

Sediment characteristics of Beaver Lake and implications for remediation; A Pilot Project.

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Abstract

We determined concentrations of copper, zinc, cadmium and percent organic matter in sediments of an urban wetland located in Stanley Park, Vancouver, B.C. Sediment profiles indicated that for all metals surficial concentrations were greatest, decreasing with increasing sediment depth. Spatial trends indicated no direct point source of metal to the lake; rather, inputs are likely of atmospheric origin. All metal concentrations were elevated, however this was notably so for copper which exceeded the Canadian Probable Effects Level. Sampled sediments were comprised primarily of silt and were ca. 60% organic matter suggesting that where sampled, within lake organic matter may be contributing to wetland infilling.

Recommendations with respect to lake restoration are:

1. Confirm the presence of high levels of metals in Beaver Lake sediments prior to dredging.
2. Remove plant growth from the interior of the wetland to reduced autochthonous organic matter inputs.
3. Replace the gravel trail with a board walk, (at least partial), restricting the amounts of gravel entering into the wetland.

Keywords: sediments, pollution, urban lake, copper, cadmium, zinc

1.0 Introduction

The urbanization of watersheds can impose multiple stressors on stream, wetland, and lake ecosystems. Sediment contamination, alterations to the natural hydrologic regime, and nutrient loading are examples of these stressors which often occur simultaneously. As a consequence, restoration is challenged by the multi-stressor reality of most urban watersheds.

Beaver Lake, located in the middle of Stanley Park, Vancouver, is typical of such an urban lake ecosystem. Created in the late 1920's, this lake is slowly filling and it is anticipated that if some type of remediation action does not occur that within 15 yrs it will be converted into a meadow.

Because of its importance as a “show case” wetland in the centre of one of Canada's largest cities, there has been efforts to restore the lake back to some type of open water system. This will involve dredging of the accumulated sediments. Hence the concern and question; given that such lakes can serve as “traps” for urban pollution, are the sediments safe to dredge and if so, can they be disposed of within the park in a safe way? Sources of pollutants to Beaver Lake include vehicle emissions which account for most of the mobile sources heavy metal emissions and constitute a large portion of the total emissions in the Fraser Valley (Zimmerman et al. 1999)

The objectives of our study were therefore twofold; 1) to determine the primary source of infilling to the lake through the analysis of sediment percent organic matter and 2) to determine zinc, copper, and cadmium concentrations in sediments, both surficial and at depth, such that an assessment of the feasibility to remediate the lake through dredging could be made. It is hoped that this study can provide a case study which demonstrates the complexity of attempting to restore and remediate such urban systems and highlights the challenges that we face in such efforts.

2.0 Materials and methods

2.1. Study site. Beaver Lake, is a 3.8 ha freshwater wetland, located within Stanley Park, Vancouver B.C. Two main streams flow into the wetland; Prospect Creek (West) and

Railway Creek (East) (Figure 1). A comprehensive review of its geology/hydrology/ecology can be found in Zimmerman et al. 1999 and will not be repeated here.

2.2. Sediment collection. Samples were collected with a stainless steel hand corer (4 cm width by 10 cm depth) (Rickly Hydrological Co Inc). Two transects with 5 sites each were defined according to lake depth and root density. Transect one (T1) ran north south and Transect two east-west (Figure 1). The location of the transects was determined by the ability to core the wetland sediments. For example, the east side of the wetland, root density was such that coring was impossible. A third transect (T3) running north south was sampled in 5 locations for upper surficial sediments which were removed by suction. Sediments were sampled in triplicate, placed in sterile plastic bags and then frozen until analysis.

2.3. Sediment analysis. Surficial sediments and cores were thawed at room temperature. Cores were sectioned into 2 cm slices and homogenized. Ten grams of sample (wet weight) were dried to a constant weight (60 C for 48 hrs) and homogenized by mortar and pestle prior to organic matter and metal analysis. Initial sieving of wet sediments indicated that sediments were silt, i.e., no gravel, either coarse or fine, or sand was present.

2.3.1. Organic matter analysis. A subsample of dried sediment was weighed and ignited at 550 C for 3 hrs, cooled then again weighed, to determine percent organic matter content.

2.3.2. Metal analysis. Dried sediment (0.5 g) was placed into a 50 mL Falcon tube to which 10 mLs of aqua regia (prepared daily as 375 mL of HCL and 125 mL of HNO₃) was added. Sediment was left overnight on a slow shaker to allow for the extraction of the metal by the aqua regia. A 1 mL aliquot was then removed, diluted ten fold with ultra-pure water and analyzed for copper, zinc and cadmium via Atomic Absorption (Perkin Elmer). Blanks and reference sediments (MESS (3)) were included to ensure QA/QC.

2.3.3. Statistical analysis. All data was tested for normality (Shapiro-Wilk) prior to applying a one-way ANOVA to determine if metal concentrations in surficial sediments was spatially

dependent. As data was normal, a one-way ANOVA with site as the one factor was applied to determine differences in percent organic matter, sediment cadmium, copper and zinc among sites. For all variables, concentrations were site dependent (ANOVA $P < 0.05$), most notably for site 5 for organic matter and site 4 for trace metals.

3.0 Results

3.1 Organic matter in sediments

3.1.1. Variation with sediment depth. Generally, percent organic matter decreased with core depth with surficial values are ca. 60% to ca. 40% at lower depths. Microbial mineralization of the older deeper sediments would explain this trend. Of the 6 cores, site 5 was significantly lower with values ranging between 30% to as low as 15% organic matter (Figure 2a and b).

