2011 monthly average peak total zooplankton density occurred in May at 18.19 individuals/L while highest biomass was found in June at 70.13 µg/L (**Table C-3, Figure C-3**). Daphnia was the most numerous in June with 2.85 individuals/L, and the highest Daphnia biomass in the season with 46.51 µg/L.

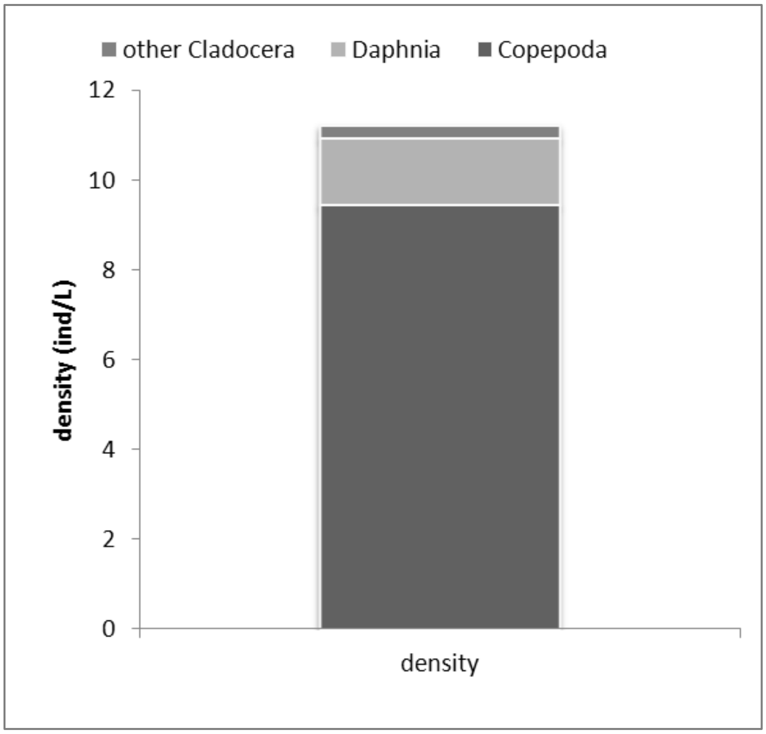
Table C-3 Monthly average density and biomass of zooplankton in Shuswap Lake in 2011 (Density is in units of individuals/L, and biomass is in units of µg/L)

Density	Species	May	Jun	Jul	Aug	Oct	Dec
	Copepoda	17.11	8.80	3.18	3.60	4.44	5.23
	Daphnia	0.89	2.85	1.29	1.93	0.44	0.01
	Other *Cladocera**	0.19	0.52	0.03	0.43	0.26	0.10
	Total Zooplankton	18.19	12.18	4.50	5.96	5.14	5.35
Biomass	**Species**	**May**	**Jun**	**Jul**	**Aug**	**Oct**	**Dec**
	Copepoda	35.01	22.88	9.57	6.85	8.47	7.21
	Daphnia	15.70	46.51	26.64	28.80	11.71	0.16
	Other *Cladocera***	0.33	0.74	0.09	11.40	1.43	0.35
	Total Zooplankton	51.05	70.13	36.29	47.05	21.61	7.72

*Values do not include *Daphnia* spp. density.

**Values do not include *Daphnia* spp. biomass.

Figure C-1 Seasonal average zooplankton density and biomass in Shuswap Lake in 2011



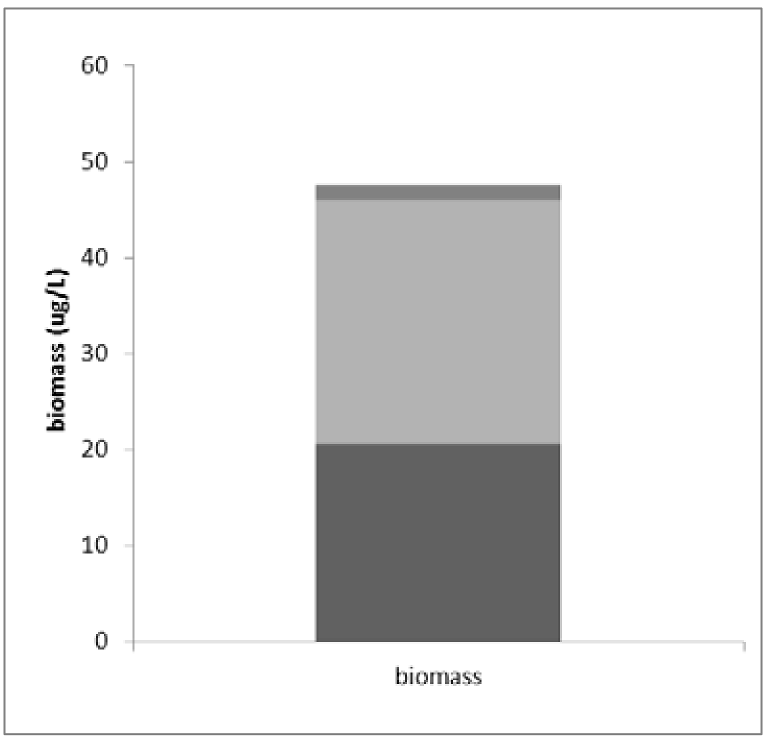


Figure C-2 Monthly average zooplankton density and biomass in Shuswap Lake in 2011

