

Water Characteristics & Bioremediation Strategy of Triumph Detention Pond

Prangthip Suppaiboonsuk, Sanjana Akella

University of British Columbia

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APSC 498 & SEEDS Project

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Prangthip Suppaiboonsuk [REDACTED]
Sanjana Akella [REDACTED]

Supervisor: Dr. Susan Baldwin

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EXECUTIVE SUMMARY

In 2009, a stormwater detention pond was constructed on University of British Columbia (UBC) south campus to detain water draining from nearby construction sites. Since then, the pond's capacity to detain and bioremediate stormwater was not systematically monitored or assessed. In 2015, a study was sponsored by the UBC SEEDS program to assess the pond's water detention efficiency, determine if organic matter, metal and oxygen concentrations meet provincial Ministry of Environment (MOE) guidelines, and recommend bioremediation methods. The chosen water quality parameters are dissolved oxygen (DO), pH, total suspended solids (TSS), turbidity, total organic carbon (TOC), and heavy metals (copper, lead, zinc, cadmium and nickel). Data Sonde equipment was used to measure the pH, temperature, DO concentration, oxygen reduction potential (ORP), salinity and total dissolved solids (TDS) at different locations in the pond. In the laboratory, water samples were filtered to determine the total suspended solids (TSS) and chemical oxygen demand (COD) test was performed to determine the organic matter concentration. For metal concentrations, water samples were evaporated and analyzed in the ICP-OES.

The results show that COD is $0.17 \mu\text{g O}_2/\text{L}$ at the outlet and $0.11 \mu\text{g O}_2/\text{L}$ at the inlet of the pond. This indicates lower organic matter than observed in natural wetland waters. The average outlet TSS concentration is 27.71 mg/L , which is 19% less than the inlet TSS value. The measured TSS values at all locations are under MOE guideline value. DO concentration is 9.65 mg/L at the outlet with 14% decrease from inlet to outlet. Overall, DO at all locations meet the criteria. For metals, cadmium (366% difference in outlet-inlet), lead (93%), zinc (8%) and nickel levels (62%) are found to be higher in the outlet than inlet. This indicates accumulation and re-dissolution of metals along the stream path due to changing redox conditions, affected by weather conditions. On the other hand, copper (-46%) concentration is reduced in the outlet. At both inlet and outlet, copper concentration exceeds MOE guideline value of $14.22 \mu\text{g/L}$. pH range is narrow and near neutral across the six locations.

Results from this study do not provide a complete understanding of the biogeochemical processes taking place in the pond. In order for a comprehensive assessment to be made, water samples should be obtained over a period of time and under different weather conditions to evaluate the effects of flooding and drainage of sedimentations. Samples should be taken from

the manholes. Soil and plants samples should be analyzed. Inlet/outlet flow rates, capacity, depth and retention time should be determined in order to evaluate the pond's efficiency and suggest the most effective configuration for bioremediation. Research into local and geographical vegetation should be undertaken to see which plant species are suitable for bioremediation. Analysis of the components in biofilm would also aid in the understanding of the adsorptive and interfacial processes already taking place.

TABLE OF CONTENTS

Executive Summary.....	i
Table of Contents.....	ii
List of Tables.....	iv
List of Figures.....	v
Introduction.....	1
Background.....	1
Theory.....	4
3.1. Chosen Water Quality Parameters.....	4
3.1.1. Dissolved Oxygen.....	4
3.1.2. pH.....	4
3.1.3. Suspended Solids & Turbidity.....	4
3.1.4. Total Organic Carbon.....	5
3.1.5. Heavy Metals.....	5
3.2. Relationship between Oxidation-Reduction Potential, pH, Dissolved Oxygen, Total Dissolved Solids and Metals.....	7
3.2.1. Oxygen Reduction Potential & Dissolved Oxygen	7
3.2.2. pH.....	7
3.2.3. Total Dissolved Solids.....	7
3.3. Principles Applying to Laboratory Tests.....	8
3.3.1. ICP-OES.....	8

3.3.2 Chemical Oxygen Demand (COD) Test.....	8
Methods.....	9
4.1. Sampling Methods.....	9
4.2. Laboratory Methods.....	9
4.2.1. Chemical Oxygen Demand (COD).....	9
4.1.2. Total Suspended Solids (TSS).....	9
4.1.3. Metals.....	10
Results & Discussion.....	11
5.1. Chemical Oxygen Demand (COD).....	11
5.2. Total Suspended Solids (TSS).....	11
5.3. Dissolved Oxygen (DO).....	12
5.4. Metals.....	13
Conclusion.....	17
Recommendations.....	18
References.....	19
Appendix A – Site Photos & Construction Draft.....	A-1
Appendix B – BC Water Quality Guideline Tables & Figures.....	B-1
Appendix C – Raw Data, Calculations & Results.....	C-1

LIST OF TABLES

Table 1: Averaged Metal Concentrations at Different Sample Locations.....	13
Table 2: Metal Concentrations Guideline Obtained from BC-MOE.....	13
Table 3: Inlet versus Outlet Metal Concentration with Percentage Difference.....	14
Table 4: Measurement using SONDE probe at Different Pond Locations.....	15
Table B1: Summary of Water Quality Criteria for Copper.....	B-2
Table B2: Summary of Water Quality Criteria for Lead.....	B-3
Table B3: Recommended Guidelines for Zinc.....	B-4
Table B4: Recommended Guidelines for Cadmium at Different Hardness.....	B-5
Table B5: Canadian Water Quality Guidelines for Cadmium.....	B-5
Table B6: Summary of water quality guidelines for turbidity, suspended and benthic sediments.....	B-6
Table B7: Summary of EIFAC (European Inland Fisheries Advisory Commission) pH Ranges for the Protection of Aquatic Life.....	B-7
Table B8: Recommended Dissolved Oxygen Criteria for the Protection of Aquatic Life.....	B-8
Table C1: Measurement using SONDE probe at Different Pond Locations.....	C-2
Table C2: Average Total Suspended Solid (TSS) at Different Pond Locations.....	C-2
Table C3: Average Chemical Oxygen Demand (COD) with TSS.....	C-2
Table C4: Average Chemical Oxygen Demand (COD) without TSS.....	C-3
Table C5: Metal Concentration.....	C-4
Table C6: Averaged Metal Concentrations at Different Sample Locations.....	C-6
Table C7: Metal Concentrations Guideline Obtained from BC-MOE.....	C-6
Table C8: Inlet versus Outlet Metal Concentration with Percentage Difference.....	C-7

LIST OF FIGURES

Figure 1: Overview Google Earth Image of Detention Pond Location.....	1
Figure 2: COD Reaction Equation	8
Figure 3: COD level at Different Sampling Locations.....	11
Figure 4: TSS at Different Sampling Locations.....	12
Figure 5: DO Level at Different Sampling Locations.....	12
Figure 6: Inlet versus Outlet Concentration for Different Metals.....	14
Figure A1: Close-up Google Earth Image of Detention Pond Location.....	A-2
Figure A2: Overview Google Earth Image of Detention Pond Location.....	A-2
Figure A3: Draft of Detention Pond.....	A-3
Figure B1: Percent reduction in growth of Salmonid/ Salmonid-like fishes at various oxygen levels.....	B-8
Figure C1: Site Sampling Map.....	C-5
Figure C2: Inlet versus Outlet Concentration for Different Metals.....	C-6
Figure C3: Inlet versus Outlet Concentration for Cadmium and Nickel.....	C-7
Figure C4: Inlet versus Outlet Concentration for Average TSS (mg/L).....	C-8
Figure C5: Inlet versus Outlet Concentration for Average COD with TSS ($\mu\text{g O}_2/\text{L}$).....	C-8
Figure C6: Copper Concentration at Different Locations.....	C-9
Figure C7: Nickel Concentration at Different Locations.....	C-9
Figure C8: Zinc Concentration at Different Locations.....	C-10
Figure C9: Lead Concentration at Different Locations.....	C-10
Figure C10: Cadmium Concentration at Different Locations.....	C-11

1. INTRODUCTION

The south campus detention pond, located near Triumph was originally constructed to detain water draining from nearby construction sites. Currently, there is no systematic evaluation of the pond's capacity to detain and remediate stormwater. The purpose of this project is to further investigate the pond's characteristics, collect on-site water samples, analyze contaminant content and provide a suitable bioremediation strategy.

2. BACKGROUND

The detention pond is located near Triumph in south campus. It was constructed in 2009 to detain runoff water as well as water from nearby construction sites. The pond treats incoming stormwater runoff by allowing particles to settle. Figure 1 shows the overview Google Earth image of the detention pond location.



Figure 1: Overview Google Earth Image of Detention Pond Location

Pond Design

From the initial draft, the pond is designed to have a depth of 1.5 m with a rip rap over trench slope of 0.5 m surrounding the pond. Impermeable and drain rock berms are implemented. The berms are used to reduce the velocity of water coming in and to increase the retention time. They also regulate erosion and sedimentation by reducing the rate of surface runoff ⁽¹⁾. Plants are grown on the impermeable berms to further stabilize and prevent erosion. The impermeable

berms are constructed at a height of 1.0 m and a slope of 0.66 m. The berm structure is found as an “L” shape in the center of the pond. The drain rock berms link the impermeable berm to the edge of the pond. The drain rock berms are constructed at a height of 0.75 m with a slope of 0.66 m. They are also constructed around the inlet and outlet in a semi-circle shape to further decrease the velocity of water. Figure A3 shows the pond draft.

Pond Inlet

The pond has a concrete bedhead wall inlet with a PVC pipe diameter of 0.45 m. The inlet is surrounded with a 10 m² rip rap pad. This is installed to slow down the inlet flow during a heavy runoff. The water in the inlet pipes is obtained from nearby roadside water drainage system.

Pond Outlet

A manhole riser with a diameter of 1.05 m is installed at the outlet. It is covered with a trash rack to prevent any debris from falling through and can be accessed to obtain effluent samples. The riser pipe is often used to discharge the cooler bottom water and avoid thermal impact on the surface water. The flow is driven by natural water pressure ⁽¹⁾.

Water Characteristics

Metal analyses of the pond were performed annually for two consecutive years. However, the data could not be found.

Initial Site Visit

On January 16, 2015 at 4:00 PM, the location of the site is investigated. The pond was halfway filled with water. Weeds with long stalk were identified in the area between the berms and pondweeds near the rim of the pond. Two waterfowls were spotted.

Pond Design Observations

Many of the pond characteristics did not match that of the initial draft. The gate was located in front of the outlet rather instead of the inlet. It is observed that drain rock berms are not implemented. However, an impermeable berm is branched off at the top of the “L” shape impermeable berm. A drawing of observed site can be found in Figure C1.

3. THEORY

3.1. Chosen Water Quality Parameters

Since water from Triumpf detention pond drains into a nearby creek, the quality of water must meet guidelines for aquatic life. The following parameters are chosen based on how crucial they are to sustain aquatic life and how they are related to known sources of contamination.