3.1.2. Spatial variation. There was significant spatial variation in surficial sediment percent organic matter, notably for site 5 (ANOVA; $P < 0.05$; Figure 3).

3.2. Trace metals in sediments

3.2.1. Variation with sediment depth. All trace metals for both transects decreased with depth (Figures 4 and 5). With the exception of site 4 which was lower in concentration for all three metals, concentrations were similar among sites.

3.2.2. Spatial variation. With the exception of site 4 which was significantly lower (ANOVA; $P < 0.05$), trace metal concentrations in surficial sediments were similar among locations (Figure 6).

4.0 Discussion

Our objectives were to first determine the trace metal content of sediments from Beaver Lake to assess whether sediments dredged from the wetland could be safely disposed of

within Stanley Park. Second, was through an analyses of grain size and percent organic matter, determine the primary source of infilling to the wetland.

Metal concentrations were in general, spatially similar suggesting a common source. The exception was site 4 (TS4) which was significantly lower for all three metals. Why metal levels at this site should be lower is uncertain, but could be partially explained by differential depositional rates within the wetland.

For all metals, sediment concentrations, both surficial and at depth were greater than the Canadian Interim Freshwater Sediment Quality Guidelines (Appendix 1). For copper these values also exceeded the probable effects level (PEL). This could have important implications for the proper disposal of these sediments should the decision be made to dredge the wetland to aid restoration. High sediment copper also has implications for the hopes of restoring the wetland such that it can support salmonids. High metal concentrations are likely as result of at least 80 years of anthropogenic inputs from typical urban activities such as vehicle exhaust, tire wear and waste incineration (e.g., as noted in Zimmerman et al. 1999).

As a first recommendation, it would be prudent to ensure that values obtained in this pilot study are indeed as high as reported. If such high metal concentrations do occur, then it is possible that alternate arrangements made need be made for the disposal of sediments should dredging occur.

As with metals, organic matter was spatially dependent being the lowest at site 5 (TS5). It is uncertain why this one location would be lower in organic matter, only that of the sampling locations, it is the region of most open water, hence within lake organic matter inputs could be less at this location.

Organic matter and grain size analysis indicated that where sampled, sediments are mostly organic and silty in composition. At these sampling locations, it is likely that infilling is a consequence of autochthonous organic material. However, sampling locations closer to

the Beaver Lake trail were impossible to core given the presence of gravel originating from the trail. Hence, infilling of Beaver Lake is likely a consequence of both within lake organic matter inputs and gravel from the surrounding trails. As a recommendation, removal of plants from the interior of the wetland would be a first step towards restoration, as would be the building of a boardwalk around the lake to prevent further gravel inputs from the trails.

5.0 Summary of Recommendations;

1. Confirm the presence of high levels of metals, notably copper in Beaver Lake sediments prior to dredging.
2. Remove plant growth from the interior of the wetland to reduced autochthonous organic matter inputs.
3. Replace the gravel trail with a board walk, (at least partial), restricting the amounts of gravel entering into the wetland.

6.0 Acknowledgements

The authors gratefully acknowledge the field support of Erin and Jane from the BCIT Ecological Restoration program and Dr. Ken Ashley for his constant support. We are also grateful to Alan Duncan of the Vancouver Parks Board and the Stanley Park Ecological Society (SPES) for initiating this study and for making access possible through the ready supply of parking passes. Funding was provided by the Faculty of Environment, Environmental Science Program, Simon Fraser University.

7.0 References

Zimmerman et al. 1999. A study of the Beaver Creek Watershed : historical sedimentation, contemporary ecology and hydrology with predictive modeling. Undergraduate Project. Environmental Sciences, University of British Columbia. April 1999.