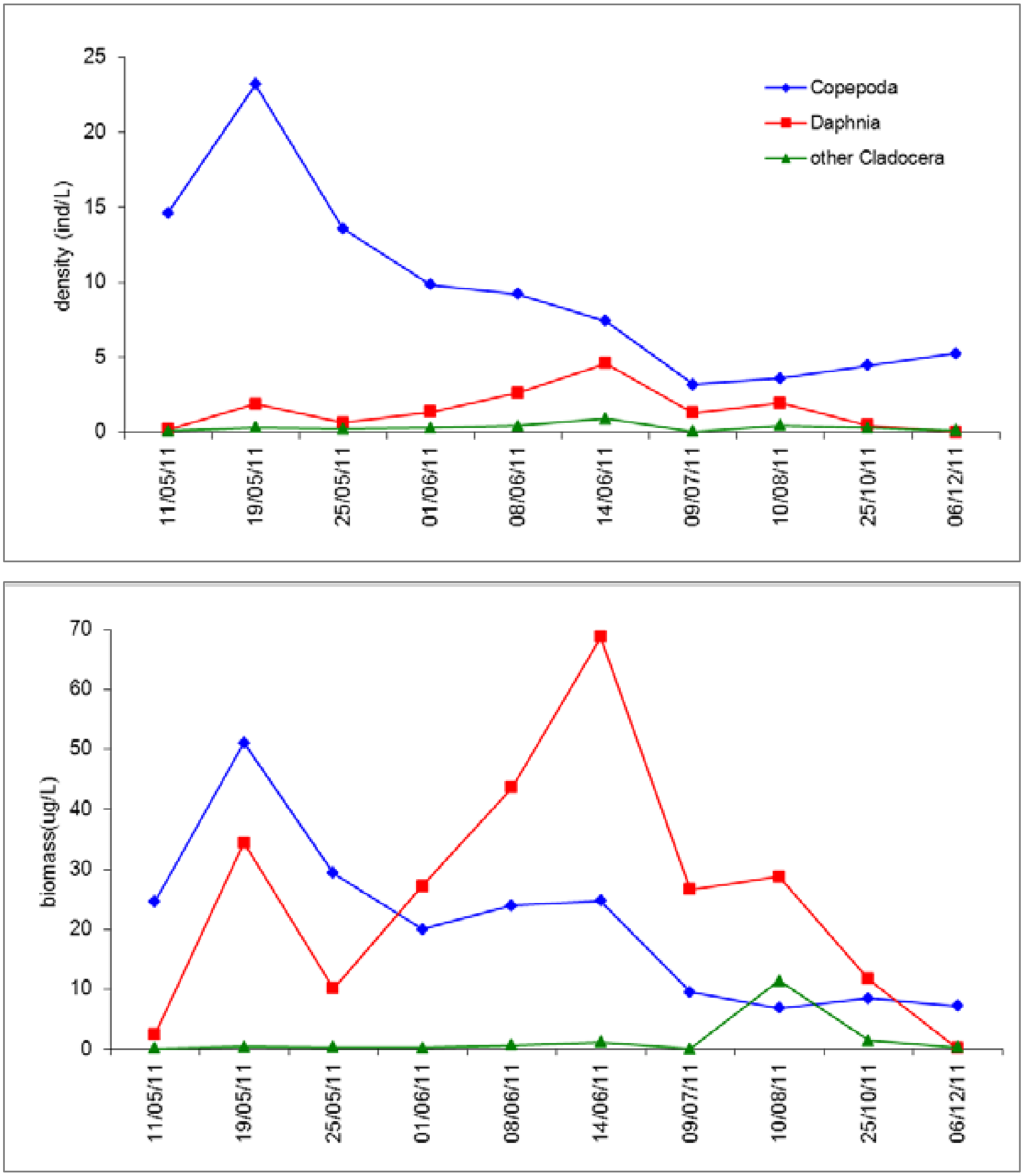
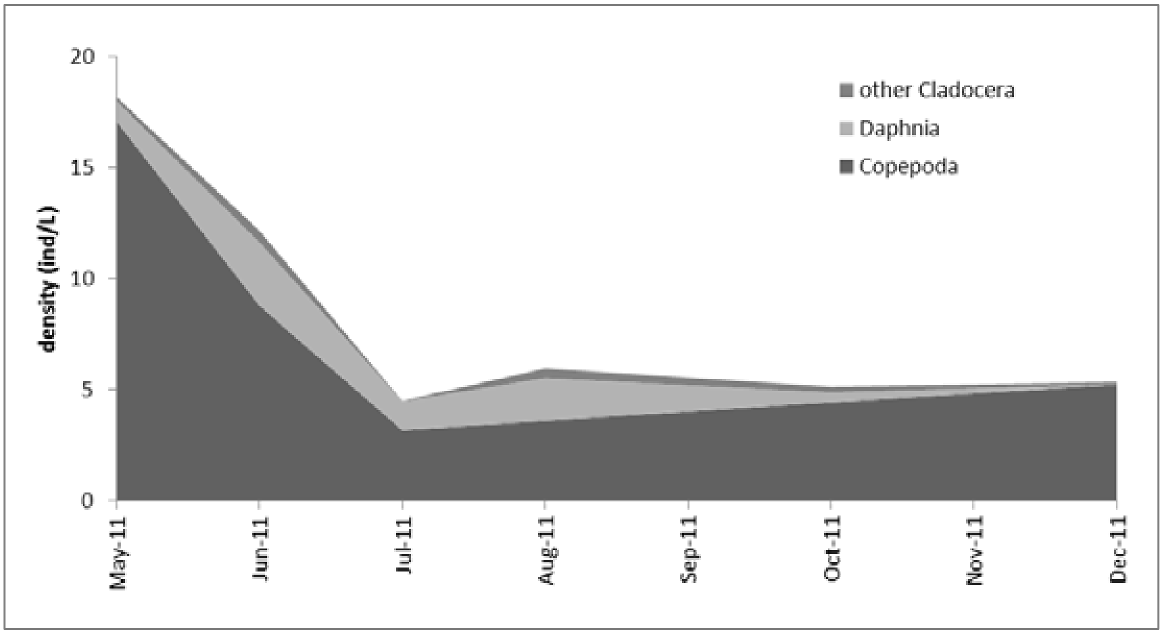
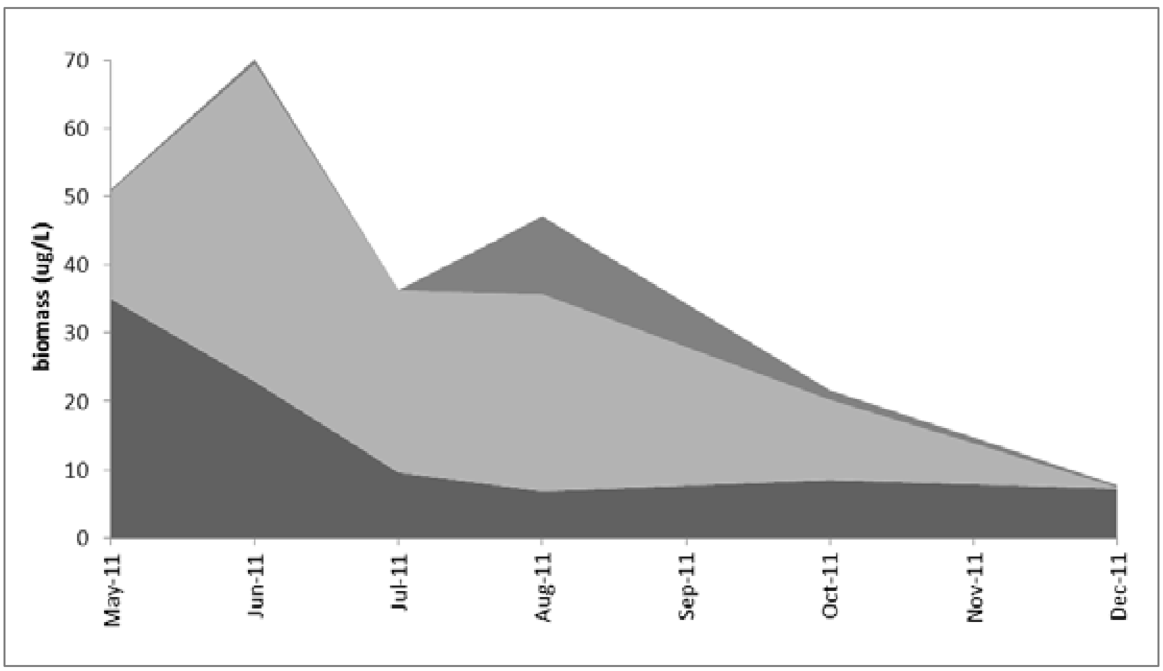


Figure C-3 Monthly average zooplankton density and biomass in Shuswap Lake in 2011


20
15
10
5
0
density (ind/L)
other Cladocera
Daphnia
Copepoda
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11


70
60
50
40
30
20
10
0
biomass (ug/L)
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11