3.1.1 Dissolved Oxygen (DO)

Dissolved oxygen refers to the level of free, non-compound oxygen present in the water. It is a crucial parameter because organisms and plants require oxygen for respiration. Crabs, oysters and worms require a minimum amount of 1-6 mg/L of dissolved oxygen. Shallow water fish require a minimum of 4-15 mg/L ⁽²⁾. Dissolved oxygen can be affected by other parameters such as temperature, pressure and organic matters. Dissolved oxygen at each sample location is measured with a probe. The guideline for dissolved oxygen can be found in Table B8.

3.1.2 pH

pH measures the activity or concentration of the hydrogen ion (H^+) on a scale from 1.0 to 14.0. It indicates acid strength in a water body; acidity increases as pH is lowered. pH is an important indicator of water quality since it affects many chemical and biological processes in water and as a result, different organisms survive in different pH ranges. Most aquatic organisms require neutral pH range of 6 – 8 ⁽³⁾. Impairment of reproductive ability or even fish kill can occur if acidity of water body drops below pH 5 ⁽³⁾. Lower pH (below 5) also allows certain heavy metals like aluminum to leach into the soil. pH can easily be measured using a pH meter.

3.1.3 Suspended Solids & Turbidity

Suspended solids (SS) are organic and inorganic matters that are maintained in suspension when a sample is filtered through 0.45 μm pore size ⁽⁴⁾. The particles can come from soil erosion runoff, discharges or algae bloom. High concentration of SS can lead to increase in water temperature because the particulates absorb more solar radiation than water molecules. The increase in temperature leads to the drop of the dissolved oxygen (DO) level. Concentration of SS also reduces light penetration through water.

3.1.4 Total Organic Carbon (TOC)

Total organic carbon takes account of organic matter in aquatic systems, which include carbohydrates, fatty acids, phenolic, natural macromolecules and colloids ⁽⁵⁾. Human contribution of organic matter can be from waste and sewage. Excess amount of organic matter encourages the growth of bacteria and algae, which lead to oxygen depletion and can lead to fish kills.

The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are tests that indicate the amount of organic matter present in the water. In this case study, only COD test is performed because it is relatively fast and the results are reproducible. However, COD may not be a true representation of the organic matter that can be decomposed by bacteria in a natural setting. In COD, non-biodegradable organic matters are oxidized as well. However, since the source of water is mainly from construction sites, organic matter is not expected to be high.

3.1.5 Heavy Metals

Since runoffs that enter the pond originated from construction sites, motor vehicles and degradation of pavement, heavy metals are key parameters. Heavy metals are toxic to living organisms. The United States Nationwide Urban Runoff Program has determined that copper, lead, zinc and cadmium are by far the most prevalent priority pollutants found in urban runoff ⁽⁶⁾. Nickel is another metal that is commonly found in exhaust emissions, lubricating oils, brake lining and tires and thus, its content should be determined. Metals are often more toxic at lower pH and in soft water ⁽⁶⁾. The BC MOE guidelines on each metal's content in fresh water aquatic life can be found in Appendix B.

Copper

Copper is an essential substance to aquatic life. However, at concentrations greater than 0.04 µg/L, it is toxic to living organisms. Fish and crustaceans lose ability to regulate transport of salts necessary for cardiovascular and nervous systems via their gills. They also lose their sense to detect odours as copper binds to the smell receptor molecules ⁽⁷⁾.

Lead

When concentration exceeds 100 ppb, lead affects gill function of fish.

Zinc

For aquatic life, zinc is the most toxic to microscopic organisms ⁽⁶⁾. However, it is also an essential element for aquatic and terrestrial biota and thus, its removal from the environment below certain levels can be harmful.

Cadmium

Cadmium is a trace element that in high concentration can lead to skeletal deformities and impairs functioning in aquatic life. Cadmium impairs aquatic plant growth. This affects the entire ecosystem since green plants are at the base of all food chains.

Nickel

Nickel is a trace element; overexposure to which can damage gill functions of fish as well as its liver and nervous systems ⁽⁶⁾.

3.2. Relationship between Oxidation-Reduction Potential, pH, Dissolved Oxygen, Total Dissolved Solids and Metals

Metals in the soluble and exchangeable forms are considered readily mobile, bio-available and pose the most risk to biological organisms. The solubility of heavy metals depends on several physical (temperature, flow) and chemical (oxidation-reduction status, E_H and pH) properties of the soils and sediments.

3.2.1 Oxygen Reduction Potential (ORP) & Dissolved Oxygen (DO)

Natural wetlands soils are generally anoxic (no oxygen) and have low redox potentials. In permanently anoxic water conditions, decomposition of organic matter is by reduction and organic matter accumulates on the sediment surface ⁽⁸⁾. The resulting organic sediment surface is responsible for accumulating heavy metals from influent stormwater and runoffs.

3.2.2 pH

Soil oxidation conditions also influence the pH, when oxidized soils are flooded and become anaerobic, the pH tends to converge toward neutrality, regardless of whether the soil was initially acidic or alkaline ⁽⁹⁾. Thus, the range of pH in wetland soils is typically small. Metal cycling in wetlands is highly dependent on pH. Drainage of wetland soils often decreases pH, which alters metal solubility. Metals bound to organic matter are released upon decomposition leading to enhanced bioavailability during water drawdowns and drought ⁽⁹⁾.

3.2.3 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) contain inorganic salts, minerals, organic molecules and other dissolved materials in water. Depending on the source of influent water, TDS can contain toxic metals in different ionic forms. Salinity and TDS are related - increase in salinity, changes ionic composition of water and toxicity of metal ions, leading to increased toxicity of TDS ⁽¹⁰⁾.

3.3 Principles Applying to Laboratory Tests

3.3.1 ICP-OES

Induced Couple Plasma – Optical Emission Spectrometry (ICP-OES) measures trace elemental concentrations by separating light emitted from plasma into discrete component wavelengths using a diffraction grating. Within the calibration range of the instrument, the amount of light on a given wavelength is proportional to the concentration of the corresponding element in the solution ⁽¹¹⁾. Concentration of water samples is required to run the ICP-OES instrument within detection limits.

3.3.2 COD Testing

The chemical oxygen demand (COD) measures the oxygen equivalent of the organic matter content in a sample that is subject to oxidation by a strong chemical oxidant ⁽¹²⁾. In this test, potassium dichromate is used to oxidize organic carbon in effluent sample to produce carbon dioxide, water and various states of chromium ions as follows:

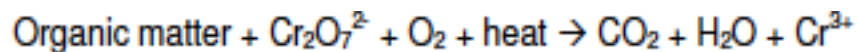


Figure 2: COD Reaction Equation

The chromium ion is transformed from a hexavalent (VI) state to a trivalent (III) state. The color of chromium in a trivalent state is strongly absorbed in the 600 nm region, where the color of chromium in a hexavalent state is strongly absorbed in the 400 nm region. Therefore, the increase in Cr^{3+} can be determined by measuring the absorbance at 600 nm ⁽¹²⁾.

COD does not distinguish between biodegradable and non-biodegradable organic compounds. Since the test results can be obtained in a matter of hours, COD is often used for frequent monitoring of treatment plant water quality.

4. METHODS

4.1 Sampling Methods

Prior to sample collection, 1 L sample bottles are acid washed. The bottles are soaked in dilute sulphuric acid, followed by nitric acid and rinsed with deionized water. The sampling locations were determined arbitrarily during initial visits to the pond site. The six locations are noted on Figure C1. Data Sonde equipment is used to measure water quality parameters such as temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), oxygen reduction potential (ORP) and salinity on site. At each sampling location, the probe is first calibrated by dangling the probe in the deionized water and waiting for the readings to normalize; the measurements are noted. 1 L water samples are collected at each sampling location to analyze metal concentration, chemical oxygen demand (COD) and total suspended solids (TSS). The bottles are attached to a 1 m extension pole and submerged completely under the water to obtain samples. Precautions must be taken to avoid air bubbles and collecting water with sediment from bottom disturbance. The bottles are filled completely to prevent oxidation of the samples.

4.2 Laboratory Methods

4.2.1 Chemical Oxygen Demand (COD)

1.2 mL of COD digestion solution and 2.8 mL of sulfuric acid reagent are prepared in 22 vials. 2 mL of potassium hydrogen phthalate (KHP) standards at concentration of 0.5 M, 1.0 M, 1.5 M and 2.0 M are added to each vial to obtain a calibration curve. In the remaining vials, 2 mL of sample from each location is added. Duplicates of each sample are performed. The vials are placed in a heating block at 150 °C for 2 hours. Once cool, the absorbance measurement is taken⁽¹²⁾.

4.2.2 Total Suspended Solid (TSS)

The initial mass of 0.45 µm Whatman 934-A glass filters in aluminum dishes are recorded. Water samples from different locations are filtered through the pre-weighted filter papers. Triplicates of sample from each location are obtained for precision and reliability of results. The

final volume of filtered water is noted. Once filtered, the filters are dried in an incubator at 40 °C for 24 hours before the final mass is recorded.

4.2.3 Metals

After filtration and preservation of samples with 20% nitric acid, 100 mL of sample in a griffin beaker is evaporated at 95 °C to a final volume of approximately 20 mL. Care is taken to prevent the sample from boiling and forming azeotropes. Evaporation is repeated to provide two 20 mL concentrates from each sampling location. The concentrates are analyzed for cadmium, copper, nickel, lead and zinc on the ICP-OES.

5. RESULTS & DISCUSSION

5.1. Chemical Oxygen Demand (COD)

In figure 3, the COD at different location is displayed. The COD is 0.17 $\mu\text{g O}_2/\text{L}$ at the outlet and 0.11 $\mu\text{g O}_2/\text{L}$ at the inlet. In all locations, the obtained COD is lower than the MOE guideline value of 0.50 $\mu\text{g O}_2/\text{L}$. The results suggest that there is low concentration of organic matter. The results obtained from location 2, 5 and 6 are very low compared to other locations. This may have been due to the fact that organic matter is consumed by sulfur reducing bacteria. Existence of sulfur reducing bacteria is suggested from smells of H_2S , black residues and bubbles emerging from sediments as samples were being collected.