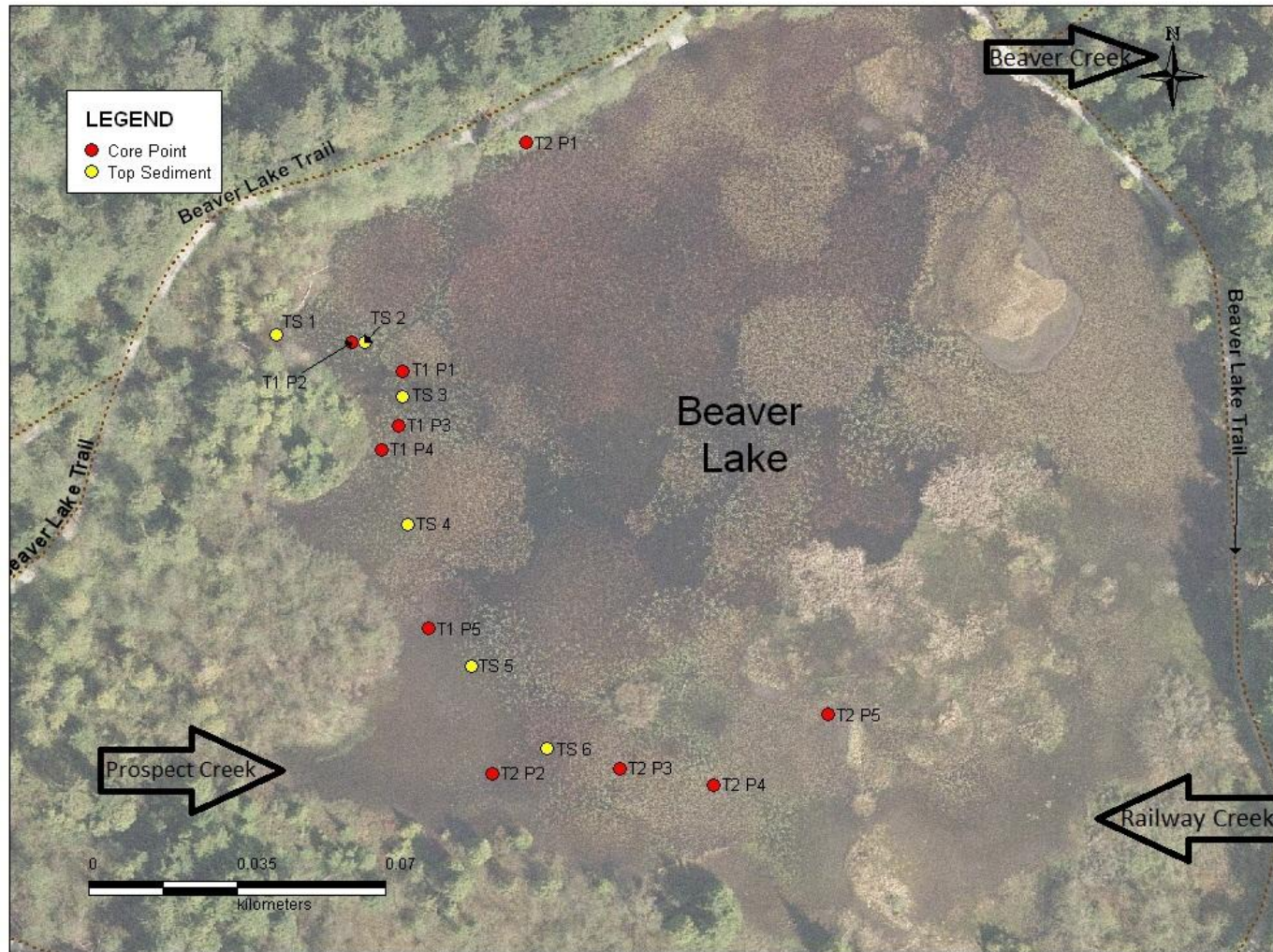


Figure 1: Beaver Lake and sediment sampling locations. T1(North-South), T2 (West-East) for sediment depth profiles and TS (North-South) for surface sediments only.

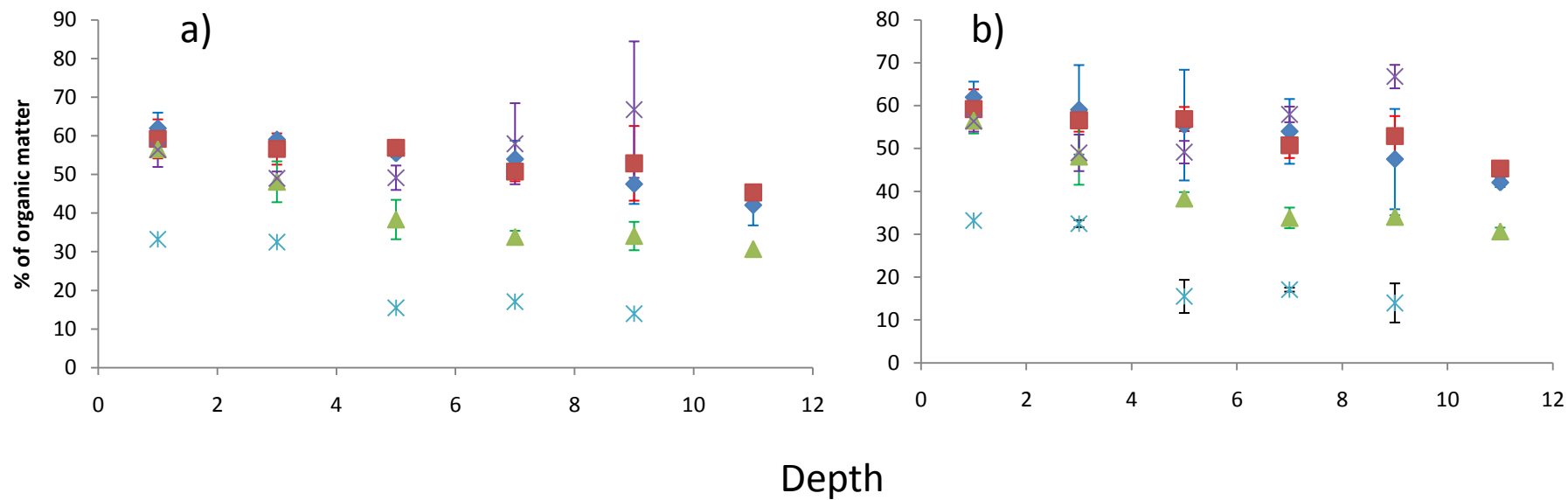


Figure 2. Percent organic matter with S.E. versus depth for Transect 1 (a) and (b) 2. See Figure 1 for site locations. Site 5 (X) is significantly lower in organic matter versus all others (ANOVA; $P < 0.05$).

