Chemical and Physical Characterisation of Effluents from Land-Based Fish Farms in Atlantic Canada.

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ABSTRACT

There are approximately fifty land-based fish farms located in Atlantic Canada. All of those facilities discharge wastewater, treated or untreated, into freshwater environments. Fish farm effluents are known to contain nutrients and chemicals, but the potential impact to surface water quality from these effluents is largely unknown. This study measured standard water quality parameters in different locations (upstream, effluent, and downstream) in streams and rivers receiving effluents from fourteen land-based fish farms. There were significant increases in total phosphorus (TP), total nitrogen (TN) and ammonia at the effluent discharge locations compared with upstream, and all of those parameters remained above background at the 100m downstream locations compared to the upstream locations. This suggests that impacts from TN, TP and ammonia may extend further than 100m downstream from effluent outfalls.

KEYWORDS; aquaculture; Canada; land-based; water quality.

INTRODUCTION

In the Atlantic Provinces of Canada (Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland), there are a number of different kinds of freshwater aquaculture facilities. While some facilities grow fish (Arctic char (*Salvelinus alpinus*), Rainbow trout (*Oncorhynchus mykiss*), Brown trout (*Salmo trutta*), Speckled trout (*Salvelinus fontinalis),* to mature sizes on land, the vast majority of facilities grow Atlantic salmon (*Salmo salar*) from eggs to parr sizes in order to supply marine cage grow out sites. A few provincially and federally-run facilities grow fish to enhance biodiversity and/or stock lakes and rivers for the recreational fishery. The value of freshwater aquaculture is hard to calculate for the Atlantic region because of the link between freshwater and marine sites for salmon. According to the Department of Fisheries and Oceans Canada, the total tonnage of freshwater fish grown to market size in Canada was over 10000 tonnes in 2010 with the majority of fish raised in Ontario and Quebec. The four Atlantic Provinces produced less than 10% of this amount. However, marine aquaculture in the four Atlantic Provinces is dominated by salmon production with New Brunswick being the second-highest producer in Canada. New Brunswick increased its production from 25000 to 30200 tonnes of Atlantic salmon from 2008 to 2012 (Surprenant 2010).

There are currently over 50 land-based aquaculture facilities in operation in the Atlantic Provinces and this number fluctuates every year with additions and closures dictated by economic considerations. In the Atlantic Provinces, freshwater aquaculture facility designs are various and include raceways, earth ponds, hatcheries, holding tanks, recirculation, re-use (Walker et al. 2003) or a combination thereof. To the best of our knowledge, there are no open net freshwater aquaculture sites in freshwater lakes located in the Atlantic Provinces. The majority of the facilities in the Atlantic Provinces are located in low order, high-quality streams or rivers, though some are on larger rivers (St John River, NB) and some discharge their effluent to brackish waters. Freshwater facilities usually divert part of the river water to flow through their different raceways or ponds and exit the facilities and back to the river after having passed through some type of wastewater treatment. Some facilities supplement the river water with well water to achieve some specific temperature requirements. In contrast to open net aquaculture (marine or freshwater), all land-based aquaculture sites discharge effluent as a point source of pollution to the receiving environment (Walker et al. 2003). Therefore the main advantage of land-based aquaculture is that the total load of dissolved nutrients and particulate matter can be reduced by wastewater treatment (Walker et al. 2003). Flow through facilities usually discharge a high volume of effluent which has a diluted waste charge whereas a recirculation system discharges a low volume of concentrated waste to the receiving environment (Rosenthal 1994). For example, True et al. (2004) calculated discharge rates for 1kg fish/year as 0.16l/min for flow through, 0.0034L/min for ponds and 0.0002L/min for recirculation.