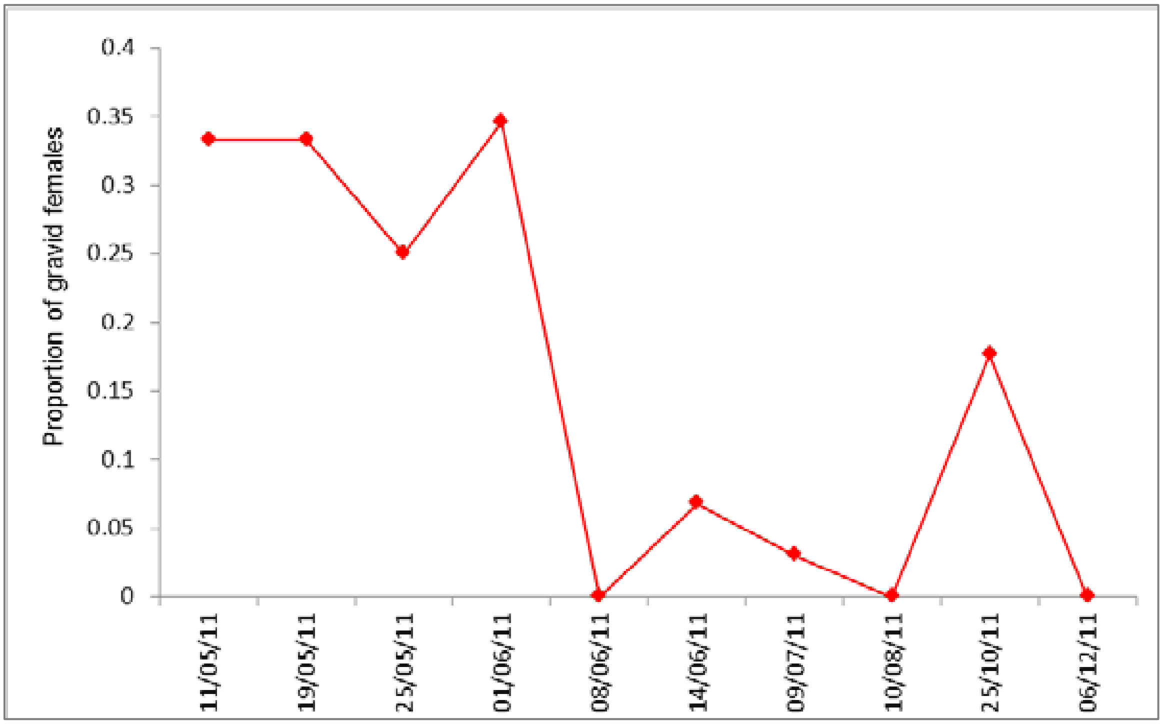
Zooplankton Fecundity

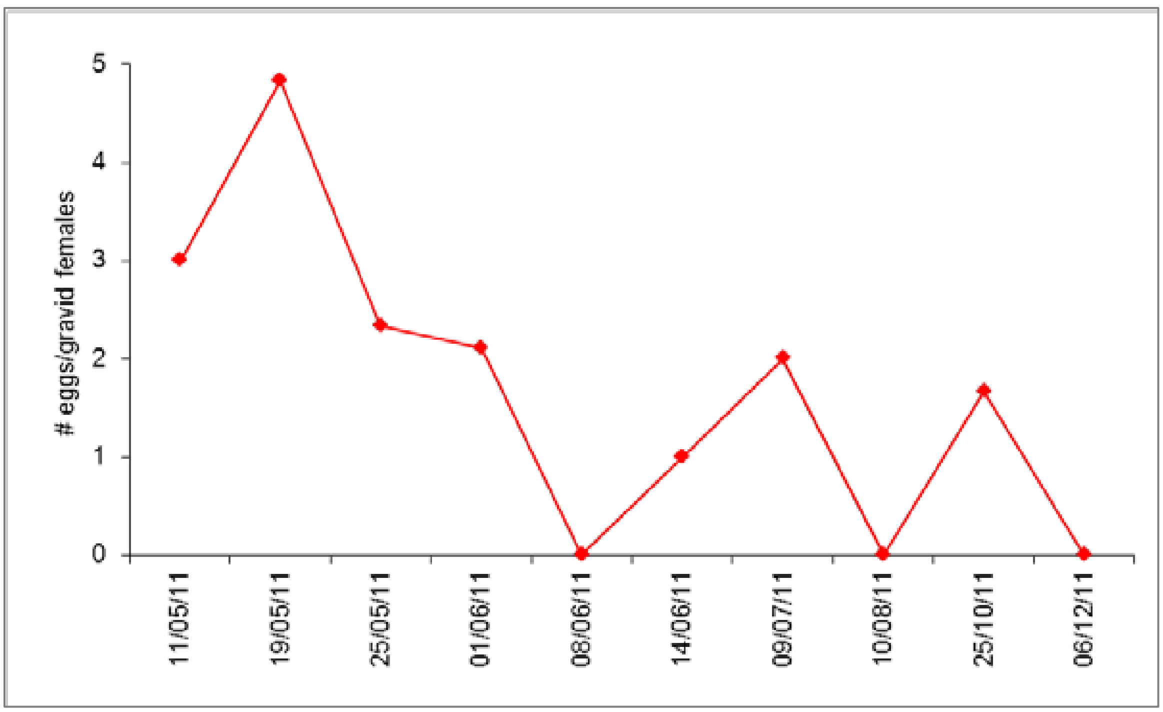
In Shuswap Lake *Daphnia* females were gravid throughout the sampling period (**Figure C-4**). From May to December 2011 the proportion of gravid females averaged 0.15. The highest proportion of *Daphnia* gravid females was found at the beginning of June when 35% of females were gravid. The highest number of eggs per gravid female was 4.83 found in mid June. On average, gravid female carry 2.42 eggs. The number of eggs per water volume averaged 0.51 eggs/L, and the number of eggs per capita averaged 0.43 eggs/individual (**Table C-4**).

Table C-4 Fecundity data for Daphnia in Shuswap Lake in 2011. Values are seasonal averages, calculated for samples collected between May – December 2011

	2011
Proportion of gravid females	0.15
# Eggs per gravid Female	2.42
# Eggs per Litre	0.51
# Eggs per Capita	0.43

Figure C-4 Fecundity features of Daphnia in Shuswap Lake in 2011





Mara Lake Zooplankton Species

Two calanoid copepod species were identified in the samples from Mara Lake (**Table C-5**). *Leptodiaptomus ashlandi* (Marsh) was present in samples during the whole season, while *Epischura nevadensis* (Lillj.) *was* observed occasionally. One cyclopoid copepod species, *Diacyclops bicuspidatus thomasi* (Forbes), was present in samples from Mara Lake during the entire sampling season. Eight species of Cladocera were present in Mara Lake during 2011 (**Table C-5**). *Daphnia galeata mendotae* (Birge), *Daphnia thorata* (Forbes), *Bosmina longispina* (O.F.M.), *Diaphanosoma brachyurum* (Lievin) and *Leptodora kindtii* (Focke) were common. Other species such as *Alona sp.*, *Ceriodaphnia sp.* or *Leydigia quadrangularis* (Leydig) were observed sporadically. *Daphnia* spp. were not identified to species for density counts.