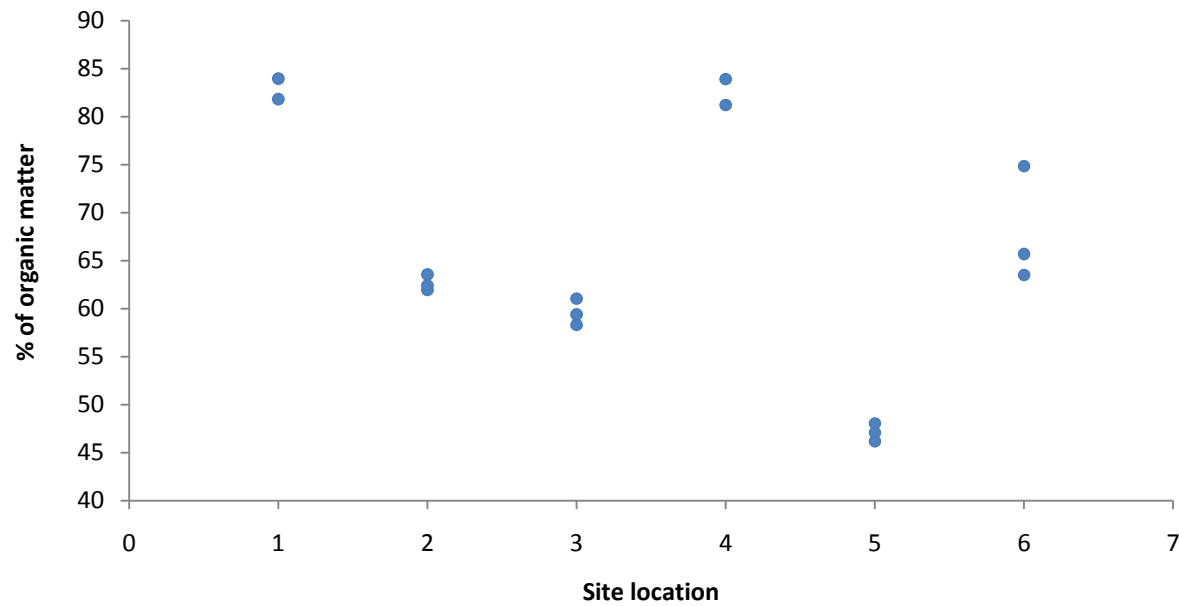


Figure 3. Spatial distribution of % organic matter in surficial sediments sampled from Beaver Lake. Each value is an average of 3 replicates with standard errors within 30%. See Figure 1 for site location.

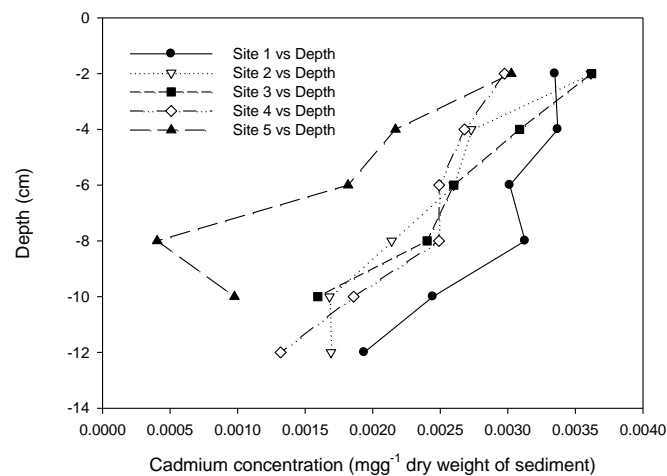
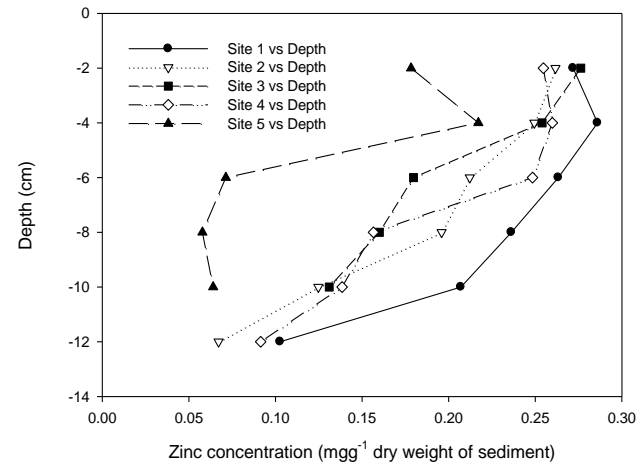
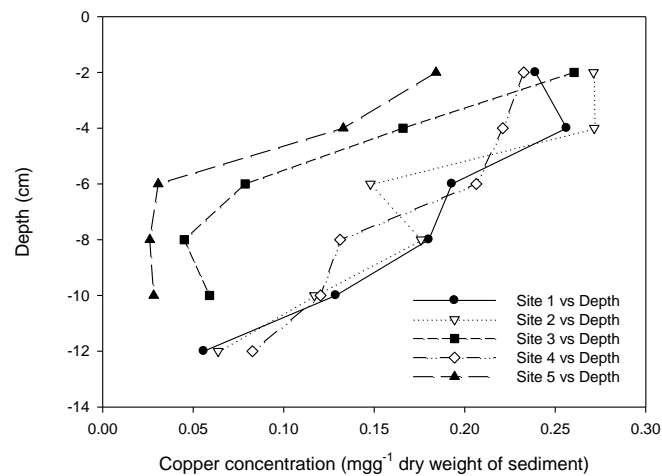


Figure 4. Average copper, zinc and cadmium concentrations versus depth for 5 sites, Transect 1, within Beaver Lake. See Figure 1 for site location. Values are means of 3 replicates. Standard errors are not shown but are generally within 30%.