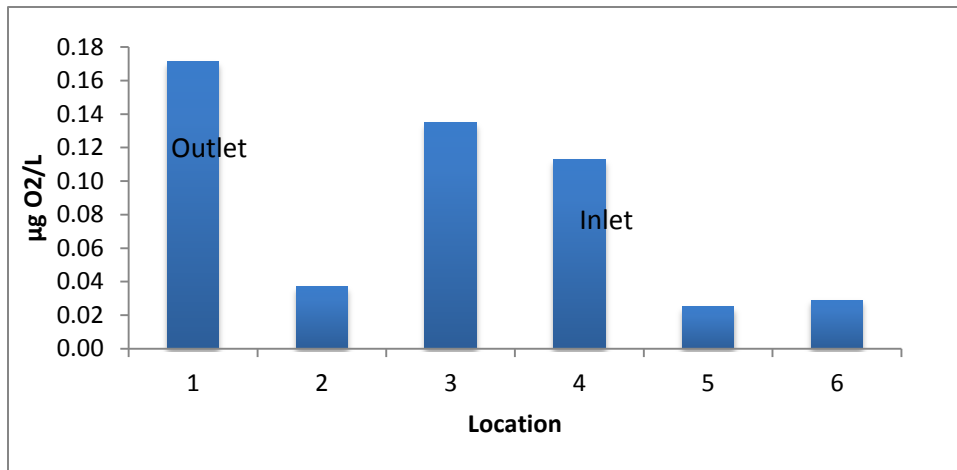


Figure 3: COD level at Different Sampling Locations

5.2. Total Suspended Solids (TSS)

Figure 4 displays TSS at different locations. The average outlet TSS concentration is 27.71 mg/L, which is 19% less than the inlet TSS value of 34.08 mg/L. The drop in TSS may be due to sedimentation through the pond. TSS has highest at location 3. Water flow rate at location 3 is observed to be relatively slow and piles of clay are observed. The MOE guideline states that runoff from site must have TSS concentration less than 25 mg/L from a background value of 10 mg/L (Table B6). The obtained TSS values at all the location meet the guideline. Low value of TSS observed is expected because the detention pond water sources are from construction sites

and urban runoff. Obtained TSS values may have been higher than actual due to the collection of small invertebrates on the filter papers.

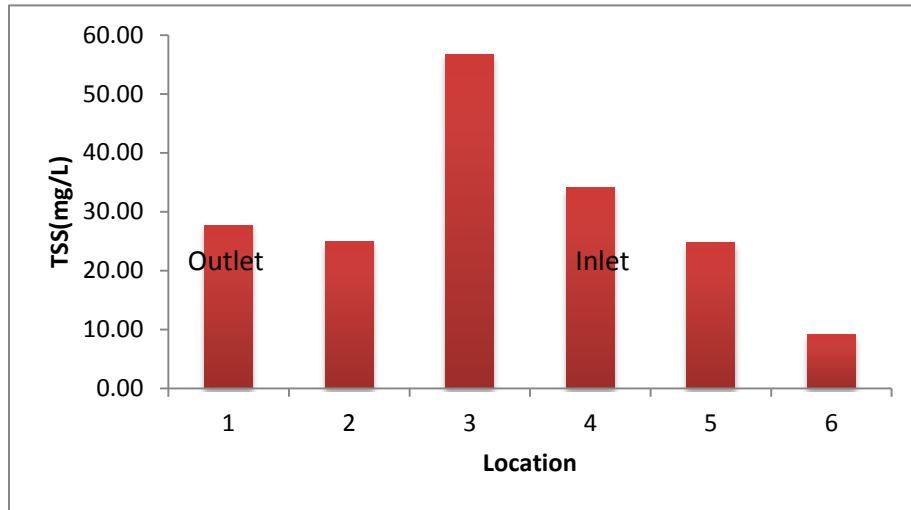


Figure 4: TSS at Different Sampling Locations

5.3. Dissolved Oxygen (DO)

Figure 5 displays the DO at different sample locations. DO concentration is 9.65mg/L at the outlet and 14.66 mg/L at the inlet with a 14% decrease from inlet to outlet. Differences in DO at the outlet and inlet may be due to changes in the temperature, salinity and pressure at the specific locations. Typically, DO is higher at lower temperatures. However, outlet temperature of 9.57 °C is lower than the inlet temperature 10.24 °C and the corresponding DO level is lower. Overall, DO at all locations meets the criteria for the protection of aquatic life of 9 mg/L O₂ (Table B8).

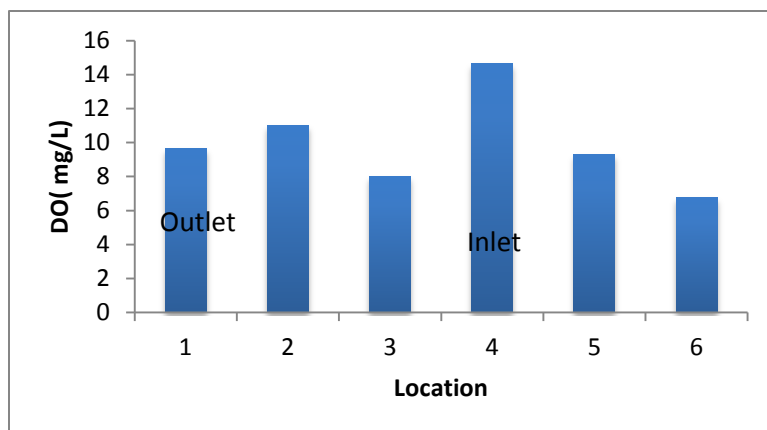


Figure 5: DO Level at Different Sampling Locations

5.4. Metals

Table 1 shows the average concentration for Cd, Cu, Pb, Ni and Zn at the six sampling locations. These values are compared to the guideline concentrations set by the BC MOE, shown in Table 2. Copper concentration is observed at 30.96 µg/L at the inlet and 16.80 µg/L at the outlet respectively exceeds the set guideline concentration of 14.22 µg/L. Copper forms insoluble complexes with hydroxides, sulfides and carbonates. Copper is relatively soluble, when chelated with certain organic compounds, presented as Cu²⁺ (8). In this form, it is bio-available to aquatic life and is toxic. All other metals meet guideline values at both the inlet and outlet.

Table 1: Averaged Metal Concentrations at Different Sample Locations

Sample Location	Cd (µg/L)	Cu (µg/L)	Pb (µg/L)	Ni (µg/L)	Zn (µg/L)
S1 (outlet)	0.2246	16.7975	4.463	1.06325	35.513
S2	0.0976	15.043	4.364666667	0.6125	12.895
S3	2.47E-02	25.32925	3.037	0.689	15.03
S4 (inlet)	0.045825	30.95575	0.732539667	0.65625	30.73
S5	1.22E-02	9.238	1.59825	0.4585	13.17
S6	2.61E-02	7.687	1.363975	0.37875	7.10

Table 2: Metal Concentrations Guideline Obtained from BC MOE [a]

Metal	Maximum Concentration (µg/L)
Cd	0.62
Cu	14.22
Pb	114.02
Ni	25.00
Zn	63.00

Figure 6 contrasts the inlet versus outlet concentration for the metals at all sample locations. Table 3 lists the inlet and outlet concentration along with the percentage increase or decrease. Cd (366%), Pb (93%) and Ni (62%) levels are much higher in outlet than inlet, whereas Cu (-46%) concentration is drastically reduced in the outlet. Zn concentration (8%) in outlet and inlet are nearly equal.

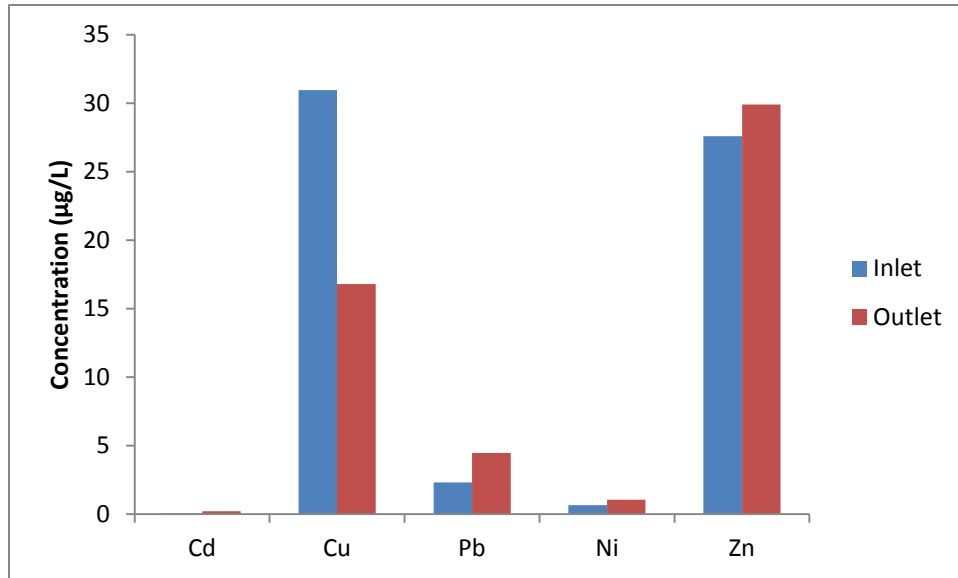


Figure 6: Inlet versus Outlet Concentration for Different Metals

Table 3: Inlet versus Outlet Metal Concentration with Percentage Difference

Metal	Inlet Concentration (µg/L)	Outlet Concentration (µg/L)	% Difference
Cd	0.046	0.21	366
Cu	30.96	16.80	-46
Pb	2.31	4.46	93
Ni	0.66	1.06	62
Zn	27.59	29.90	8

As shown in Table 4, the ORP and DO at locations 5 and 6 measured near the sediment-water interface, 8.5 mV and 4.76 mg/L are much lower than at the air-water interface, 17.7 mV and 9.28 mg/L respectively for location 5. Wetland surface waters typically show a vertical gradient in DO with water depth. The low redox potential at the sediment-water interface is due to the decomposition of decaying organic matter, which is oxygen intensive⁽⁸⁾.

Table 4: Measurement using SONDE probe at Different Pond Locations

	Location	pH	Temperature	%DO	DO	ORP	Salinity	TDS
			°C	%	mg/L	mV		g/L
OUTLET	1	8.67	9.57	90.50	9.65	250	0.21	0.279
	2	8.20	8.53	95.20	11.03	232	0.2	0.271
	3	8.00	10.24	76.10	8.02	31.2	0.2	0.264
INLET	4	7.92	10.22	130.70	14.66	26.5	0.19	0.262
TOUCHING SOIL	5	7.86	9.56	53.10	4.76	8.5	0.2	0.274
WATER SURFACE	5b	7.93	9.90	76.00	9.28	17.7	0	0.002
TOUCHING SOIL	6	8.2	8.71	45	4.11	-16	0.2	0.26
WATER SURFACE	6b	7.99	9.17	53.7	6.77	16	0	0.002

TDS and salinity remain fairly constant across all six locations. TDS are not much affected by wetland processes and cannot be effectively reduced. Chloride ions are relatively unaffected by wetland processes and remain conserved, this explains the constancy in salinity. pH range is narrow and near neutral across the six locations. When oxidized soils are flooded and become anaerobic, the pH tends to converge toward neutrality, regardless of whether the soil was initially acidic or alkaline ⁽⁹⁾.