Wastewater treatment varies among facilities and may include rotary drum filters, settling decks, constructed wetlands or re-use/recirculation systems (Environment Canada 2003). The effluent from land-based aquaculture facilities may contain, uneaten feed, feces, fish scales, and various chemicals such as antibiotics, vaccines, anesthetics, additives, pesticides, and disinfectants (Environment Canada 2003, Tello et al. 2010, Lalonde et al. 2012). Although we have determined some concentrations of these chemicals (oxytetracycline, emamectin benzoate, formalin) in some facilities in Atlantic Canada (Lalonde et al. 2012) , this paper only deals with typical water quality parameters such as the various forms of nitrogen, phosphorus, solids, carbon etc. Previous studies of the characterization of effluent from land-based fish farms have occurred in the United States (True et al. 2004, MacMillan et al. 2003, Tucker 2005, Masters et al. 2008), Europe (Boaventura et al. 1997, Guilpart et al. 2012) and, Australia (Gross 2001). However the general trends from these cannot easily be translated to the potential impacts to the Canadian environment due to differences in species, aquaculture practices, chemical used and environmental conditions (Walker et al. 2003). In Canada, studies on water quality impacts from freshwater aquaculture facilities are limited. Environment Canada (1979) characterised waste water from salmon rearing facilities in British Columbia and concluded that ammonia was the only appropriate index to monitor the variability in water quality of the discharge. More recent published Canadian studies have characterised waste outputs from freshwater cage culture in Ontario lakes (Bureau et al. 2003, Yan 2005), however no other Canadian studies have described changes in river and stream water quality from land-based aquaculture facilities.

The objective of this study was to characterize the impact to the freshwater environment from the physical and chemical parameters within the effluent leaving land-based fish farm facilities in Atlantic Canada.

MATERIAL AND METHODS

Water samples were collected at 14 different facilities in New Brunswick and Nova Scotia, Canada. Most of the facilities were growing Atlantic salmon (n=10) but a few were farming speckled trout (n=2), rainbow trout (n=4), and arctic char (n=1). Six facilities were sampled on one occasion, 5 facilities were sampled twice, two facilities were sampled three times and another facility was sampled on nine occasions for a total of 31 different sets of samples (i.e. events). The majority of the events (20 out of 31) were collected in the months from July to October. The majority of events were obtained at the time of the year when the biomass of the farms are at their highest and the river levels are at their lowest. The combination of these factors results in a worst case scenario and therefore to more conservative results. Two events were collected in each of the months of November, December while 3 events were collected in March from the same facility. One event was collected in each of the following months; February, April, May and June. Sampling was conducted in all four seasons, though 65% of samples were collected in summer and autumn. The biomass of fish as well as the flow rate at each farm was estimated by the operators for the day when the sampling occurred. The sampling procedure at each facility was similar. Sigmamotor 900 Series Automated samplers were deployed at three sampling stations at each facility. One sampling station was located upstream of the water intake for the facility, one was located in the mixing zone where the effluent outfall flowed into the stream while the third station was located 100m downstream of the effluent outfall. The auto samplers were programmed to take a sample every five minutes, to make up a composite sample of the surface water over a three hour period. The samples were pumped through Teflon tubing and into a hexane-rinsed glass carboy. After three hours, the glass carboy containing the composite sample was stirred and poured into the appropriate sampling bottles. The bottles were then labeled and placed in a cooler with ice packs until overnight delivery to the analytical laboratory.

The first four sampling events were analysed by Maxxam Analytical (Bedford, N.S.) and the next 27 events were analysed by Environment Canada’s Water Quality Laboratory (Moncton N.B.). Methodologies used at both laboratories are listed in appendix 1. Reported detection limits (RDLs) for each analysis in this study are presented in Tables 1 and 2. Ten percent of the samples were sub-sampled in the laboratory for QA/QC analysis.

The following analytes were determined in each sample; biological oxygen demand (BOD), volatile solids, total suspended solids (TSS), total solids (TS), chloride, sulphate, nitrate, ammonia, total nitrogen (TN), total organic carbon (TOC), conductivity, pH, alkalinity, turbidity, hardness, ortho-phosphate, total phosphorus (TP), sodium, potassium, calcium and magnesium. Metal analysis included aluminum, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, silver, strontium, vanadium and zinc. Although the probability of fish farms discharging any metals was low, their measurements were still obtained at all facilities to confirm this supposition. Biological oxygen demand and ortho-phosphorus (ORP) were only determined in the first four samples, and, chloride, sulphate, alkalinity, turbidity, volatile solids, sodium and potassium were omitted from those samples.