Density and Biomass

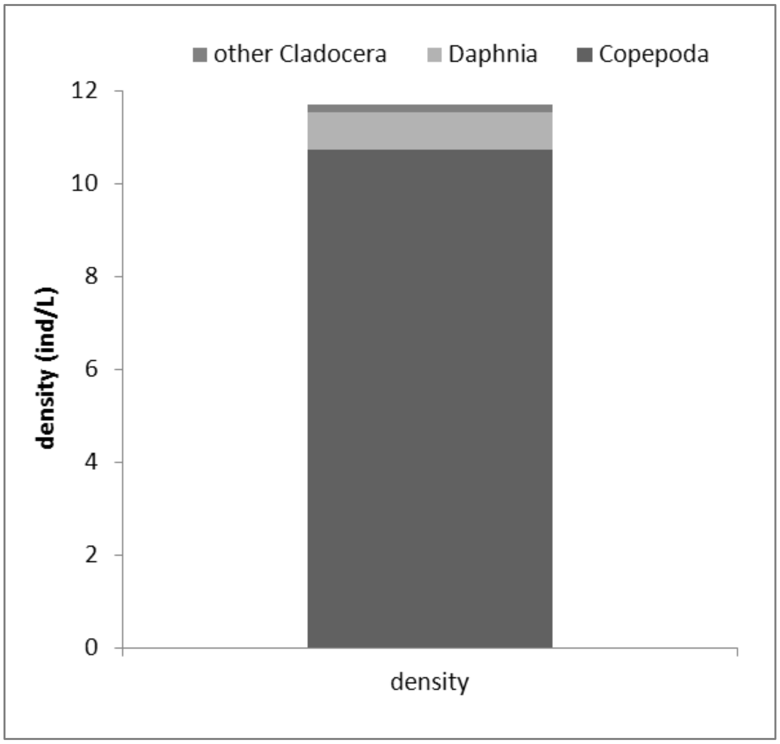
The zooplankton community was primarily composed of copepods, which made up 92% of the zooplankton density and 51% of the zooplankton biomass during the studied period in 2011. *Daphnia* accounted for 7% of the density and 41% of the biomass during the same time period, while other cladocerans comprised 1% of density and 9% of zooplankton biomass (**Table C-6**).

Seasonal average zooplankton density in 2011 (May to December) was 11.70 individuals/L. Copepods were the most abundant with 10.74 individuals/L. Annual average density of *Daphnia* was 0.80 individuals/L, while density of other Cladocerans (mainly *Bosmina*) was 0.16 individual/L. (**Table C-6, Figure C-5**). Total zooplankton biomass, averaged for the whole reservoir was 37.63 µg/L. Copepods contributed 51% of the total zooplankton biomass with annual average biomass of 19.02 µg/L. *Daphnia* and other cladocerans made up 41% and 9%, with 15.31 µg/L, and 3.30 µg/L of the total zooplankton biomass (**Table C-6, Figure C-5**, **Figure C-6**).

Table C-5 List of zooplankton species identified in Mara Lake in 2011 ("+" indicates a consistently present species and "r" indicates a rarely present species)

Cladocera	Status
Alona sp.	r
Bosmina longispina	+
Ceriodaphnia sp.	r
Daphnia galeata mendotae	+
Daphnia thorata	+
Diaphanosoma brachyurum	+
Leptodora kindtii	+
Leydigia quadrangularis	r
Copepoda	
Diacyclops bicuspidatus thomasi	+
Epischura nevadensis	r
Leptodiaptomus ashlandi	+

Figure C-5 Seasonal average zooplankton density and biomass in Mara Lake in 2011


other Cladocera
Daphnia
Copepoda
density (ind/L)
12
10
8
6
4
2
0
density

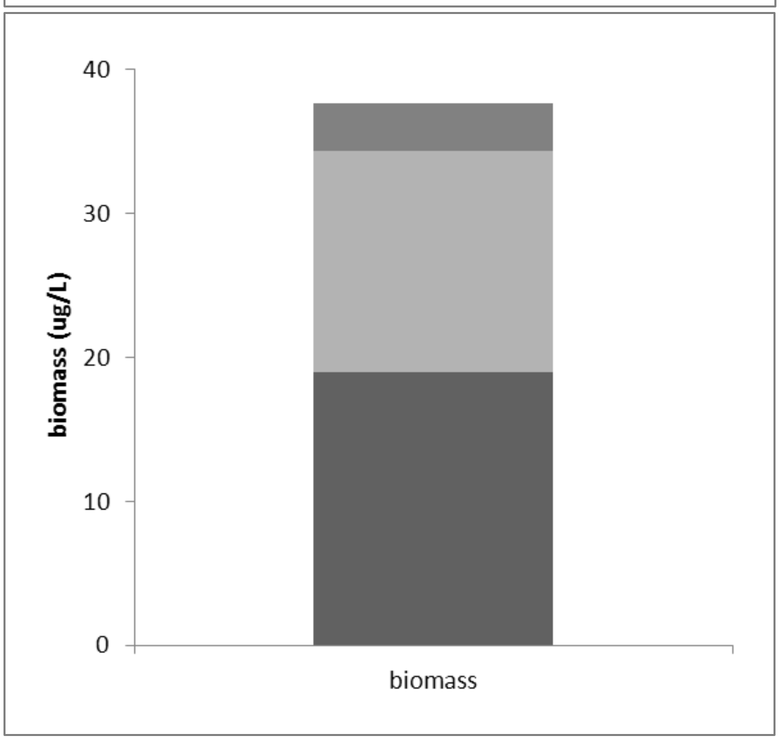

biomass (ug/L)
40
30
20
10
0
biomass

Figure C-6 Zooplankton density and biomass at two sampling stations in Mara Lake in 2011