Metal concentration is expected to be lower in the outlet compared to inlet, however the converse is observed. This deviation could be due to a variety of reasons described as follows. Certain studies found manganese concentration in the sediment increased from the inlet, where organic loading is high and dissolved oxygen low, to the outlet due to changing redox conditions in the sediment ⁽¹³⁾. At the inlet, reduction of Mn oxides takes place from Mn (IV) to Mn (II) which can migrate through reed beds leading to a higher dissolved Mn concentration at the outlet. Metals such as Cu, Cd, Zn, Ni, Pb could become associated with Fe and Mn oxides due to co-precipitation and adsorption. Under changing redox conditions, the metals retained in Fe and Mn

oxides could re-dissolve, leading to higher dissolved concentration of metals in the outlet ⁽¹³⁾. When metals are reduced and are in an insoluble form, they accumulate in the sediment. Weather changes causing flooding or drainage can change the redox conditions of the sediment and re-dissolve metals in the surface waters. In wetlands, after the reed beds or other plants that adsorb metals exceed their operational lifetime, lack of maintenance of the plants could lead to unwanted flushing of the metals into the effluent ⁽¹⁴⁾.

6. CONCLUSION

In this project, the effectiveness of the Triumph detention pond by measuring various water quality parameters is assessed. The organic matter, metals and oxygen concentration of the pond water is compared to BC MOE guidelines. The COD is $0.17 \mu\text{g O}_2/\text{L}$ at the outlet and $0.11 \mu\text{g O}_2/\text{L}$ at the inlet. This indicates lower organic matter than observed in natural wetland waters. Sample locations in which the sulfur reducing bacteria are observed have lower COD values compared to the other locations. The average outlet TSS concentration is 27.71 mg/L , which is 19% less than the inlet TSS. The drop in TSS is due to sedimentation through the pond. The obtained TSS value may be higher than actual due to the collection of small invertebrates on the filter papers. The TSS value at all locations is lower than the MOE guideline. Dissolved oxygen (DO) is 9.65 mg/L at the outlet and 14.66 mg/L in the inlet. The DO level at all locations meets the guideline of 9 mg/L O_2 . For metals, cadmium, lead, zinc and nickel levels are found to be higher in the outlet than inlet. This indicates accumulation and re-dissolution of metals along the stream path due to changing redox conditions, affected by weather and natural processes. Copper concentration is reduced in the outlet, however at both inlet and outlet, copper concentration exceeds guideline values. At this level, copper poses a threat to aquatic life.

Results from this study do not provide a comprehensive understanding of the biogeochemical processes and elemental cycling taking place in the detention pond. Since samples were only collected on one single day, it does not fully represent the pond water's characteristics.

7. RECOMMENDATIONS

A comprehensive assessment of water quality can be made after employing the following recommendations. More samples should be obtained over a period of time in order to assess whether metal concentration, especially copper, is consistently higher than the guideline and if further actions to remediate the metal are needed. Sampling should be done for a year or more, in order to see seasonal differences in water quality. Under different weather conditions, the effects of flooding and drainage of the sediment bed on dissolved oxygen, pH and metal solubility can be observed.

Sampling from the inlet and outlet manholes are recommended to test metal concentration without disturbances present in the detention pond. Additionally, analyzing the concentration of other metals such as manganese and iron is recommended to evaluate the effects of chelation, co-precipitation and adsorption phenomena taking place. Analyzing sediment samples from each location is also recommended because metals in their insoluble forms as oxides, sulfide and phosphates primarily accumulate in the sediment bed. This will provide a better understanding of the specific ionic forms of metals under different weather and hydric soil conditions.

Pond characteristics such as influent and effluent flow rates, capacity and depth, retention time and flow through the pond must be determined in order to determine the pond's efficiency. This information is also crucial in determining the configurations in which remediation vegetation should be planted. Identifying the pond vegetation and analyzing metal concentration in different plant parts such as the roots, shoots and leaves would be beneficial in developing a bioremediation strategy. Further, research into local and geographical vegetation should be undertaken to see which plants are endemic to the area and have higher chance of flourishing with minimal upkeep. Analysis of the components in biofilm would also aid in the understanding of the adsorptive and interfacial processes already taking place.

8. REFERENCES

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**Appendix A - POND SITE PICTURES
AND CONSTRUCTION DRAFTS**