Results of the analysis for various parameters of water quality were tested for normality using the Shapiro test and were subsequently $\log_{10}$ transformed to meet normality, if required, prior to statistical analysis. Results of each parameter were evaluated based on selected categorical variables (sampling locations, seasons/biomass of sampling) using ANOVAs with Bonferonni post-hoc tests. All statistical analyses were performed using Systat 11™ (Systat 2004). Statistical significance was determined at a p value of <0.05.

Temporal variability was tested by grouping the sampling events into one of two groups according to a combination of seasons and biomass. Samples obtained between July and October where biomass is typically highest and water flow in the receiving environment is at its lowest were grouped into one category (summer/autumn) while all other samples obtained outside of the months between July and October were grouped as another (winter/spring). ANOVAS were calculated on each parameters as function of the new category (seasons), stations (upstream, effluent and downstream) and the interaction between seasons and stations (seasons*stations).

RESULTS

Results of analysis are presented in Tables 1 and 2. Biological oxygen demand (RDL< 5mg/L) and volatile solids (RDL< 20mg/L) concentrations were below the RDL for all samples obtained in this study.

Box plots for each parameter separated by sampling locations (upstream, downstream and effluent) illustrate the spread of the data and differences associated with sampling locations. ANOVAs, with post hoc pairwise comparisons, on the physical and chemical parameters separated by sampling locations (upstream, effluent and downstream) were run to determine any significant differences between sampling locations. Of the 19 physico-chemical parameters which had enough data for comparison (Table 1), only 3 were significant different between sites according to the ANOVAs. Concentrations of $\log_{10}$(TP) (R^2=0.321, $p<0.001$), $\log_{10}$ (TN) (R^2=0.236, $p<0.001$) and $\log_{10}$ (ammonia) (R^2=0.500, $p<0.001$) were significantly different between sampling locations (upstream, downstream, effluent) (Figure 1). The post hoc pairwise comparisons (with Bonferonni adjustment) revealed that the significant differences were always for the comparisons between effluent/downstream locations and the upstream (background) sampling location. In the case of ammonia, there was also a significant decrease in concentration between effluent and downstream. Therefore concentrations of ammonia, total phosphorus and total nitrogen were significantly higher at the effluent outfall and downstream locations compared with the upstream sampling location.

Of the 19 physico-chemical parameters which had enough data for comparison (Table 1), only TP was significantly different between seasons. Concentrations of $\log_{10}$(TP) (R^2=0.356) were significantly different between stations ($p<0.001$) and seasons ($p=0.040$). The interaction seasons*stations was not statistically significant ($p=0.808$). Therefore, concentrations of TP were significantly higher in the July-October months compared with the winter-spring seasons with a modest increase of the R^2 value.

Total phosphorus, ammonia and nitrate concentrations were compared to the Canadian Council of the Ministers of the Environment (CCME) water quality guideline for the protection of aquatic life. No nitrate measurements in this study exceeded the CCME guideline (CCME 2003) in freshwater of 13 mg/L (Table 1). Furthermore, there was not a significant increase in nitrate concentration in the effluent or downstream sampling locations compared with the upstream location. The CCME water quality guideline for ammonia in freshwater varies with the pH and temperature of the water (CCME 2010) Even though ammonia concentrations were significantly greater at the effluent and/or the downstream sampling locations, none of the samples from this study exceeded the CCME guideline. The CCME guideline for total phosphorus is different from other CCME guidelines in that it was developed based on a non-toxic endpoint (changes in trophic status) (CCME 2004) The CCME has developed some trigger ranges for total phosphorus in Canadian lakes and rivers. According to the CCME guidelines, eutrophic surface waters have a range of TP from 0.035-0.1 mg/L, mesotrophic waters have a range from 0.01-0.02 mg/L, oligotrophic from 0.004-0.01 mg/L (CCME 2004) Any input of phosphorus into a lake or river should not increase the phosphorus concentration to a degree that shifts the river or lake into a new trigger range. Using the trigger range from the CCME guideline, and the associated means (and standard deviations) of TP measured in the three sampling locations (upstream, effluent, downstream), the upstream locations could be described as mesotrophic (between ultra-oligotrophic end eutrophic) while the effluent and downstream locations could be described as eutrophic (Figure 1).