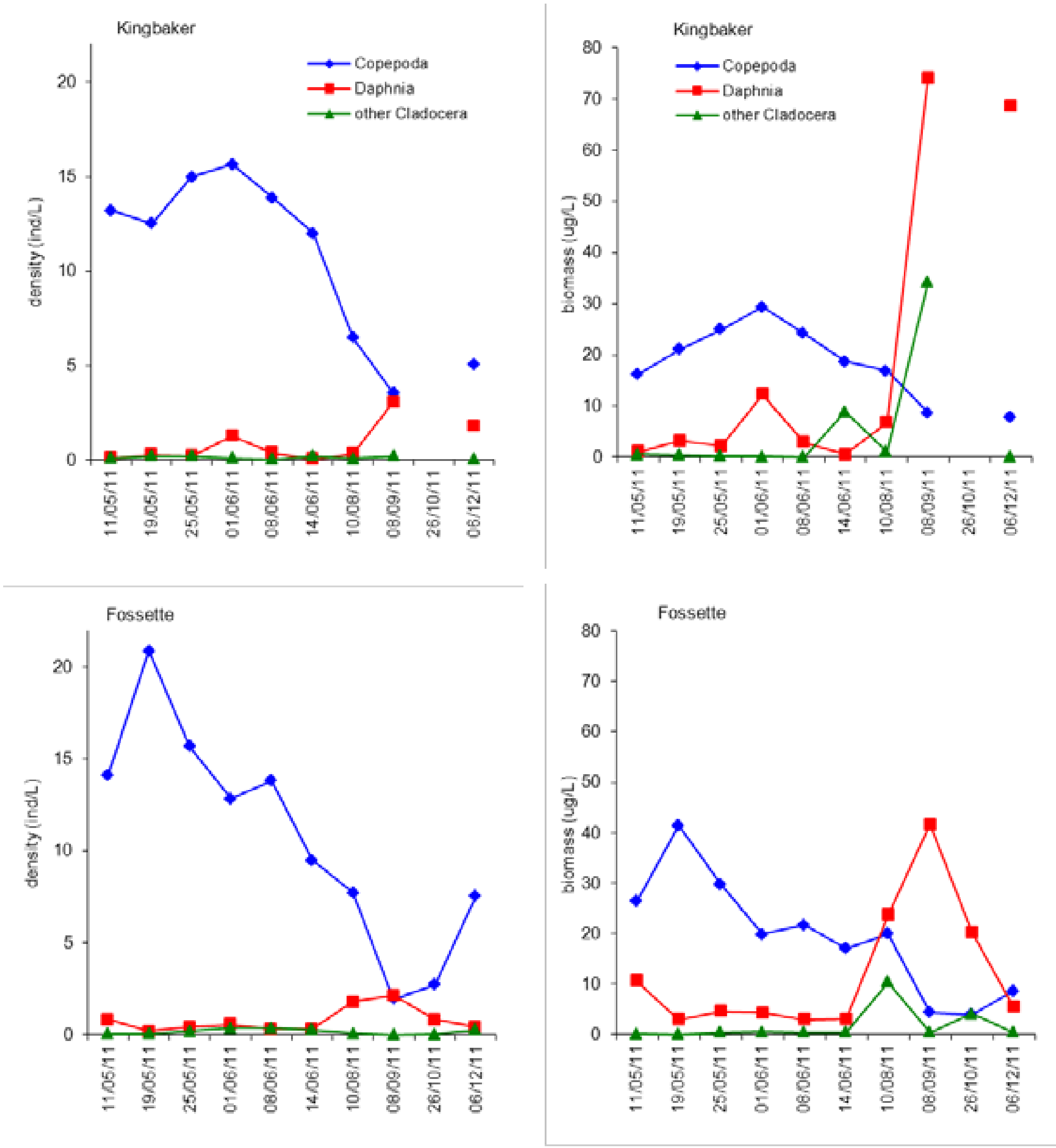


Table C-6 Annual average zooplankton abundance and biomass in Mara Lake 2011 (Data are averaged for May to December 2011)

Density	Species	2011	%
	Copepoda	10.74	92
	Daphnia	0.80	7
	other Cladocera	0.16	1
	Total	**11.70**	**100**
Biomass	**Species**	**2011**	**%**
	Copepoda	19.02	51
	Daphnia	15.31	41
	other *Cladocera*	3.30	9
	Total	**37.63**	**100**

During 2011 sampling season Copepods were the most numerous in May with 15.24 individuals/L consisting mainly of *L. ashlandi.* They numerically prevailed during the whole sampling season, with the most numerous populations found at station opposite of Fosett (**Figure C-6**). The pattern of seasonal changes of zooplankton density and biomass followed the usual trend of zooplankton fluctuation, with decreasing copepods in spring and summer, and a cladoceran increase in the late summer and early fall (**Table C-7**). Number of Copepoda decreased from May to September and increased again toward the end of the season. *Daphnia* density slowly increased from May to September and then decreased in the following months. *Daphnia* was present in significant numbers from August to December, and although was present in samples during the whole season, made up the majority of the biomass from September to December. Number of other Cladocera stayed low during the entire sampling season (**Figure C-7**).

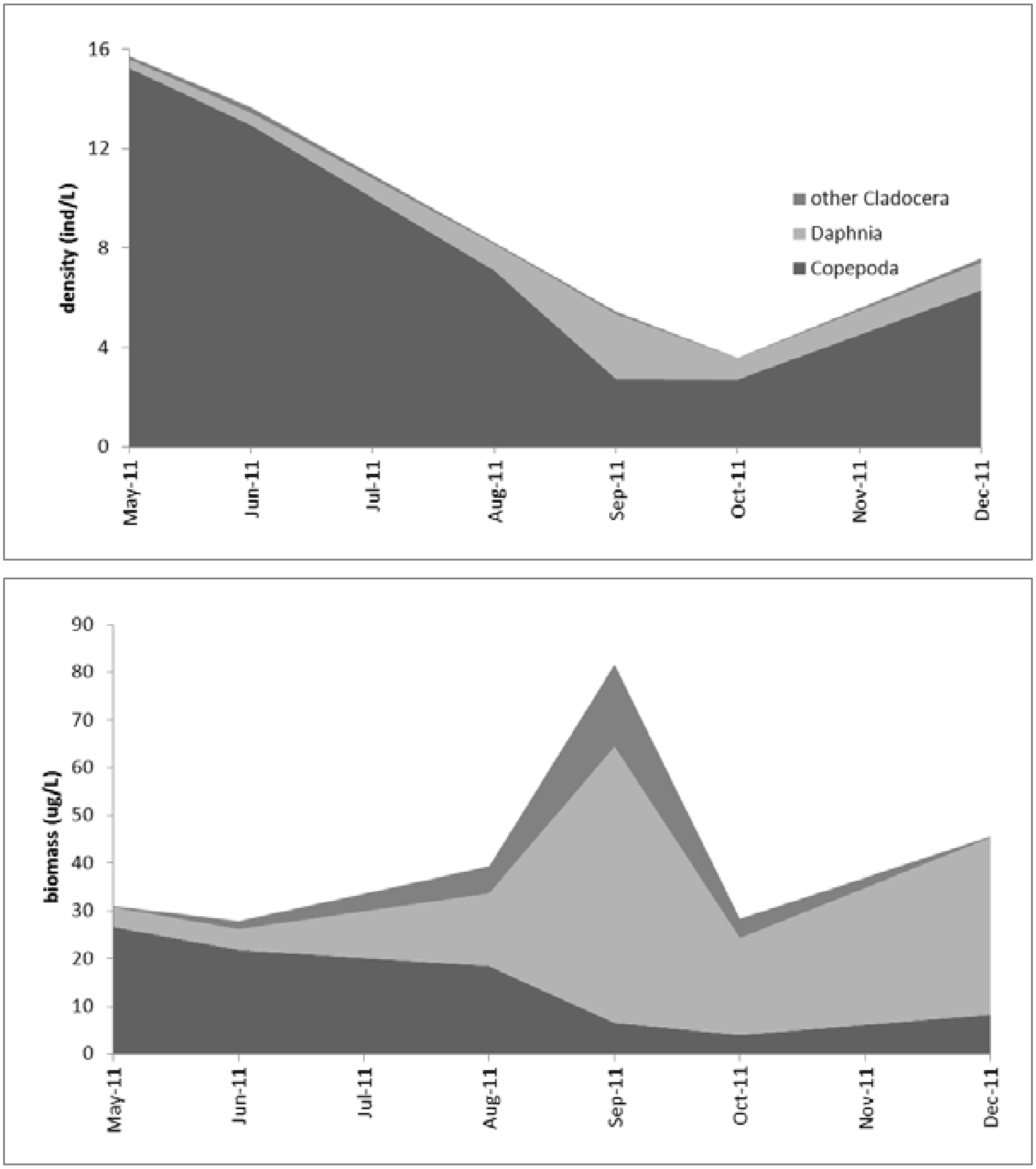
Table C-7 Monthly average density and biomass of zooplankton in Mara Lake in 2011 (Density is in units of individuals/L, and biomass is in units of µg/L)