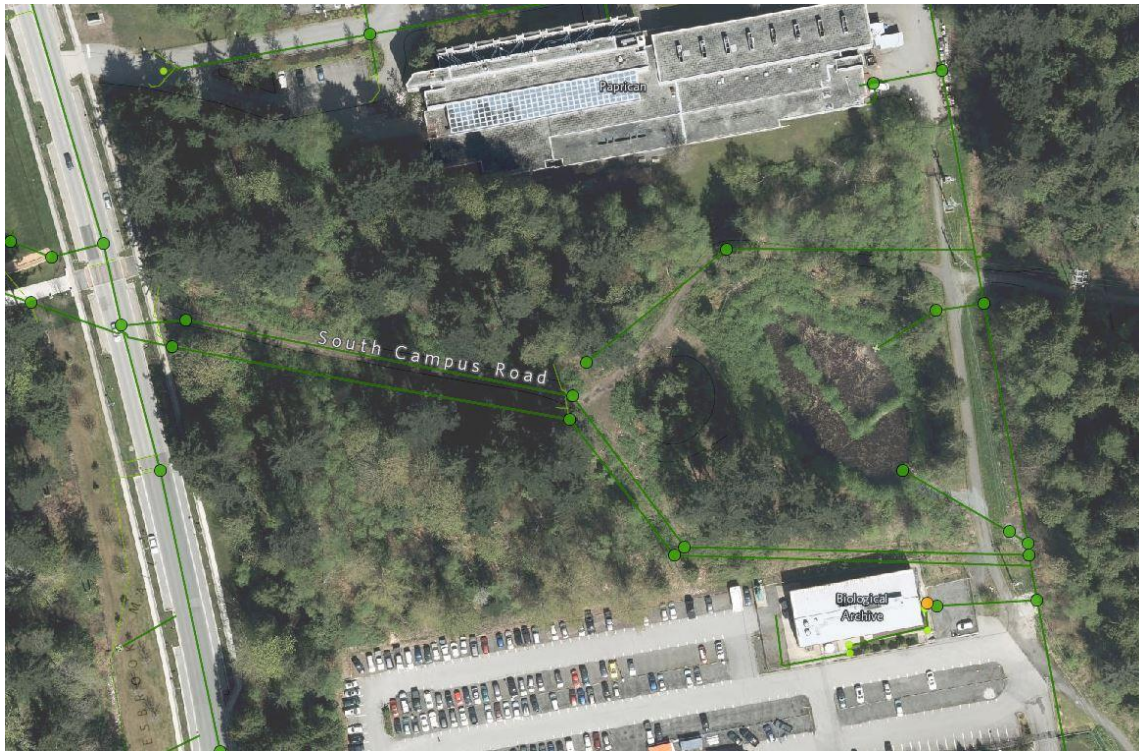


Figure A1: Close-up Google Earth Image of Detention Pond Location

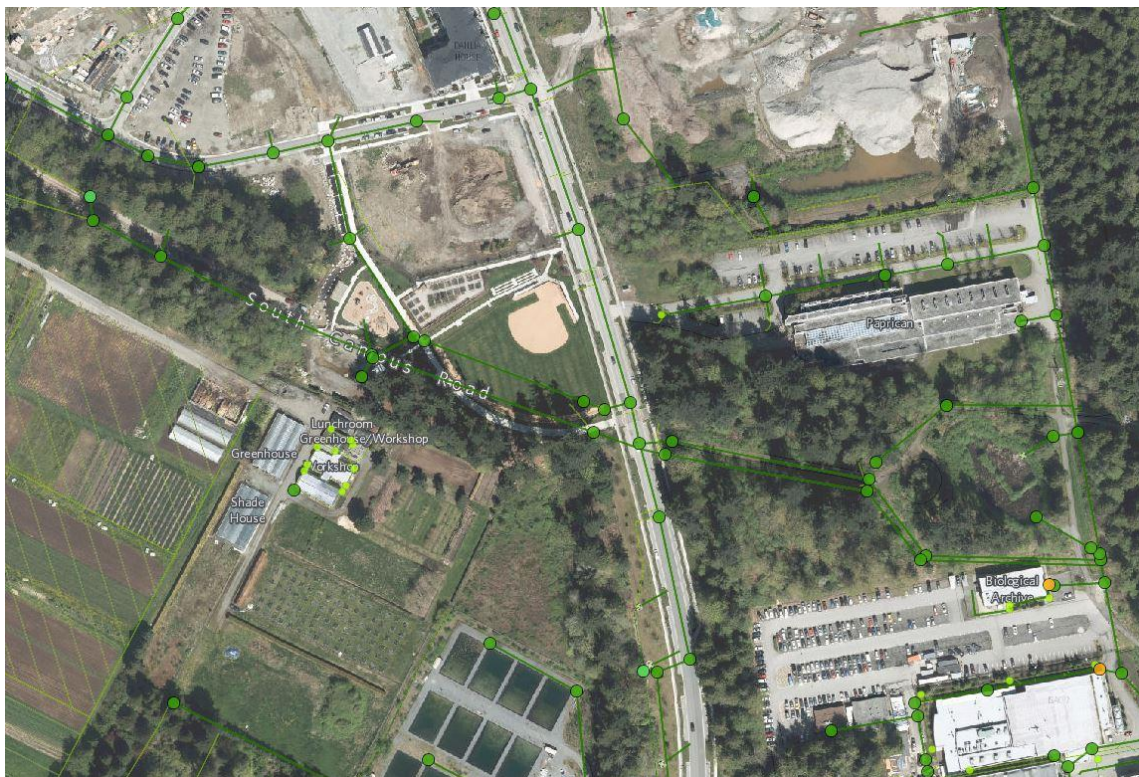


Figure A2: Overview Google Earth Image of Detention Pond Location

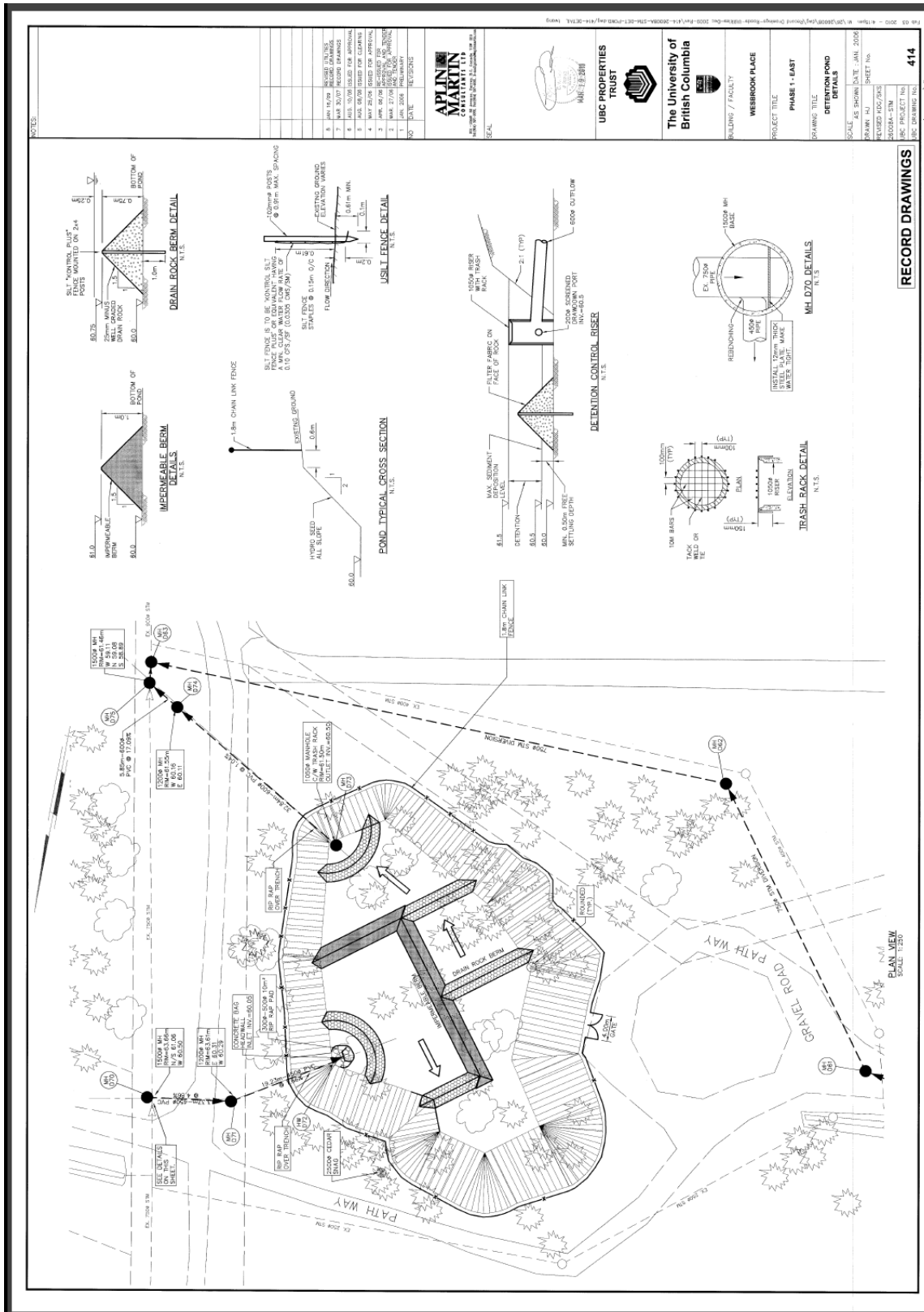


Figure A3: Draft of Detention Pond

Appendix B - BC WATER QUALITY GUIDELINES TABLES AND FIGURES

Table B1: Summary of Water Quality Criteria for Copper⁽⁸⁾

Water Use	30-day Average µg/L Total Copper	Maximum µg/L Total Copper
Raw Drinking Water Supply	—	500 µg/L
Fresh Water Aquatic Life (when average water hardness as CaCO ₃ is less than or equal to 50 mg/L)	less than or equal to 2 µg/L	(0.094(hardness)+2) µg/L (hardness as mg/L CaCO ₃)
Fresh Water Aquatic Life (when average water hardness as CaCO ₃ is greater than 50 mg/L)	less than or equal to 0.04 (mean hardness) µg/L	(0.094(hardness)+2) µg/L (hardness as mg/L CaCO ₃)
Wildlife	None proposed	300 µg/L
Livestock Water Supply	None proposed	300 µg/L
Irrigation Water Supply	None proposed	200 µg/L
Recreation and Aesthetics	None proposed	1000 µg/L
Marine and Estuarine Aquatic Life	less than or equal to 2 µg/L	3 µg/L

- 1. The average is calculated from at least 5 weekly samples taken in a period of 30 days.***
- 2. When detailed knowledge on the bioavailable forms of copper is available, the form of copper in the criteria for aquatic life can be modified, as justified by the data***
- 3. If natural background levels exceed the criteria for aquatic life, the increase in total copper above natural levels to be allowed, if any, should be based on site-specific data.***

Table B2: Summary of Water Quality Criteria for Lead⁽⁸⁾

Water Use	30-Day Average (µg/L Total Lead)	Maximum (µg/L Total Lead)
Drinking Water Supply	None proposed	50 µg/L total lead
Fresh Water Aquatic Life (water hardness as Ca CO ₃ less than or equal to 8 mg/L)	None proposed	3 µg/L total lead
Fresh Water Aquatic Life (water hardness as Ca CO ₃ greater than 8 mg/L)	Less than or equal to 3.31 + $e^{(1.273 \ln(\text{mean hardness}) - 4.704)}$	$e^{(1.273 \ln(\text{hardness}) - 1.460)}$
Wildlife Water Supply	None proposed	100 µg/L total lead
Livestock Water Supply	None proposed	100 µg/L total lead
Marine and Estuarine Aquatic Life	Less than or equal to 2 µg/L total lead —— (80% of the values less than or equal to 2 µg/L total lead)	140 µg/L total lead
Irrigation Water Supply (neutral and alkaline fine-textured soils)	None proposed	400 µg/L total lead
Irrigation Water Supply (all other soils)	None proposed	200 µg/L total lead
Industrial Water Supply (food processing industry)	None proposed	50 µg/L total lead
Recreation and Aesthetics	None proposed	50 µg/L total lead

The average is calculated from at least 5 weekly samples taken in a period of 30 days.

If natural levels exceed the criteria for aquatic life, the increase in total lead above natural levels to be allowed, if any, should be based on site-specific data.

Table B3: Recommended Guidelines for Zinc⁽⁸⁾

Water Use	Guideline (µg/L Total Zinc)
Drinking Water	5000
Marine Life	10
Freshwater Aquatic Life - maximum concentration _____ water hardness less than or equal to 90 water hardness equal to 100 water hardness equal to 200 water hardness equal to 300 water hardness equal to 400	Use the Equation $33 + 0.75 \times (\text{hardness} - 90)$ _____ 33 40 115 190 265
Freshwater Aquatic Life - 30 day average concentration _____ water hardness less than or equal to 90 water hardness equal to 100 water hardness equal to 200 water hardness equal to 300 water hardness equal to 400	Use the Equation $7.5 + 0.75 \times (\text{hardness} - 90)$ _____ 7.5 15 90 165 240

- 1. When the ambient zinc concentration in the environment exceeds the guideline, then further degradation of the ambient or existing water quality should be avoided*
- 2. These are instantaneous maximums*
- 3. Averages are of five weekly measurements taken over a 30-day period.*
- 4. Water hardness is measured as mg/L of CaCO₃*

Table B4: Recommended Guidelines for Cadmium at Different Hardness ⁽⁸⁾

Hardness (mg·L ⁻¹ CaCO ₃)	Guideline value (µg Cd·L ⁻¹)	
	Short-term	Long-term
Lower limit*	0.11	0.04
Soft (60)	1.2	0.10
Medium (120)	2.5	0.18
Hard (180)	3.8	0.26
Upper limit**	7.7	0.37

Lower and upper limits for hardness reflect the minimum and maximum hardness values, respectively, that were used in the derivation of hardness slopes, beyond which values should not be extrapolated.

*A lower limit of 0.11 µg·L⁻¹ is the short-term benchmark that applies to all waters of hardness below 5.3 mg CaCO₃·L⁻¹. A lower limit of 0.04 µg·L⁻¹ is the long-term guideline value that applies to all waters of hardness below 17 mg CaCO₃·L⁻¹.

**An upper limit of 7.7 µg·L⁻¹ is the short-term benchmark that applies to all waters of hardness above 360 mg CaCO₃·L⁻¹. An upper limit of 0.37 µg·L⁻¹ is the long-term guideline that applies to all waters of hardness above 280 mg CaCO₃·L⁻¹.

Table B5: Canadian Water Quality Guidelines for Cadmium ⁽⁸⁾

Table 1. Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life for cadmium.

	Long-term Exposure (µg·L ⁻¹)	Short-term Exposure (µg·L ⁻¹)
Freshwater	0.09 ^a	1.0 ^b
Marine	0.12 ^c	NRG

NRG = no recommended guideline

^a The long-term CWQG of 0.09 µg·L⁻¹ is for waters of 50 mg CaCO₃·L⁻¹ hardness. At other hardness values, the CWQG can be calculated with the equation $CWQG = 10^{(0.83(\log[\text{hardness}]) - 2.46)}$, valid for hardness between 17 and 280 mg CaCO₃·L⁻¹.

^b The short-term benchmark concentration of 1.0 µg·L⁻¹ is for waters of 50 mg CaCO₃·L⁻¹ hardness. At other hardness values, the benchmark can be calculated with the equation $Benchmark = 10^{(1.016(\log[\text{hardness}]) - 1.71)}$, valid for hardness between 5.3 and 360 mg CaCO₃·L⁻¹.

^c This value was not assessed as part of the present update; value is from CCME (1996).

Table B6: Summary of water quality guidelines for turbidity, suspended and benthic sediments⁽⁸⁾

Water Use	Turbidity	Non-filterable residue (total suspended solids)	Streambed Substrate Composition
Aquatic life (fresh, marine, estuarine)	Change from background of 8 NTU at any one time for a duration of 24 h in all waters during clear flows or in clear waters	Change from background of 25 mg/L at any one time for a duration of 24 h in all waters during clear flows or in clear waters	% fines not to exceed: • 10% <2 mm • 19% <3 mm • 28% <6.35 mm at salmonid spawning sites
	Change from background of 2 NTU at any one time for a duration of 30 d in all waters during clear flows or in clear waters	Change from background of 5 mg/L at any one time for a duration of 30 d in all waters during clear flows or in clear waters	Geometric mean diameter not less than 12 mm (minimum 30-d intragravel DO of 6 mg/L)
	Change from background of 5 NTU at any time when background is 8 - 50 NTU during high flows or in turbid waters	Change from background of 10 mg/L at any time when background is 25 - 100 mg/L during high flows or in turbid waters	Fredle number not less than 5 mm (minimum 30-d intragravel DO of 8 mg/L)
	Change from background of 10% when background is >50 NTU at any time during high flows or in turbid waters	Change from background of 10% when background is >100 mg/L at any time during high flows or in turbid waters	

Table B7: Summary of EIFAC (European Inland Fisheries Advisory Commission) pH Ranges for the Protection of Aquatic Life⁽⁸⁾

Table 8

Summary of EIFAC pH Ranges for the Protection of Aquatic Life
(from Alabaster and Lloyd, 1982)