Range, mean, standard deviations and RDLs for all metals are presented in Table 2. Metals which were analysed but not detected in any of the water samples obtained in this study, along with their reported detection limit, included beryllium (<1 ug/L), cadmium (<3 ug/L), chromium(<2 ug/L), cobalt (<5 ug/L), lead(<20 ug/L), molybdenum(<5 ug/L), nickel (<6 ug/L), silver (<2 ug/L) and vanadium(<4 ug/L). Copper was detected in 4 of 30 samples submitted for metal analysis while zinc was detected in 50% of the samples. Interestingly, the CCME zinc guideline were only exceeded once and it was from an upstream sample. In three sets of samples, aluminum exceeded the CCME guideline in all locations sampled (upstream, downstream and effluent). ANOVAs with post hoc pairwise comparisons were run on all metal concentrations above detection limits separated by locations (upstream, effluent and downstream). ANOVAs on aluminum, barium, copper, iron, manganese and strontium were all non-significant ($p>0.05$). Depending on numerous factors (pH, oxidation, colloids, speciation, complexation, precipitation), the low concentration of metals in the effluent will probably sorb to the sediment in the receiving environment (USEPA 2007).

DISCUSSION

Impacts from land-based fish farms to the freshwater environment have been characterised by elevated levels of nutrients (phosphorus, nitrate, nitrite, ammonia), suspended solids, bacteria, pathogens, BOD and low levels of oxygen in numerous countries around the world (Australia, Turkey, France, US) (Tello et al. 2010, Guilpart et al. 2012, Gross 2001, USEPA 2002). In a single Canadian study, the concentrations of nitrate, nitrite, ORP, TKN (total Kjeldahl nitrogen), TP, and BOD did not vary significantly between inlet and outlet of fish hatcheries in British

Columbia (Environment Canada 1979). However in that study, ammonia levels were considered as a good indication of the impacts from fish hatcheries to the freshwater aquatic environment.

Ammonia has been noted as a water quality parameter which increases downstream of land-based aquaculture sites (Boaventura et al. 1997, Environment Canada 1979, Kirkagac et al. 2009). As with the results of the current study, Kirkagac et al. (2009) described a mean ammonia concentration rising significantly downstream of a rainbow trout farm in Turkey from 0.16 to 0.39 mg/L. This study also measured a significant increase in ammonia concentrations with an average of 0.03 mg/L at the upstream location, 0.35 mg/L at the effluent outfall and 0.22mg/L at the 100m downstream location. Guilpart et al. (2012) detected a positive relationship between ammonia immediately downstream of outlet and biomass of the fish kept on the farm/discharge ratio. Total ammonia in effluent ranged from 0.01 to 1.52 mg/L in a study by Boaventura et al. (1997) while total ammonia ranged from 0.13-0.57 mg/L at five catfish hatcheries (Tucker 2005). Pulatsu et al. (2004) measured an increase in average ammonia concentration from 0.038 upstream to 0.114 mg/L at the downstream location; however that increase was not statistically significant. In the Environment Canada (1979) study the effluent from salmon rearing facilities had an average ammonia concentration of 0.11mg/L. Mean ammonia concentration ranged from 0.27-1.64 mg/L at three rainbow trout farms and the concentrations were significantly higher downstream of the farms (Boaventura et al. 1997) Overall ammonia concentrations at the effluent outfalls from the current study averaged 0.35 mg/L and ranged from 0.015-2.776 mg/L. The average detected in the current study falls within the range presented above while our maximum value of 2.776 mg/L from a single sampling event is almost twice the maximum ammonia concentration reported by Boaventura et al. (1997). USEPA (2002) found ammonia to be the main form of nitrogen discharged but not at a concentration considered toxic when factoring pH and temperature. Our results corroborate the USEPA (2002) conclusion. The neutral pH of the waters flowing though the facilities in this study (average 6.9, Table 1) is the most likely reason why the CCME ammonia guideline was not exceeded. Ammonia concentration in this study decreased significantly between the effluent discharge point and the downstream locations suggesting a sharp decrease in concentration of ammonia in the first 100 m of those streams. That is of importance since of all three parameters which increased significantly at the outfall location, ammonia is the only parameter which also decreased significantly at the 100 m downstream location. Nevertheless, the concentration of ammonia at the downstream location was still significantly higher than the upstream location suggesting that ammonia levels are not reduced to background levels within 100 m of the effluent outfall.