Density		May	June	Aug.	Sept.	Oct.	Dec.
	Copepoda	15.24	12.95	7.10	2.74	2.71	6.31
	Daphnia	0.34	0.48	1.04	2.60	0.83	1.09
	Other *Cladocera**	0.14	0.23	0.08	0.11	0.03	0.18
	Total Zooplankton	**15.71**	**13.66**	**8.22**	**5.45**	**3.57**	**7.57**
Biomass		**May**	**June**	**Aug.**	**Sept.**	**Oct.**	**Dec.**
	Copepoda	26.66	21.81	18.43	6.56	3.99	8.29
	Daphnia	4.08	4.33	15.23	57.80	20.27	37.02
	Other *Cladocera***	0.28	1.74	5.69	17.30	4.09	0.27
	Total Zooplankton	**31.02**	**27.88**	**39.35**	**81.66**	**28.35**	**45.59**

*Values do not include *Daphnia* spp. density.

**Values do not include *Daphnia* spp. biomass.

Figure C-8 Monthly average zooplankton density and biomass in Mara Lake in 2011



Density of *Daphnia* was low during the entire sampling season in 2011. It was less than 1 individual/L at both stations except in September when *Daphnia* density increased to 3.05 individuals/L at King-Baker station and 2.14 individuals/L at Fosett station. Although *Daphnia* were present in samples during the entire season, they accounted for 0.4 to 52% of the zooplankton community from May to December. Its density was relatively low averaging 0.18 to 2.60 individual/L at both stations from May to December (**Figure C-7**). The highest *Daphnia* biomass was found at King-Baker station with 73.97 µg/L in September, when *Daphnia* accounted for 63% of the total zooplankton biomass.

During 2011 peak total zooplankton density occurred in June with 13.66 individuals/L (**Table C-7, Figure C-8**). The peak total zooplankton biomass occurred in September with 81.66 µg/L, when *Daphnia* biomass reached its peak with 57.80 µg/L comprising 71% of the total zooplankton biomass.

Zooplankton Fecundity

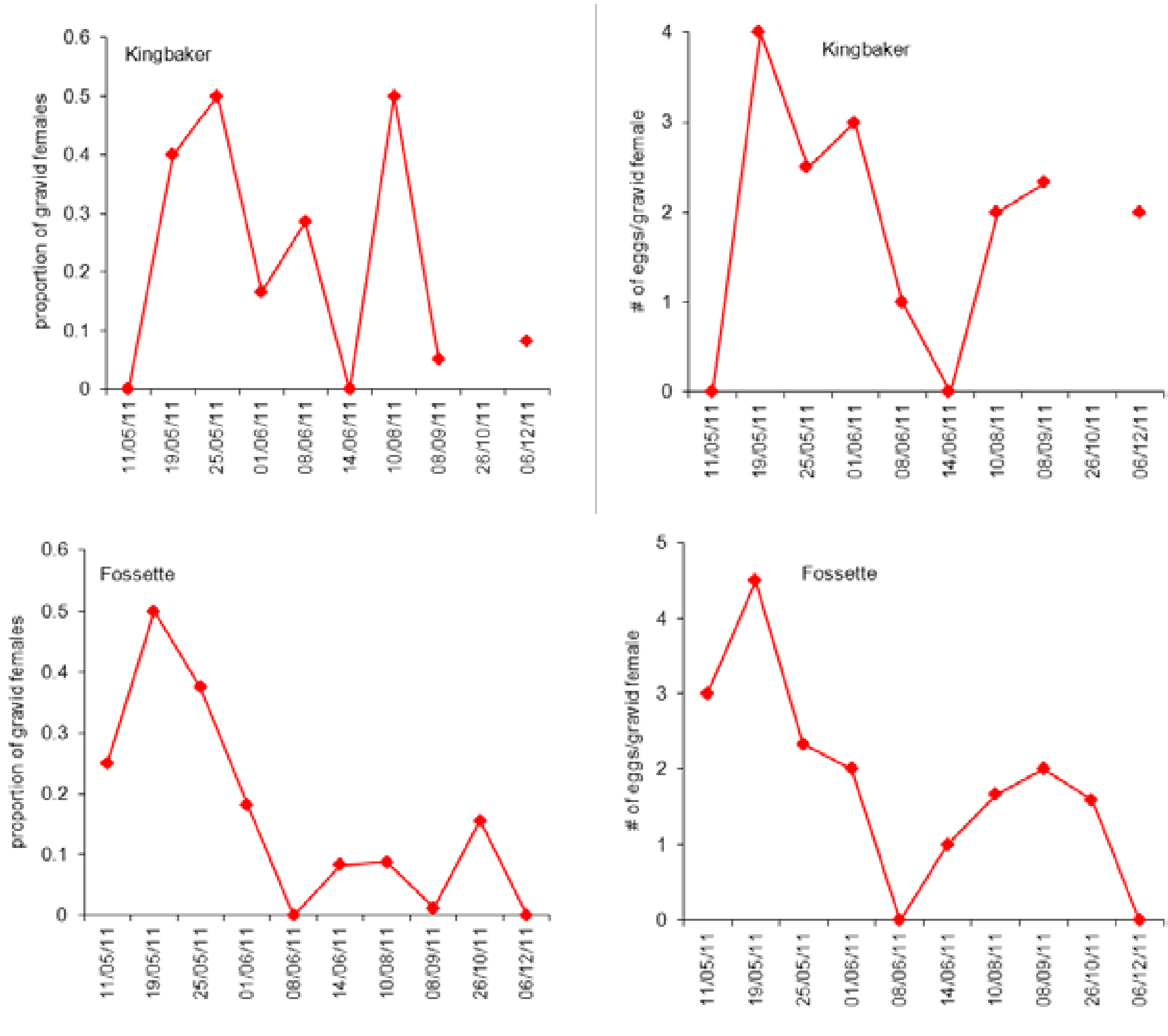
Daphnia spp. gravid females were observed in Mara Lake throughout the sampling season. The proportion of females that were gravid was variable across the season and along the reservoir (**Figure C-9**). The highest proportion of gravid *Daphnia* females have been found at the end of May and in August at King-Baker station, and middle of May at Fosett station, when 50% of females were gravid.

The highest number of eggs per gravid female was 4.50 found in mid May at Fosett station. The proportion of gravid females averaged 0.19 in 2011 (**Table C-7**). The seasonal average number of eggs per gravid female was 2.33. Across the sampling season the number of eggs per water volume averaged 0.24 eggs/L, and the number of eggs per capita averaged 0.51 eggs/individual over the study period in 2011.