3-3.5	Unlikely that any fish can survive for more than a few hours in this range, although some plants and invertebrates can be found at pH values lower than this.
3.5-4	This range is lethal to salmonids. There is evidence that roach, tench, perch and pike can survive in this range, presumably after a period of acclimation to slightly higher, non-lethal levels, but the lower end of this range may still be lethal for roach.
4-4.5	Likely to be harmful to salmonids, tench, bream, roach, goldfish, and common carp which have not previously been acclimated to low pH values, although the resistance to this pH range increases with the size and age of the fish. Fish can become acclimated to these levels, but of perch, bream, roach, and pike, only the last named may be able to breed.
4.5-5	Likely to be harmful to the eggs and fry of salmonids, and to adults particularly in soft water containing low concentrations of calcium, sodium, and chloride. Can be harmful to common carp.
5-6	Unlikely to be harmful to any species unless either the concentration of free carbon dioxide is greater than 20 mg/L, or the water contains iron salts which are freshly precipitated as ferric hydroxide, the precise toxicity of which is not known. The lower end of this range may be harmful to non-acclimated salmonids if the calcium, sodium, and chloride concentrations or the temperature of the water are low, and may be detrimental to roach production.
6-6.5	Unlikely to be harmful to fish unless free carbon dioxide is present in excess of 100 mg/L.
6.5-9	Harmless to fish, although the toxicity of other poisons may be affected by changes within this range.
9-9.5	Likely to be harmful to salmonids and perch if present for a considerable length of time.
9.5-10	Lethal to salmonids over a prolonged period of time, but can be withstood for short periods. May be harmful to developmental stages of some species.
10-10.5	Can be withstood by roach and salmonids for short periods but lethal over a prolonged period.
10.5-11	Rapidly lethal to salmonids. Prolonged exposure to the upper limit of this range is lethal to carp, tench, goldfish and pike.
11-11.5	Rapidly lethal to all species of fish.

Table B8: Recommended Criteria for the Protection of Aquatic Life⁽⁸⁾

Life Stages	All Life Stages Other Than Buried Embryo / Alevin	Buried Embryo / Alevin Life Stages	Buried Embryo / Alevin Life Stages
Dissolved Oxygen - concentration	Water Column mg/L O ₂	Water Column mg/L O ₂	Interstitial Water mg/L O ₂
Instantaneous Minimum	5	9	6
30-day Mean	8	11	8

1. For the buried embryo / alevin life stages these are in-stream concentrations from spawning to the point of yolk sac absorption or 30 days post-hatch for fish; the water column concentrations recommended to achieve interstitial dissolved oxygen values when the latter are unavailable. Interstitial oxygen measurements would supersede water column measurements in comparing to criteria.
2. The instantaneous minimum level is to be maintained at all times.
3. The mean is based on at least five approximately evenly spaced samples. If a diurnal cycle exists in the water body, measurements should be taken when oxygen levels are lowest (usually early morning).

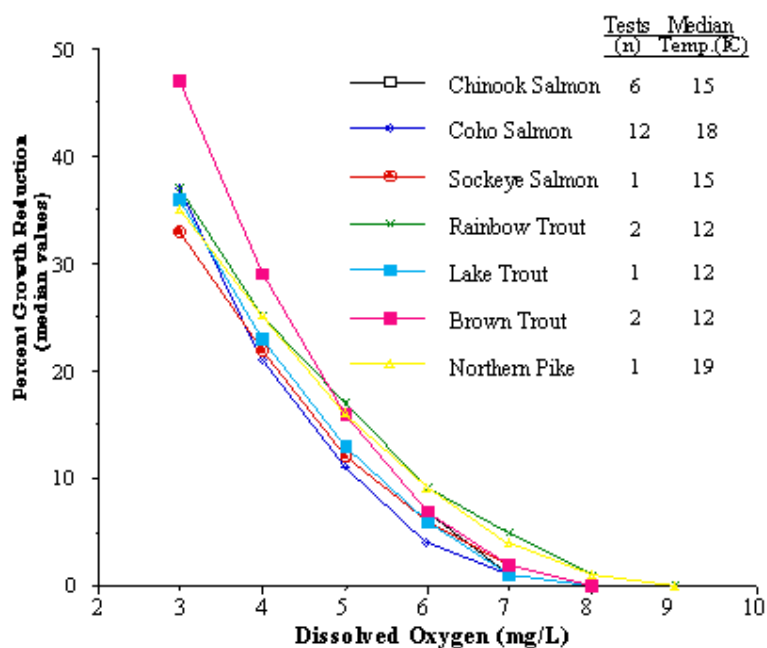


Figure B1: Percent reduction in growth of Salmonid/ Salmonid-like fishes at various oxygen levels

Appendix C - RAW DATA, CALCULATIONS & RESULTS

Table C1: Measurement using SONDE probe at Different Pond Locations

	Location	pH	Temperature	%DO	DO	ORP	Salinity	TDS
			°C	%	mg/L	mV		g/L
OUTLET	1	8.67	9.57	90.50	9.65	250	0.21	0.279
	2	8.20	8.53	95.20	11.03	232	0.2	0.271
	3	8.00	10.24	76.10	8.02	31.2	0.2	0.264
INLET	4	7.92	10.22	130.70	14.66	26.5	0.19	0.262
TOUCHING SOIL	5	7.86	9.56	53.10	4.76	8.5	0.2	0.274
WATER SURFACE	5b	7.93	9.90	76.00	9.28	17.7	0	0.002
TOUCHING SOIL	6	8.2	8.71	45	4.11	-16	0.2	0.26
WATER SURFACE	6b	7.99	9.17	53.7	6.77	16	0	0.002

Table C2: Average Total Suspended Solid (TSS) at Different Pond Locations

	Location	TSS	ΔTSS
		mg/L	mg/L
OUTLET	1	27.71	2.48
	2	24.98	2.50
	3	56.75	2.50
INLET	4	34.08	2.55
	5	24.71	2.47
	6	9.21	2.45

Table C3: Average Chemical Oxygen Demand (COD) with TSS

	Location	μg O₂/L	Δμg O₂/L
		μg/L	μg/L
OUTLET	1	0.17	0.01
	2	0.04	0.01
	3	0.13	0.01
INLET	4	0.11	0.01
	5	0.02	0.01
	6	0.03	0.01

Table C4: Average Chemical Oxygen Demand (COD) without TSS

	Location	$\mu\text{g O}_2/\text{L}$	$\Delta\mu\text{g O}_2/\text{L}$
		<i>$\mu\text{g/L}$</i>	<i>$\mu\text{g/L}$</i>
OUTLET	1	0.00	0.01
	2	0.03	0.01
	3	0.07	0.01
INLET	4	0.06	0.01
	5	0.03	0.01
	6	0.03	0.01

Table C5: Metal Concentration

Sample	Metal Concentration (mg/L)				
	Cd	Cu	Pb	Ni	Zn
Blank	-0.00025	0.001026	-0.00479	0.000282	-0.01876
Blank	-0.00019	0.000402	0.000837	0.000148	0.019276
S1-A	0.000268	0.025053	0.007868	0.001275	0.032431
S1-B	0.000186	0.013536	0.003541	0.001296	0.040716
S1-A2	0.000265	0.012348	0.004814	0.000684	0.013077
S1-B2	0.000136	0.016253	0.001629	0.000998	0.033392
S2-A	0.000301	0.017644	0.005258	0.000636	0.011938
S2-B	-4.6E-05	0.012648	0.003136	0.000705	0.031575
S2-A2	0.000142	0.016073	0.0047	0.000448	0.009074
S2-B2	-6.6E-06	0.013807	0.001055	0.000661	0.017673
S3-A	1.36E-05	0.036655	0.003933	0.000737	0.016913
S3-B	3.58E-05	0.023441	0.002535	0.000832	0.025405
S3-A2	-6.1E-05	0.023026	0.002643	0.000661	0.011527
S3-B2	-9.7E-05	0.018195	0.001338	0.000526	0.016637
S4-A	0.000108	0.037021	0.002388	0.000729	0.023247
S4-B	0.000109	0.027589	0.003231	0.000758	0.037733
S4-A2	-2.4E-05	0.03391	0.001421	0.000585	0.018161
S4-B2	-9.7E-06	0.025303	0.002192	0.000553	0.031202
S5-A	-2.8E-05	0.011585	0.001517	0.000464	0.012498
S5-B	5.79E-05	0.007627	0.003077	0.000586	0.033059
S5-A2	1.44E-05	0.010777	0.000801	0.000331	0.007281
S5-B2	4.35E-06	0.006963	0.000998	0.000453	0.019738
S6-A	-7.5E-06	0.02103	0.003425	0.000374	0.00611
S6-B	5.98E-05	0.007313	0.001282	0.000427	0.023774
S6-A2	2.01E-05	0.008958	0.000691	0.00021	0.002287
S6-B2	3.21E-05	0.00679	5.79E-05	0.000504	0.012907