Total nitrogen increased significantly in our study from an average of 0.33 mg/L upstream of the land-based fish farms to 0.83 mg/L and 0.67 mg/L at the effluent and downstream sampling locations respectively (Table 1). Our averages are similar to those of Tucker (2005) who measured a TN range of 0.19-0.72 mg/L; however Tucker (2005) measured an average net loading of 0.28 mg/L while our average net loading at the effluent location was almost twice that at 0.5 mg/L. Guilpart et al. (2012) also produced similar results with total nitrogen increasing significantly in first 100m from the outfall of land-based fish farms. In contrast, a study by Gross (2001) concluded that total nitrogen did not vary significantly between upstream (0.3 mg/L), effluent (1.1 mg/L) and 100 m downstream (0.8 mg/L) locations. Total nitrogen concentrations at the 100 m downstream locations in this study were significantly different from the upstream location suggesting that significant increases in the concentrations of total nitrogen from land-based fish farms in Atlantic Canada can still be measured 100 m downstream of the outfall.

Nitrate concentrations in our study did not increase significantly from the upstream location although average nitrate concentrations did increase from 0.13 mg/L (upstream) to 0.43 mg/L (effluent). The data were highly variable with a large standard deviation (0.43±0.91 mg/L) which probably contributed to that lack of significance (Table 1). Boaventura et al. (1997) did not measure a significant increase in nitrate concentrations downstream of 3 rainbow trout farms. However, nitrate concentrations increased significantly between upstream and downstream locations in the Pulatsu et al. (2004) study.

Total phosphorus concentrations increased significantly from the upstream location (0.13mg/) to both the effluent (0.101 mg/L) and downstream location (0.69 mg/L). Similarly, Pulatsu et al. (2004) recorded a significant increase in TP with an average of 0.069 (±0.034) mg/L upstream and 0.117 (±0.041) mg/L downstream of land-based fish farms. Kirkagac et al. (2009) measured TP from 0.6 to 1.74 mg/L downstream of land-based fish farms while ORP concentrations varied from 0.41-0.76 mg/L. In contrast, our ORP concentrations were at or below the method detection limit (0.01 mg/L) and were only measured in the first 12 samples of this study. Tucker [9] reported a total phosphorus range from 0.15-0.53 mg/L at five catfish hatcheries and an average TP concentration in effluent of 0.45 mg/L. However net loadings (0.06-0.13 mg/L) of phosphorus in the study by Tucker [9] were lower than background concentrations (0.06-0.37

mg/L) and therefore reflected the quality of the water source in respect to TP. True et al. (2004) described phosphorus concentrations from five rainbow trout farms in the United States. The results of this study indicate that the concentrations of phosphorus being discharged from these facilties are high enough to change the CCME trigger range TP concentration of these rivers. Some of the values of phosphorus measured at the outfall and downstream locations classify the rivers as hyper eutrophic based on the CCME trigger ranges.

TSS concentrations in freshwater facilities located in the United States ranged from 7-19 mg/L for an average net loading of 10.7 mg/L (Tucker 2005). Our range of TSS values ranged from 1 to 7.5 mg/L at the effluent outfall. Although the USEPA (2002) study indicated that solids were the largest pollutant from land-based aquaculture, our study revealed a negligible difference average TSS concentrations upstream (2.4 mg/L) and effluent (2.7 mg/L). Differences in solids concentrations may be due to the difference in species grown and type of facilities (open net in lakes versus flow through in this study). As in our study, neither Gross (2001) nor Pulatsu et al. (2004) measured changes in suspended solids downstream of salmon farms, respectively.