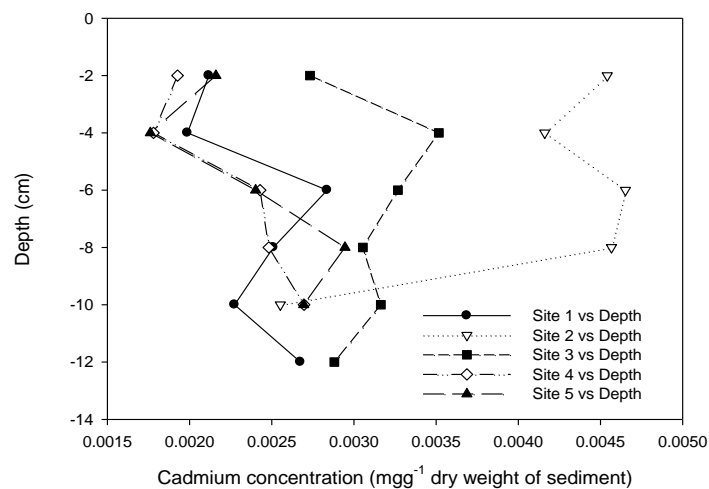
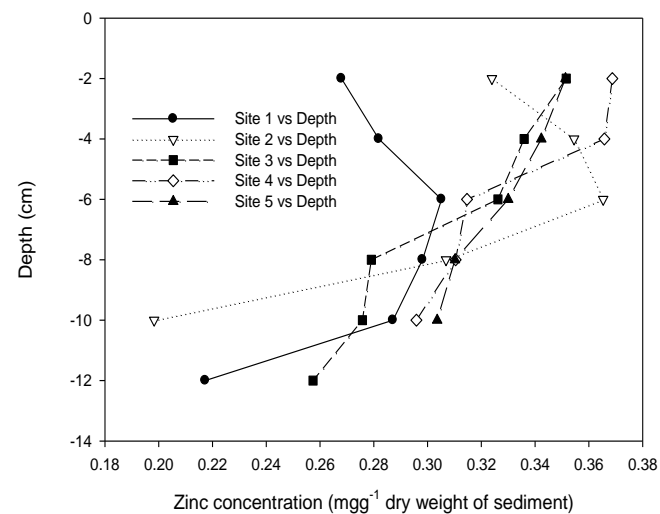
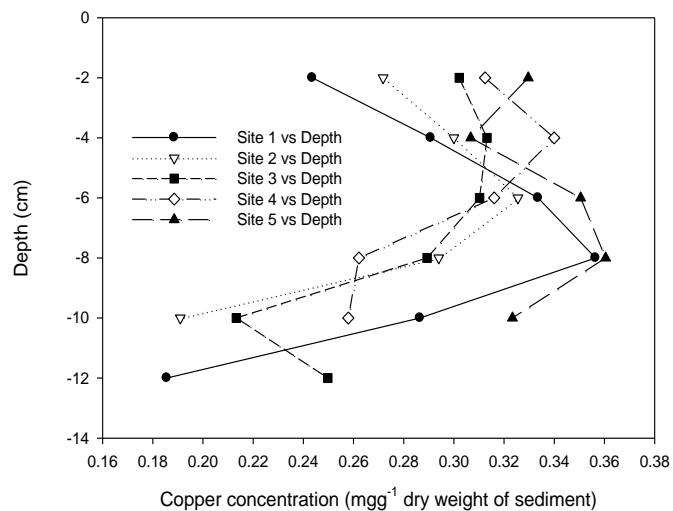


Figure 5. Average copper, zinc and cadmium concentrations versus depth for 5 sites, Transect 2, within Beaver Lake. See Figure 1 for site location. Values are means of 3 replicates. Standard errors are not shown but are generally within 30%.