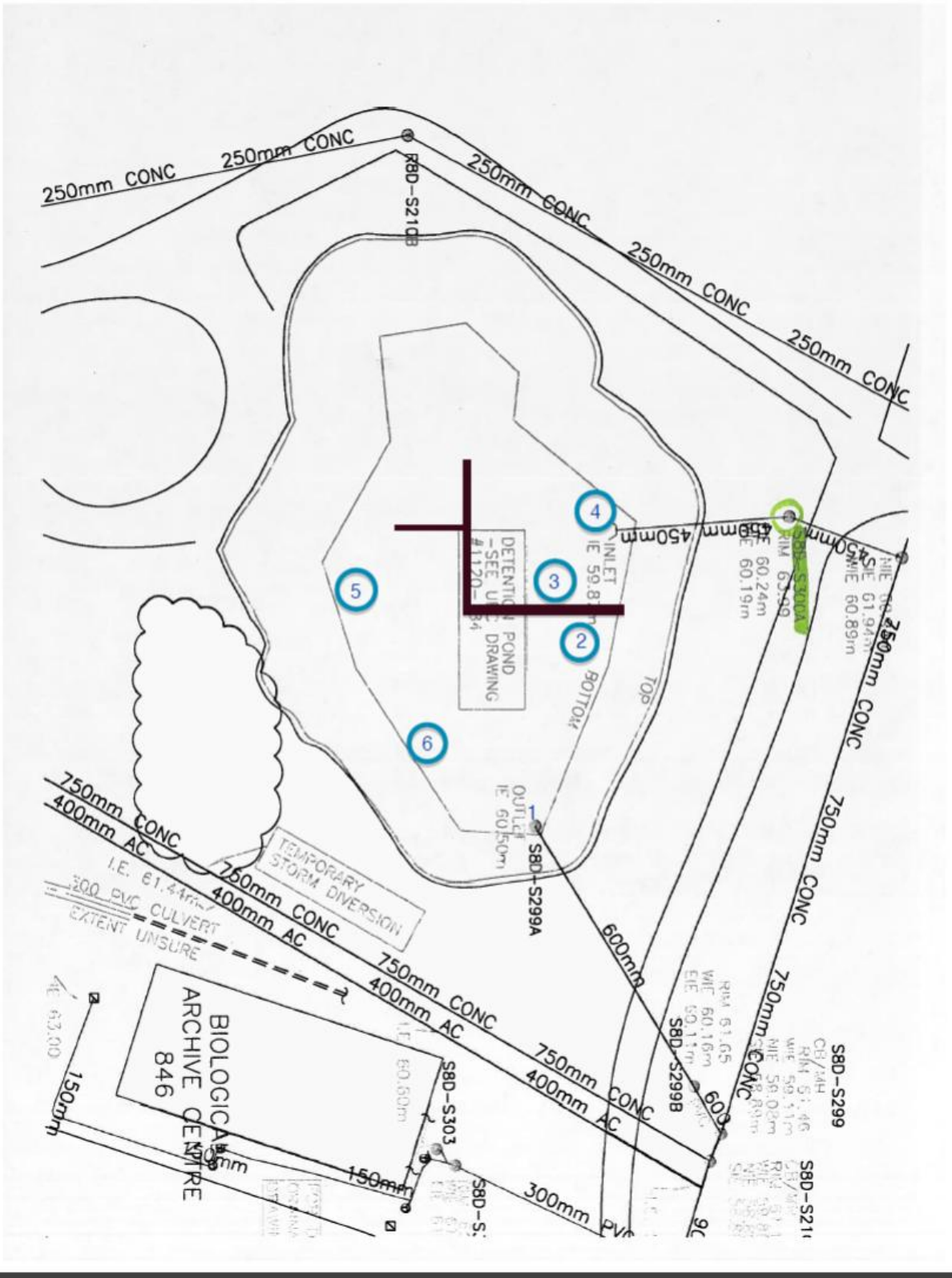


Figure C1: Site Sampling Map

Table C6: Averaged Metal Concentrations at Different Sample Locations

Sample Location	Cd (µg/L)	Cu (µg/L)	Pb (µg/L)	Ni (µg/L)	Zn (µg/L)
S1	0.2246	16.7975	4.463	1.06325	35.513
S2	0.0976	15.043	4.364666667	0.6125	12.895
S3	2.47E-02	25.32925	3.037	0.689	15.03
S4	0.045825	30.95575	0.732539667	0.65625	30.73
S5	1.22E-02	9.238	1.59825	0.4585	13.17
S6	2.61E-02	7.687	1.363975	0.37875	7.10

Table C7: Metal Concentrations Guideline Obtained from BC-MOE ^[a]

Metal	Maximum Concentration (µg/L)
Cd	0.62
Cu	14.22
Pb	114.02
Ni	25.00
Zn	63.00

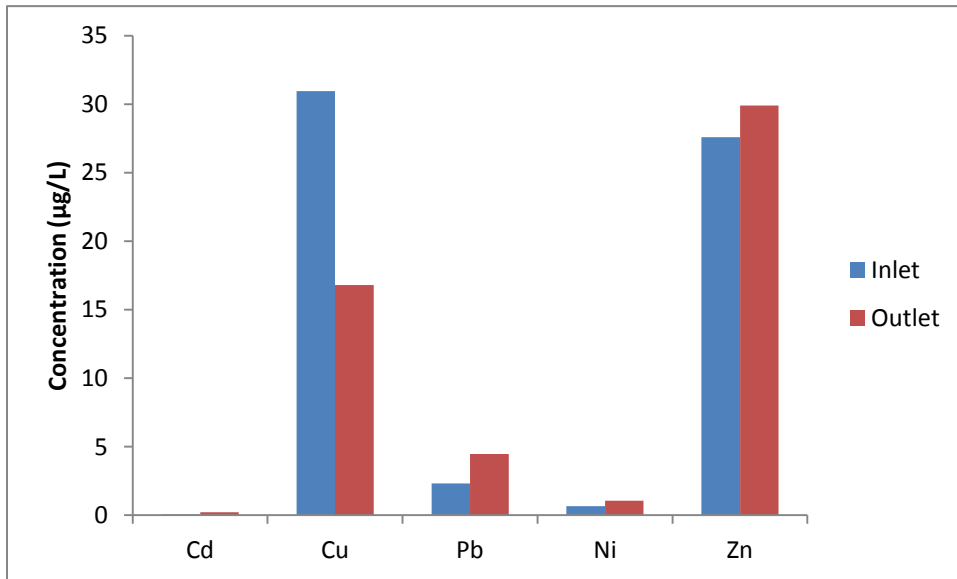


Figure C2: Inlet versus Outlet Concentration for Different Metals

Table C8: Inlet versus Outlet Metal Concentration with Percentage Difference

Metal	Inlet Concentration (µg/L)	Outlet Concentration (µg/L)	% Difference
Cd	0.045825	0.21375	366.4484
Cu	30.95575	16.7975	-45.7371
Pb	2.308	4.463	93.37088
Ni	0.65625	1.06325	62.01905
Zn	27.58575	29.904	8.403795

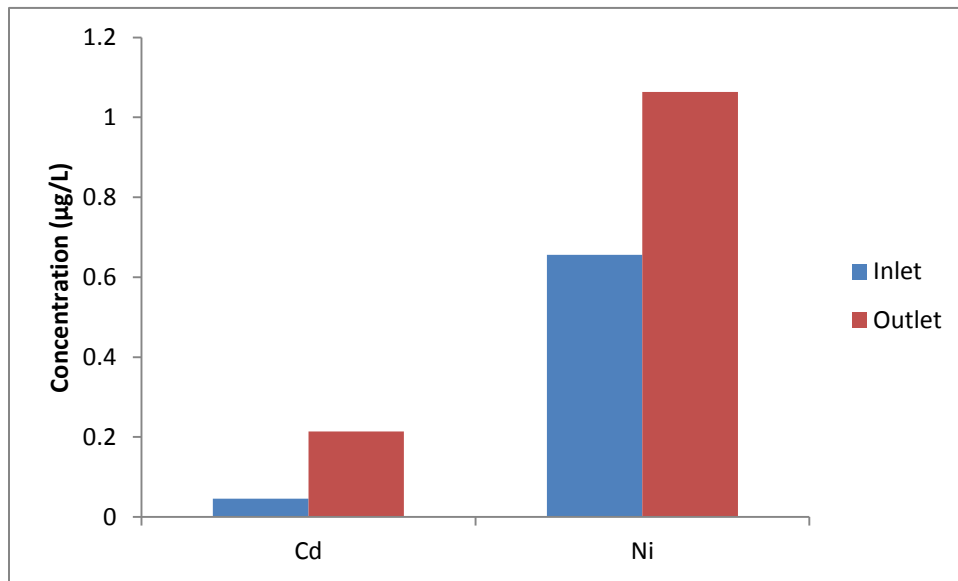


Figure C3: Inlet versus Outlet Concentration for Cadmium and Nickel

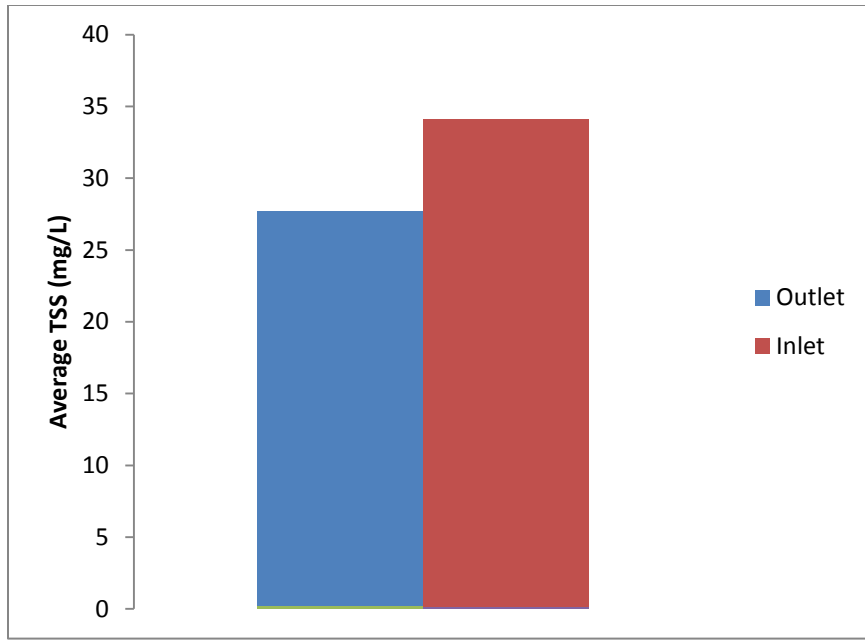


Figure C4: Inlet versus Outlet Concentration for Average TSS (mg/L)

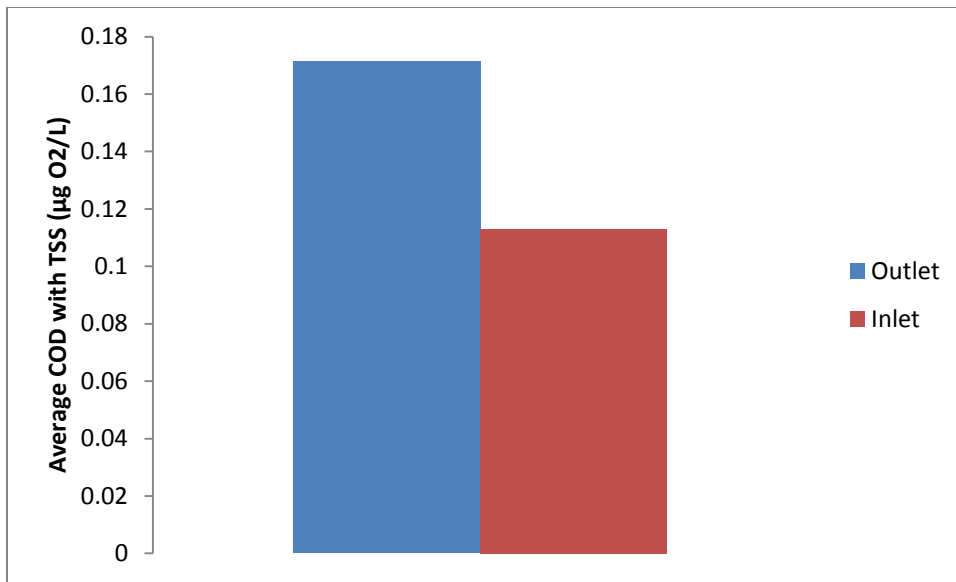


Figure C5: Inlet versus Outlet Concentration for Average COD with TSS (µg O2/L)