Temporal variations in effluent concentrations of water quality parameters have not been extensively studied at freshwater aquaculture facilities. In one of the few published studies, Hennessy et al. (1996) described variations in effluent characteristics in relation to the life stage of fish. Although the studies by Masters et al. (2008) and Pulatsu et al. (2004) involved monthly sampling for 6 and 11 months respectively, there were no attempts in either study to estimate temporal variations between water quality parameters. However, timing of the samples can be a key factor in the ability to detect changes (Gross 2001) Gross (2001) specifically chose 4 monthly samples at a time when biomass was greatest and flow was at a minimum, which was expected to result in maximum pollution potential. Twenty of the 31 samples collected as part of our study were in the 4 months from July to October which are generally the times when biomass is highest and water levels lowest. ANOVAs were performed with this subset of our data to determine if impacts were more pronounced during that time. The only parameter that changed significantly from upstream to effluent and/or downstream locations as a function of seasons was TP with only a modest increase of 3% in the overall R^2 value. Therefore our results do not indicate a seasonal difference in the degree of impacts on receiving environments. Similarly, Tello et al. (2010) described the temporal variability of the effluent discharge from land-based salmonids farms as continuous on a yearly time scale and fluctuating within a flexible range of values.

Tello et al. (2010) described the spatial scale of a disturbance from land-based aquaculture effluent as the furthest downstream distance where physical, biological and chemical parameters remain significantly different from background values. Results from our study indicated that TN, TP and ammonia which increased significantly at the outfall locations did not return to background concentrations at the 100m downstream location suggesting that elevated TN, TP and ammonia due to the farm effluent could be measured beyond 100m from the effluent outfall. Our results are corroborated by a study by Boaventura et al. (1997) which measured the distance of pollution downstream of three rainbow trout farms as 3, 5 and 12km.

Results from this study have demonstrated that the concentrations of TP, TN and ammonia in the effluent from a variety of land-based aquaculture facilities in Atlantic Canada remained significantly elevated at both the effluent outfall location and at the 100m downstream location compared with background locations and this regardless of the time of the year or species grown. Other physical and chemical parameters (especially solids) measured as part of this study did not change significantly from background. Finally, the average concentrations of TP discharged from the facilities are high enough to change trophic status of these streams or rivers based on trigger ranges of CCME guideline.

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APPENDIX

Appendix 1. Method reference for analysis conducted by Environment Canada's Water Quality Laboratory and Maxxam.

Parameter	Reference
Chloride, sulphate, nitrate	Atlantic Laboratory for Environmental Testing, Anions-chloride, nitrate-N and sulphate (Ion chromatography, Dionex DX 120 System, Revisions: 2009-06-26, 2010-06-04, 2011-07-04
Nitrate*	ASTM standard D3867, 2009, " 09 Standard Test Methods for Nitrite-Nitrate in Water," ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03
TOC	Atlantic Laboratory for Environmental Testing, TOC & DOC (non-purgeable), Total Carbon Analyzer, automated. Revisions: Draft, 2010-08-10, 2012-04-24
Conductivity, pH, alkalinity	Atlantic Laboratory for Environmental Testing, Alkalinity (H2SO4 titration), pH, conductance, total and Gran alkalinity (automated, using PC titration System), Revisions: 2009-11-10, 2010-03-08, 2010-08-11, 2011-06-30.
Turbidity	Atlantic Laboratory for Environmental Testing, Turbidity (Turbidimetric), Revisions: 2009-08-11, 2011-07-04.
TSS	Atlantic Laboratory for Environmental Testing, Total Suspended Solids (Gravimetric), Revisions: 2006-04-04, 2011-03-09, 2011-05-26.
Hardness, VS, BOD, TN*,	22nd Edition Standard Methods for the Examination of Water & WasteWater, 2012, by E.Rice, R. Baird, A. Eaton, L.Clesceri,