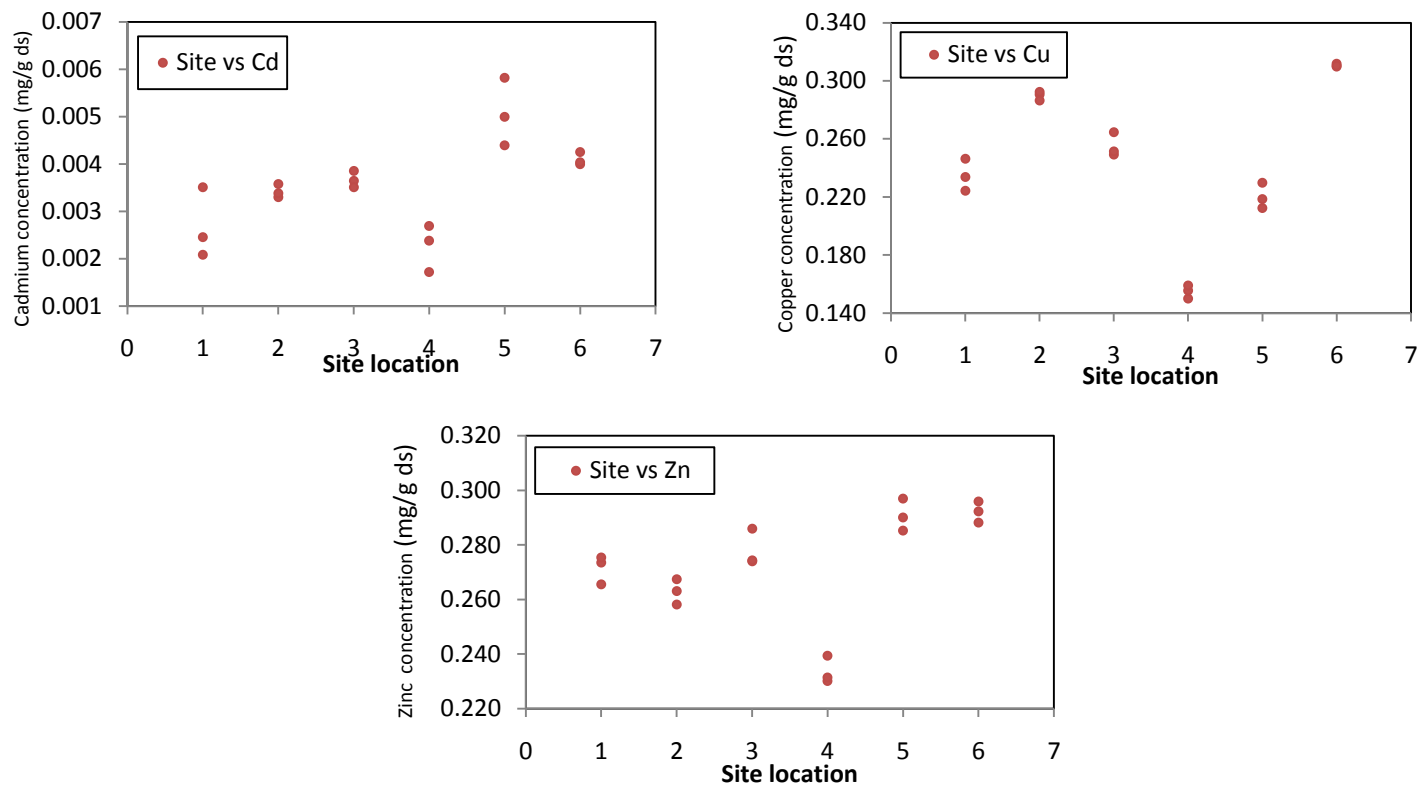


Figure 6. Concentration of copper, zinc and cadmium concentrations versus 6 sites within Beaver Lake. See Figure 1 for site location. There are 3 replicates per site. Standard errors are not shown but are generally within 30%.



Canadian Sediment Quality Guidelines for the Protection of Aquatic Life

SUMMARY TABLES

Update 2002

Table 1. Interim freshwater sediment quality guidelines (ISQGs; dry weight), probable effect levels (PELs; dry weight), and incidence (%) of adverse biological effects in concentration ranges defined by these values.*

Substance	ISQG	PEL	% = ISQG	ISQG < % < PEL	% = PEL
Acenaphthene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Acenaphthylene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Anthracene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Aroclor 1254 [See Polychlorinated biphenyls (PCBs)]					
Arsenic	5.9 mg·kg ⁻¹	17.0 mg·kg ⁻¹	5	25	12
Benz(a)anthracene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Benzo(a)pyrene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Cadmium	0.6 mg·kg ⁻¹	3.5 mg·kg ⁻¹	11	12	47
Chlordane	4.50 µg·kg ⁻¹	8.87 µg·kg ⁻¹	2	17	70
Chromium	37.3 mg·kg ⁻¹	90.0 mg·kg ⁻¹	2	19	49
Chrysene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Copper	35.7 mg·kg ⁻¹	197 mg·kg ⁻¹	4	38	44
DDTs					
DDD [†] (2,2-Bis(<i>p</i> -chlorophenyl)-1,1,-dichloroethane; Dichloro diphenyl dichloroethane)	3.54 µg·kg ⁻¹	8.51 µg·kg ⁻¹	3	30	85
DDE [†] (1,1-Dichloro-2,2,bis(<i>p</i> -chlorophenyl)-ethene; Diphenyl dichloro ethylene)	1.42 µg·kg ⁻¹	6.75 µg·kg ⁻¹	6	20	47
DDT [†] (2,2-Bis(<i>p</i> -chlorophenyl)-1,1,1-trichloroethane; Dichloro diphenyl trichloroethane)	1.19 µg·kg ^{-1†}	4.77 µg·kg ^{-1§}	8	5	59
Dibenz(a,h)anthracene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Dieldrin	2.85 µg·kg ⁻¹	6.67 µg·kg ⁻¹	1	10	60
Endrin	2.67 µg·kg ⁻¹	62.4 µg·kg ⁻¹	1	64	59
Fluoranthene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Fluorene [See Polycyclic aromatic hydrocarbons (PAHs)]					

Continued.

SUMMARY TABLES

Canadian Sediment Quality Guidelines for the Protection of Aquatic Life

Update 2002

Table 1. Continued.