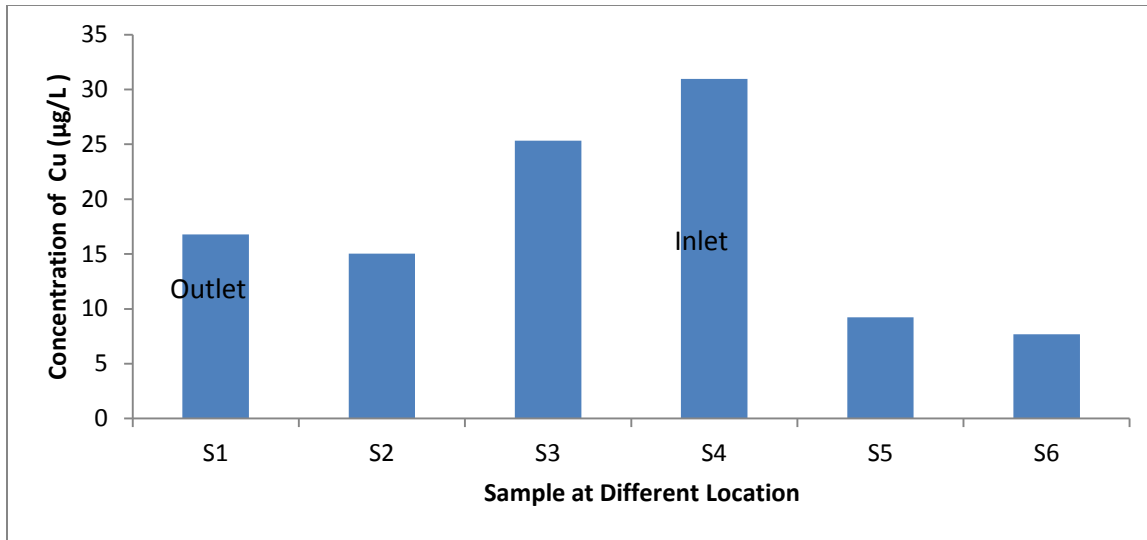


Figure C6: Copper Concentration at Different Locations

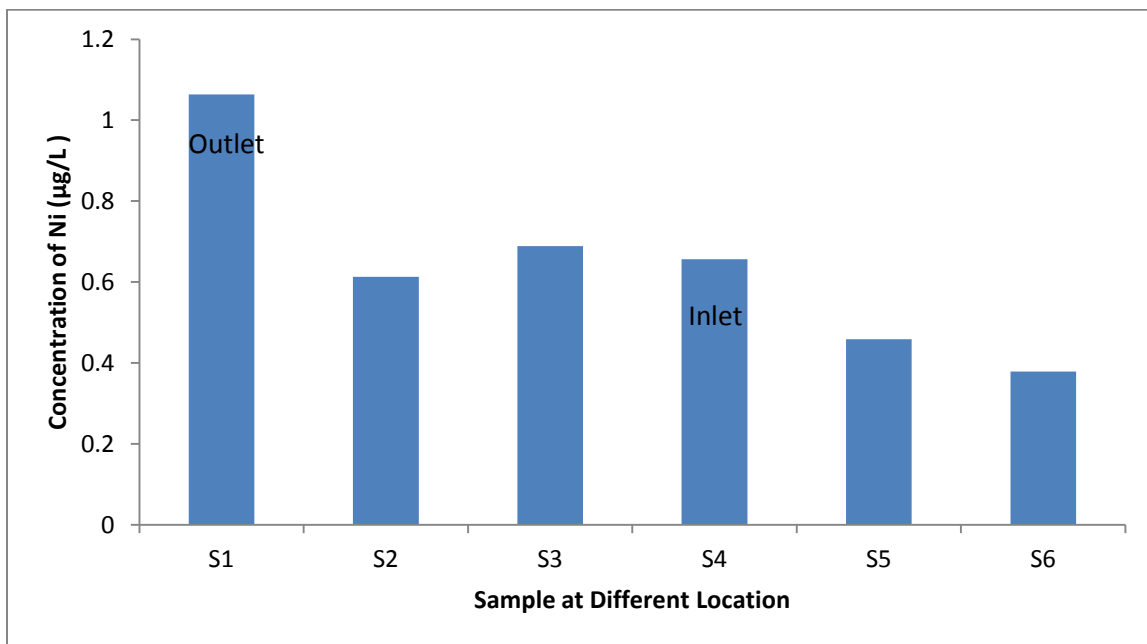


Figure C7: Nickel Concentration at Different Locations

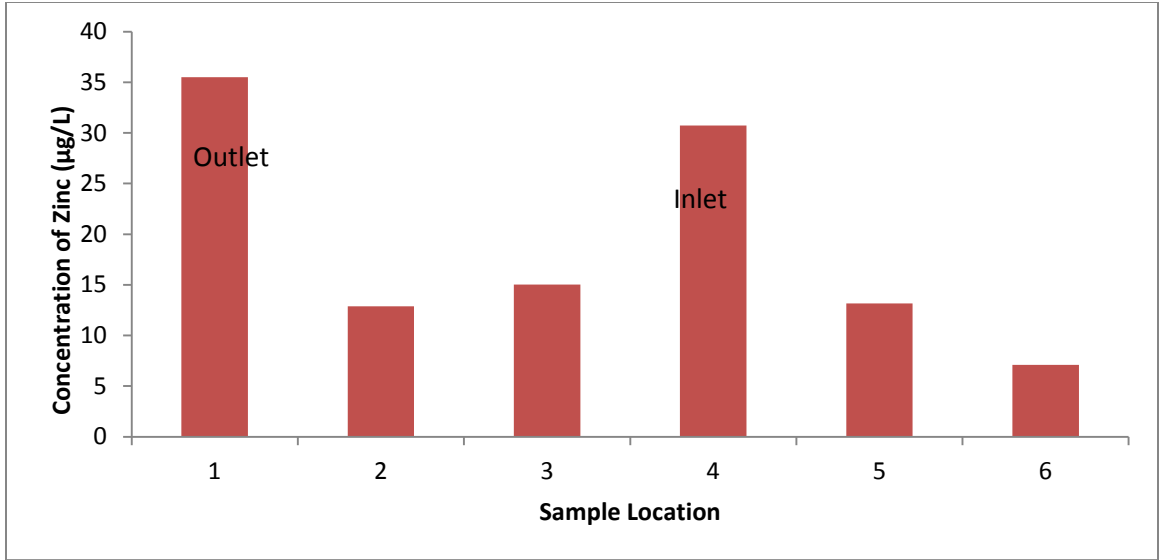


Figure C8: Zinc Concentration at Different Locations

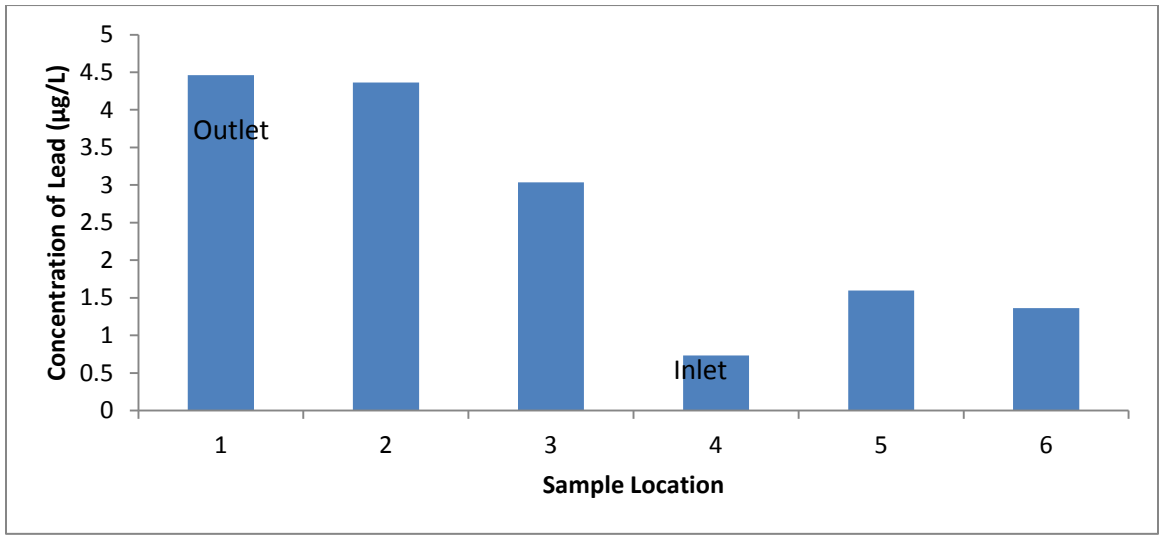


Figure C9: Lead Concentration at Different Locations

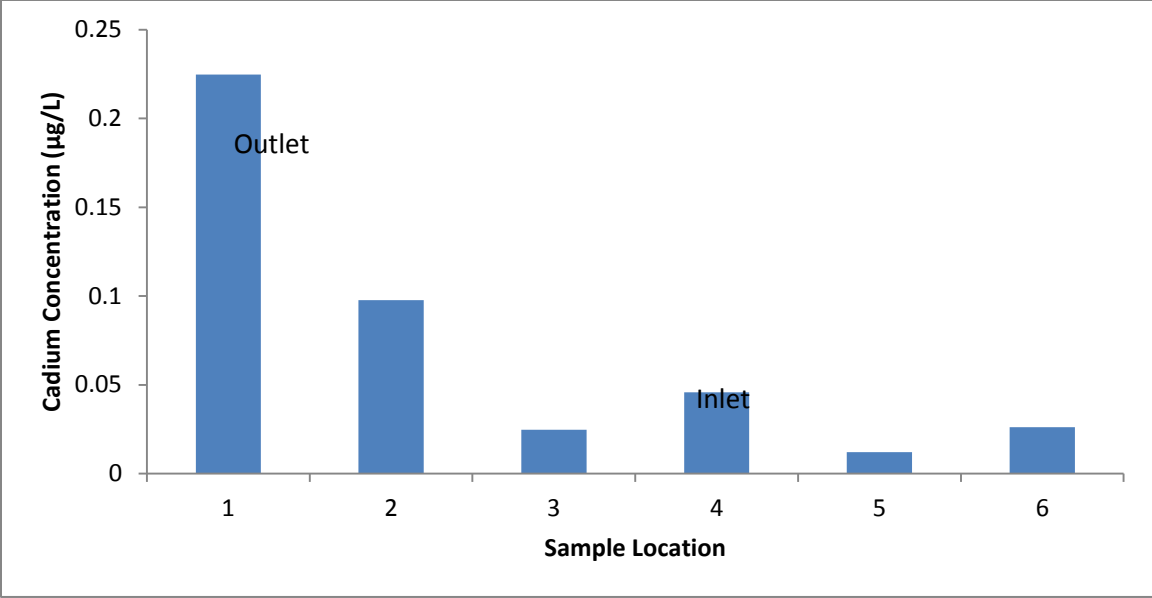


Figure C10: Cadmium Concentration at Different Locations