TOC*	
pH, ORP, TP, TS, TSS*	pH (EPA 150.1, 1982, EPA/600/4-79/020)), ortho-phosphorus and TP (EPA 365.1 1993. EPA/600/R-93-100), total solids and TSS (EPA 160.3 and 160.2, 1971, Residue, Total 600/4)
TP	Atlantic Laboratory for Environmental Testing, Total Phosphorous Flow Injection Analysis Colorimetry (Acid persulfate digestion method). Dissolved Phosphorus, Soluble and Reactive Phosphorus, Revisions: 2011-01-19, 2012-02-07
Ammonia	Atlantic Laboratory for Environmental Testing, Ammonia-N Lachat 8500 Flow injection analysis system), Revisions: 2009-06-29, 2011-01-06, 2011-07-04
Ammonia*	USEPA 350.1, 1993, 600/4-79-020
TN	Atlantic Laboratory for Environmental Testing, Total Nitrogen by flow injection analysis colorimetric (Basic persulfate digestion method), Revisions: Draft, 2010-08-10, 2012-06-01
Metals	Atlantic Laboratory for Environmental Testing, Metals Dissolved/Total Recoverable by ICP-OES Revisions: 2011-11-01, 2012-05-31

(*Maxxam lab only)

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Figure and Table Captions

Figure 1. Box plots of log transformed concentrations of ammonia, total nitrogen and total phosphorus as a function of sampling locations (upstream, effluent and downstream).

Table 1. Range, mean and standard deviation of physical and chemical parameters obtained at the three sampling stations from all facilities combined.

Table 2. Range, mean and standard deviation of metals in water samples at the three sampling stations from all facilities.

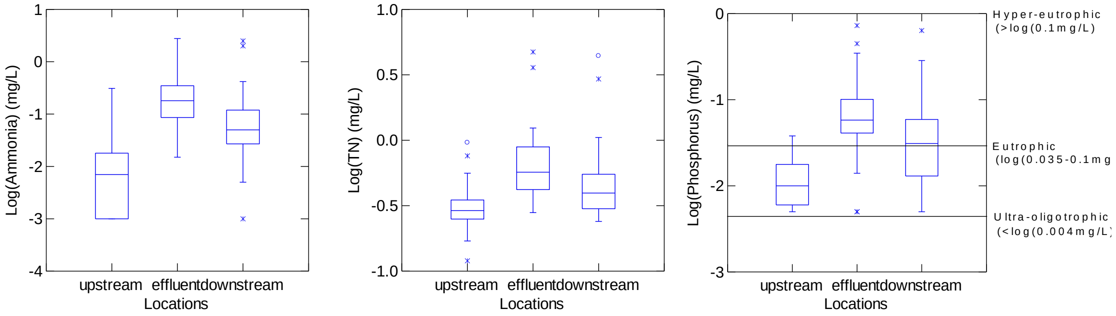

Figure 1. Box plots of log transformed concentrations of ammonia, total nitrogen and total phosphorus as a function of sampling locations (upstream, effluent and downstream).

Table 1. Range, mean and standard deviation of physical and chemical parameters obtained at the three sampling stations from all facilities combined.