Table C-7 Fecundity data for *Daphnia* in Mara Lake in 2011 (Values are seasonal averages, calculated for samples collected between May and December 2011)

	2011
Proportion of gravid females	0.19
# Eggs per gravid Female	2.33
# Eggs per Litre	0.24
# Eggs per Capita	0.51

Figure C-9 Fecundity features of Daphnia in Mara Lake in 2011



Zooplankton Comparison to other BC Lakes

In comparison to several other oligotrophic BC lakes and reservoirs, both Shuswap and Mara Lakes have moderate zooplankton density (**Figure C-10**). Zooplankton density in Shuswap and Mara Lakes averaged 11.21 and 11.67 individuals/L respectively. This is almost two times higher than in the Upper Arrow Lake, Alouette, Kinbasket and Revelstoke. In Lower Arrow and Wahleach Reservoirs zooplankton density was almost two times higher than in Shuswap and Mara Lake, and in both North and South Arm of Kootenay Lake total zooplankton density almost three folds higher with 32.47 individuals/L and 29.89 individuals/L (**Table C-8, Figure C-10**).

Daphnia density In Shuswap Lake with 1.49 individuals/L was higher than in all other studied lakes and reservoirs in 2011 except in Wahleach, where average seasonal *Daphnia* density was 1.86 individuals/L. Density of *Daphnia* in Mara Lake was 0.80 individuals/L, at the same level as in the South Arm of Kootenay Lake, and lower than in Wahleach or Alouette. The percentage of total zooplankton density accounted for by *Daphnia* in Shuswap Lake was the highest among those lakes (13%), while in Mara Lake proportion of *Daphnia* density was lower than in Alouette or Wahleach, and same as in Kinbasket Reservoir (**Table C-8, Figure C-10**).

There is similar pattern with the biomass. In 2011 *Daphnia* biomass in Shuswap and Mara Lakes was higher than in both Arrow Lakes, Revelstoke or Kinbasket Reservoir, but lower than in both Kootenay Arms, Alouette or Wahleach Reservoir. At the same time *Daphnia* biomass in Shuswap Lake was amongst the highest in comparison to other lakes, comprising 53% to the total zooplankton biomass, which was even higher than in Wahleach Reservoir where *Daphnia* comprised 50% of the zooplankton biomass (**Table C-9, Figure C-11**).

Table C-8 Seasonal average zooplankton density in Shuswap and Mara Lakes in 2011 compared to other BC Lakes (Density is in units of individuals/L)

Reservoir	Density (#/L)	*Daphnia spp.*	*Daphnia* %
Upper Arrow	7.82	0.01	0.1
Lower Arrow	18.91	0.21	1
Kootenay North	32.47	0.48	2
Kootenay South	29.89	0.83	3
Alouette	8.47	1.02	12
Wahleach	21.24	1.86	9
Kinbasket	7.97	0.54	7
Revelstoke	4.59	0.25	5
Shuswap	**11.21**	**1.49**	**13**
Mara	**11.70**	**0.80**	**7**

Although Arrow, Kootenay, Alouette and Wahleach are considered to be at the more productive end of oligotrophy, since the long term nutrient addition affected zooplankton community increase (lab data), *Daphnia* abundance and biomass comprised 0.1-12% and 1-50% of the total zooplankton community in 2011, while in Shuswap and Mara Lake, *Daphnia* comprised 13% and 7% of the total zooplankton density, and 53% and 41 of the total zooplankton biomass (Figure 41).

Table C-9 Seasonal average zooplankton biomass in Shuswap and Mara Lakes in 2011 compared to other BC Lakes (Biomass is in units of µg/L)

Reservoir	Biomass µg/L	*Daphnia spp.*	*Daphnia %*
Upper Arrow	12.06	0.13	1
Lower Arrow	28.56	3.20	11
Kootenay North	64.08	7.80	12
Kootenay South	61.72	16.32	27
Alouette	48.82	22.93	50
Wahleach	90.01	25.79	29
Kinbasket	19.74	7.78	39
Revelstoke	16.05	4.23	26
Shuswap	**47.62**	**25.39**	**53**
Mara	**37.63**	**15.31**	**41**

Figure C-10 Seasonal average total zooplankton and Daphnia density and proportion of Daphnia