Substance	ISQG	PEL	% = ISQG	ISQG < % < PEL	% = PEL
Heptachlor epoxide	0.60 µg·kg ⁻¹	2.74 µg·kg ⁻¹	3	12	67
Hexachlorocyclohexane [See Lindane]					
Lead	35.0 mg·kg ⁻¹	91.3 mg·kg ⁻¹	5	23	42
Lindane (Hexachlorocyclohexane)	0.94 µg·kg ⁻¹	1.38 µg·kg ⁻¹	0	50	49
Mercury	0.17 mg·kg ⁻¹	0.486 mg·kg ⁻¹	8	34	36
2-Methylnaphthalene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Naphthalene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Nonylphenol and its ethoxylates	1.4 mg·kg ⁻¹ †††,***				
PAHs [See Polycyclic aromatic hydrocarbons (PAHs)]					
PCBs [See Polychlorinated biphenyls (PCBs)]					
PCDD/Fs [see Polychlorinated dibenzo- <i>p</i> -dioxins and polychlorinated dibenzofurans]					
Phenanthrene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Polychlorinated biphenyls (PCBs)					
Aroclor 1254	60 µg·kg ⁻¹ ‡	340 µg·kg ⁻¹ **			
Total PCBs	34.1 µg·kg ⁻¹	277 µg·kg ⁻¹	4	40	50
Polychlorinated dibenzo- <i>p</i> -dioxins and polychlorinated dibenzofurans	0.85 ng·TEQ/kg dw §§	21.5 ng·TEQ/kg dw §§	0 ^{###}	24 ^{###}	46 ^{###}
Polycyclic aromatic hydrocarbons (PAHs)					
Acenaphthene	6.71 µg·kg ⁻¹ ‡	88.9 µg·kg ⁻¹ §			
Acenaphthylene	5.87 µg·kg ⁻¹ ‡	128 µg·kg ⁻¹ §			
Anthracene	46.9 µg·kg ⁻¹ ‡	245 µg·kg ⁻¹ §			
Benz(<i>a</i>)anthracene	31.7 µg·kg ⁻¹	385 µg·kg ⁻¹	13	6	38
Benzo(<i>a</i>)pyrene	31.9 µg·kg ⁻¹	782 µg·kg ⁻¹	11	16	30
Chrysene	57.1 µg·kg ⁻¹	862 µg·kg ⁻¹	8	14	25
Dibenz(<i>a,h</i>)anthracene	6.22 µg·kg ⁻¹ ‡	135 µg·kg ⁻¹ §			
Fluoranthene	111 µg·kg ⁻¹	2355 µg·kg ⁻¹	8	23	49
Fluorene	21.2 µg·kg ⁻¹ ‡	144 µg·kg ⁻¹ §			
2-Methylnaphthalene	20.2 µg·kg ⁻¹ ‡	201 µg·kg ⁻¹ §			
Naphthalene	34.6 µg·kg ⁻¹ ‡	391 µg·kg ⁻¹ §			
Phenanthrene	41.9 µg·kg ⁻¹	515 µg·kg ⁻¹	4	17	44
Pyrene	53.0 µg·kg ⁻¹	875 µg·kg ⁻¹	7	16	32
Pyrene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Toxaphene	0.1 µg·kg ⁻¹ ††	— ††			
Zinc	123 mg·kg ⁻¹	315 mg·kg ⁻¹	5	32	36

* ISQGs and PELs presented here have been calculated using a modification of the NSTP approach (CCME 1995).

† Sum of *p,p'* and *o,p'* isomers.

‡ Provisional; adoption of marine ISQG.

§ Provisional; adoption of marine PEL.

Provisional; adoption of lowest effect level from Ontario (Persaud et al. 1993).

*** Provisional; 1% TOC; adoption of severe effect level of 34 µg·g⁻¹ TOC from Ontario (Persaud et al. 1993).

†† Provisional; 1% TOC; adoption of the chronic sediment quality criterion of 0.01 µg·g⁻¹ TOC of the New York State Department of Environmental Conservation (NYSDEC 1994).

††† No PEL derived.

§§ Values are expressed as toxic equivalency (TEQ) units, based on WHO 1998 TEF values for fish.

Expressed on a TEQ basis using NP TEFs; assumes 1% TOC.

***Provisional; use of equilibrium partitioning approach.

††† Note that the incidence of adverse biological effects below the TEL, between the TEL and PEL, and above the PEL were 22%, 24% and 65%, respectively, prior to the application of a safety factor.

SUMMARY TABLES

Canadian Sediment Quality Guidelines for the Protection of Aquatic Life

Update 2002

Table 2. Interim marine sediment quality guidelines (ISQGs; dry weight), probable effect levels (PELs; dry weight), and incidence (%) of adverse biological effects in concentration ranges defined by these values.*