Parameter	Upstream	Effluent	Downstream	RDL
TSS (mg/L) (n=29)	1.0-21.3 (2.4±4.2)	1-7.5 (2.7±1.7)	1-12.4 (3.1±3.1)	1 (first 4 samples), 2 (all others)
Chloride (mg/L) (n=29)	1.01-154.9 (12.9±28.8)	0.05-257.7 (21.8±53.3)	1.1-394.5 (24.3±76.1)	0.1
Sulphate (mg/L) (n=29)	1.2-62.4 (5.1±11.5)	0.05-67.5 (6.5±13.5)	1.1-55.8 (5.8±10.9)	0.1
Nitrate (mg/L) (n=31)	0.01-0.76 (0.13±0.15)	0.01-4.2 0.43±0.91	0.01-3.2 (0.39±0.7)	0.05 (first 4 samples), 0.02 (all others)
Ammonia (mg/L) (n=33)	0.001-0.31 (0.03±0.06)	0.015-2.776 (0.35±0.61)	0.001-2.5 (0.22±0.6)	0.05 (first 4 samples), 0.002 (all others)
TN (mg/L) (n=33)	0.12-0.96 (0.33±0.17)	0.28-4.73 (0.83±0.9)	0.24-4.4 (0.67±0.86)	0.02
TOC (mg/L) (n=31)	0.8-15.3 (5.3±3.7)	0.8-19.2 (7.0±4.8)	1-15.4 (6.0±3.6)	0.5 (first 4 samples), 0.2 (all others)
Conduct. (uS/cm) (n=33)	20.5-711 (81.1±120.4)	23-976 (114.3±194.5)	22-1416 (116.1±249.8)	1 (first 4 samples), 0.5 (all others)

Parameter	Upstream	Effluent	Downstream	RDL
pH (n=33)	5.17-7.85 (6.9±0.8)	5.5-7.7 (6.9±0.5)	5.3-7.9 (6.9±0.7)	0.05
Alkalinity (mg/L) (n=29)	<20-41.4 (12.9±7.8)	<20-46 (13.4±10.0)	<20-49 (13.5±9.4)	20
Turbidity (NTU) (n=29)	0.3-4.3 (1.1±0.9)	0.2-12.4 (1.5±2.3)	0.2-3.6 (1.1±0.8)	0.1
Hardness (mg/L) (n=33)	2.6-78.9 (17.7±15.3)	3.3-98.3 (22.2±22.0)	2.6-135 (23.0±25.6)	0 (calculated)
ORP (mg/L) (n=4)	<0.01	<0.01-0.01	<0.01	0.01
TP (mg/L) (n=33)	0.005-0.038 (0.013±0.01)	0.005-0.727 (0.101±0.15)	0.005-0.636 (0.069±0.12)	0.02 (first 4 samples), 0.001 (all others)
Sodium (mg/L) (n=29)	1.2-103.4 (9.1±19.1)	1.4-146.3 (13.5±31.8)	1.3-215.7 (14.1±41.3)	0.02
Potassium (mg/L) (n=29)	0.20-0.86 (0.37-0.19)	0.2-5.4 (0.60±1.0)	0.2-8.2 (0.7±1.5)	0.1
Calcium (mg/L) (n=33)	0.51-29.4 (5.3±5.6)	0.77-29.5 (6.1±6.1)	0.5-18.0 (5.8±4.8)	0.01
Magnesium (mg/L) (n=33)	0.32-2.1 (1.1±0.5)	0.34-16.93 (1.7±2.8)	0.3-24.6 (2.0±4.5)	0.01 (first 4 samples), 0.05 (all others)

Table 2. Range, mean and standard deviation of metals in water samples at the three sampling stations from all facilities.

Parameter	Upstream	Effluent	Downstream	RDL
Aluminum (ug/L) (n=28)	22-454 (102±103)	23-456 (106.3±105.4)	21-538 (109.4±114.7)	4
Barium (ug/L) (n=29)	3-30 (10.2±7.2)	3-52 (12.3±10.1)	3-25 (11.2±7.4)	1
Copper (ug/L) (n=11)	<2	<2-10 (2.4±3.1)	<2-6 (1.5±1.5)	2
Iron (mg/L) (n=28)	0.04-0.66 (0.19±0.16)	0.04-0.74 (0.22±0.18)	0.05-0.84 (0.22±0.18)	0.02
Manganese (ug/L) (n=28)	5-399 (47.9±73.2)	5-174 (47.7±35.8)	1-188 (47.7±42.3)	2
Strontium (ug/L) (n=29)	4-189 (31.5±39.1)	4-210 (42.2±53.1)	4.5-206 (41.9±50.5)	1
Zinc (ug/L) (n=11)	<2-48 (5.8±14)	<2-15 (3.9±4.2)	<2-5 (2±1.5)	2