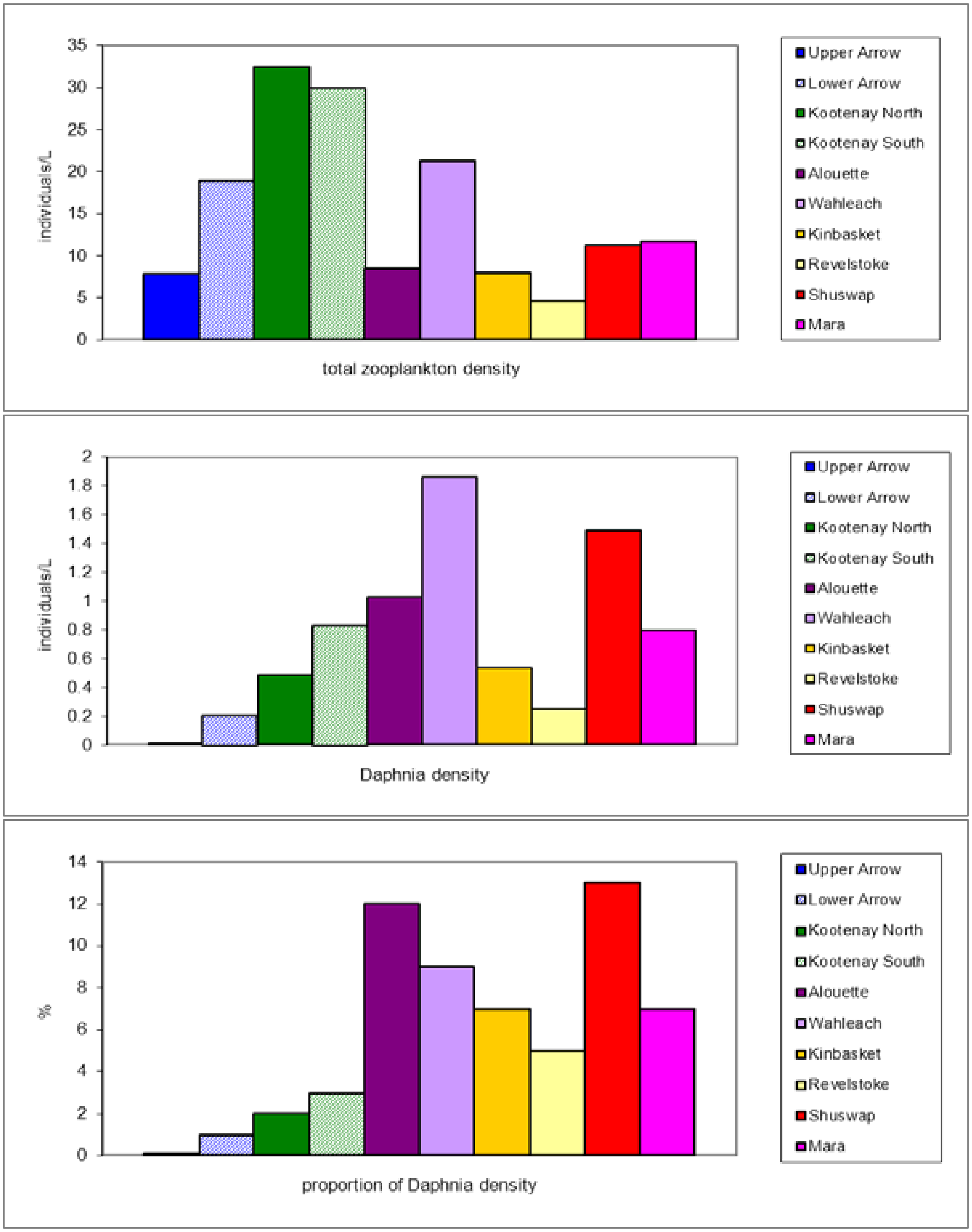
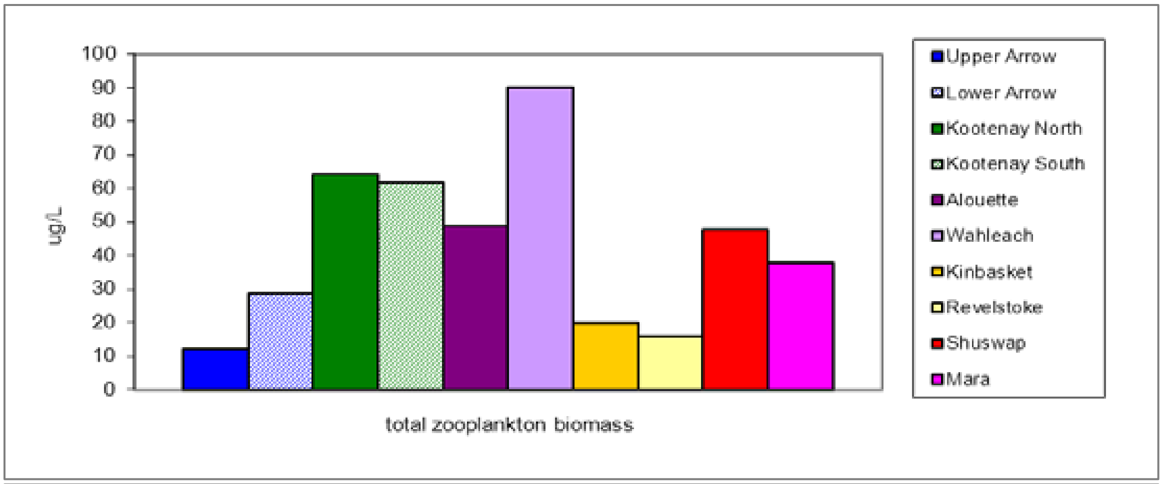
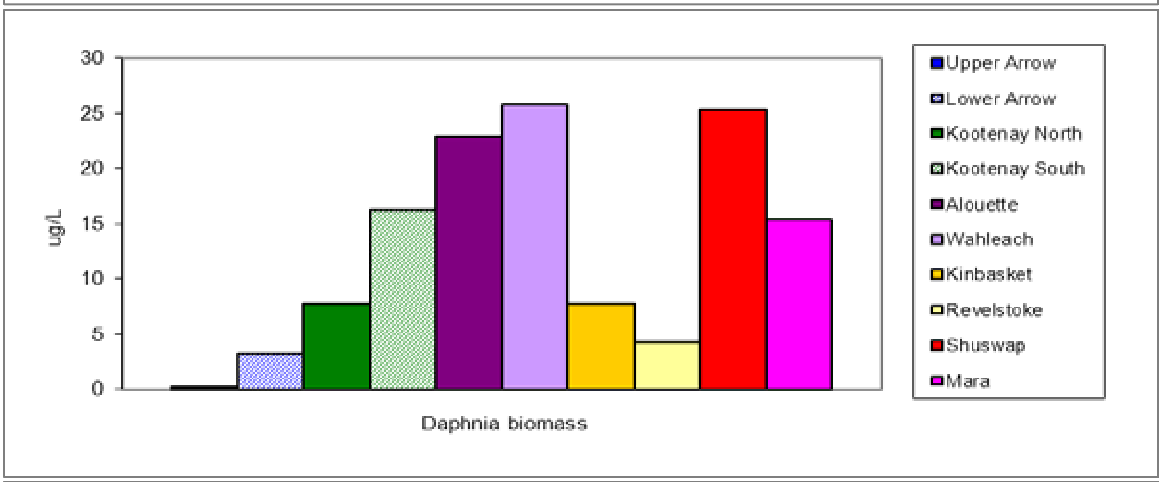
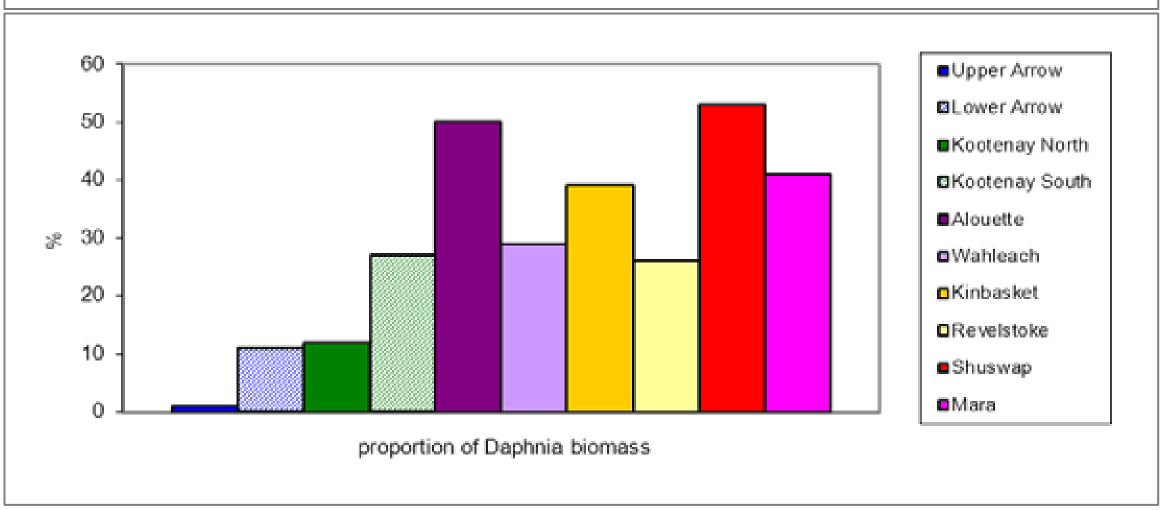


Figure C-11 Seasonal average total zooplankton and Daphnia biomass and proportion of Daphnia


100
90
80
70
60
50
40
30
20
10
0
ug/L
total zooplankton biomass
Upper Arrow
Lower Arrow
Kootenay North
Kootenay South
Alouette
Wahleach
Kinbasket
Revelstoke
Shuswap
Mara


30
25
20
15
10
5
0
ug/L
Daphnia biomass
Upper Arrow
Lower Arrow
Kootenay North
Kootenay South
Alouette
Wahleach
Kinbasket
Revelstoke
Shuswap
Mara


60
50
40
30
20
10
0
%
proportion of Daphnia biomass
Upper Arrow
Lower Arrow
Kootenay North
Kootenay South
Alouette
Wahleach
Kinbasket
Revelstoke
Shuswap
Mara