Substance	ISQG	PEL	% = ISQG	ISQG < % < PEL	% = PEL
Acenaphthene [See Polycyclic aromatic hydrocarbons; (PAHs)]					
Acenaphthylene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Anthracene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Aroclor 1254 [See Polychlorinated biphenyls (PCBs)]					
Arsenic	7.24 mg·kg ⁻¹	41.6 mg·kg ⁻¹	3	13	47
Benz(<i>a</i>)anthracene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Benzo(<i>a</i>)pyrene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Cadmium	0.7 mg·kg ⁻¹	4.2 mg·kg ⁻¹	6	20	71
Chlordane	2.26 µg·kg ⁻¹	4.79 µg·kg ⁻¹	9	12	17
Chromium	52.3 mg·kg ⁻¹	160 mg·kg ⁻¹	4	15	53
Chrysene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Copper	18.7 mg·kg ⁻¹	108 mg·kg ⁻¹	9	22	56
DDTs					
DDD [†] (2,2-Bis(<i>p</i> -chlorophenyl)-1,1-dichloroethane; Dichloro diphenyl dichloroethane)	1.22 µg·kg ⁻¹	7.81 µg·kg ⁻¹	4	11	46
DDE [†] (1,1-Dichloro-2,2-bis(<i>p</i> -chlorophenyl)-ethene; Diphenyl dichloro ethylene)	2.07 µg·kg ⁻¹	374 µg·kg ⁻¹	5	16	50
DDT [†] (2,2-Bis(<i>p</i> -chlorophenyl)-1,1,1-trichloroethane; Dichloro diphenyl trichloroethane)	1.19 µg·kg ⁻¹	4.77 µg·kg ⁻¹	8	5	59
Dibenz(<i>a,h</i>)anthracene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Dieldrin	0.71 µg·kg ⁻¹	4.30 µg·kg ⁻¹	4	13	50
Endrin	2.67 µg·kg ^{-1 †}	62.4 µg·kg ^{-1 §}			
Fluoranthene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Fluorene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Heptachlor epoxide	0.60 µg·kg ^{-1 †}	2.74 µg·kg ^{-1 §}			
Hexachlorocyclohexane [See Lindane]					
Lead	30.2 mg·kg ⁻¹	112 mg·kg ⁻¹	6	26	58
Lindane (Hexachlorocyclohexane)	0.32 µg·kg ⁻¹	0.99 µg·kg ⁻¹	3	21	26

Continued.

Table 2. Continued.

Substance	ISQG	PEL	% = ISQG	ISQG < % < PEL	% = PEL
Mercury	0.13 mg·kg ⁻¹	0.70 mg·kg ⁻¹	8	24	37
2-Methylnaphthalene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Naphthalene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Nonylphenol and its ethoxylates	1.0 mg·kg ⁻¹ ††,§§				
PAHs [See Polycyclic aromatic hydrocarbons (PAHs)]					
PCBs [See Polychlorinated biphenyls (PCBs)]					
PCDD/Fs [see Polychlorinated dibenzo- <i>p</i> -dioxins and polychlorinated dibenzo furans]					
Phenanthrene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Polychlorinated biphenyls (PCBs)					
Aroclor 1254	63.3 µg·kg ⁻¹	709 µg·kg ⁻¹	1	24	76
Total PCBs	21.5 µg·kg ⁻¹	189 µg·kg ⁻¹	16	37	55
Polychlorinated dibenzo- <i>p</i> -dioxins and polychlorinated dibenzo furans	0.85 ng TEQ/kg dw ^{††}	21.5 ng TEQ/kg dw ^{††}			
Polycyclic aromatic hydrocarbons (PAHs)					
Acenaphthene	6.71 µg·kg ⁻¹	88.9 µg·kg ⁻¹	8	29	57
Acenaphthylene	5.87 µg·kg ⁻¹	128 µg·kg ⁻¹	7	14	51
Anthracene	46.9 µg·kg ⁻¹	245 µg·kg ⁻¹	9	20	75
Benz(<i>a</i>)anthracene	74.8 µg·kg ⁻¹	693 µg·kg ⁻¹	9	16	78
Benzo(<i>a</i>)pyrene	88.8 µg·kg ⁻¹	763 µg·kg ⁻¹	8	22	71
Chrysene	108 µg·kg ⁻¹	846 µg·kg ⁻¹	9	19	72
Dibenz(<i>a,h</i>)anthracene	6.22 µg·kg ⁻¹	135 µg·kg ⁻¹	16	12	65
Fluoranthene	113 µg·kg ⁻¹	1 494 µg·kg ⁻¹	10	20	80
Fluorene	21.2 µg·kg ⁻¹	144 µg·kg ⁻¹	12	20	70
2-Methylnaphthalene	20.2 µg·kg ⁻¹	201 µg·kg ⁻¹	0	23	82
Naphthalene	34.6 µg·kg ⁻¹	391 µg·kg ⁻¹	3	19	71
Phenanthrene	86.7 µg·kg ⁻¹	544 µg·kg ⁻¹	8	23	78
Pyrene	153 µg·kg ⁻¹	1 398 µg·kg ⁻¹	7	19	83
Pyrene [See Polycyclic aromatic hydrocarbons (PAHs)]					
Toxaphene	0.1 µg·kg ⁻¹ #	—**			
Zinc	124 mg·kg ⁻¹	271 mg·kg ⁻¹	4	27	65

* ISQGs and PELs presented here have been calculated using a modification of the NSTP approach (CCME 1995).

† Sum of *p,p'* and *o,p'* isomers.

‡ Provisional; adoption of freshwater ISQG.

§ Provisional; adoption of freshwater PEL.

Provisional; 1% TOC; adoption of the chronic sediment quality criterion of 0.01 µg·g⁻¹TOC of the New York State Department of Environmental Conservation (NYSDEC 1994).

** No PEL derived.

†† Values are expressed as toxic equivalency (TEQ) units, based on WHO 1998 TEF values for fish.

^{††} Expressed as a TEQ basis using NP TEF; assumes 1% TOC.

^{§§} Provisional; use of equilibrium partitioning approach.

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Canadian Council of Ministers of the Environment. 2002. Canadian sediment quality guidelines for the protection of aquatic life: Summary tables. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

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