Ministry of Environment

LOWER MAINLAND REGION

Assessments of Stormwater Quality and Snowmelt Runoff in Whistler Creeks

2007-2008

ENVIRONMENTAL QUALITY

Assessments of Stormwater Quality and Snowmelt Runoff in Whistler Creeks

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Preface

This report is one in a series of water, groundwater, and air quality reports that are being issued by the Lower Mainland Regional Office in fiscal year 2009/10. It is the intention of the Regional Office to publish air and water quality reports on our website (http://www.env.gov.bc.ca/epd/regions/lower_mainland/) in order to provide the information to industry and local government, other stakeholders and the public at large. By providing such information in a readily understood format, and on an ongoing basis, it is hoped that local environmental quality conditions can be better understood, and better decisions regarding air and water quality management can be made.

Acknowledgements

This study was funded through Water and Air Monitoring and Reporting (Ministry of Environment) and partnership contributions (Resort Municipality of Whistler). The author would like to acknowledge the support and assistance of Heather Beresford, Betty Rebellato, and Vesna Young at the Resort Municipality of Whistler. The author would also like to acknowledge the field support, technical assistance, and automated data analysis provided by Jason McCoy, as well as the report review provided by Brent Moore of the Ministry of Environment.

EXECUTIVE SUMMARY

The British Columbia Ministry of Environment (MoE), in partnership with the Resort Municipality of Whistler (RMOW), conducted water quality monitoring programs in three urbanized Whistler watersheds during stormwater (October 2007) and snowmelt (May 2008) runoff periods. This partnership was viewed as beneficial to both parties, as overlapping internal goals of each organization were clearly identified from the outset. For RMOW, their *Whistler 2020* goals included a commitment to effective stormwater management. For MoE, effective stormwater management is a regulatory requirement for RMOW under their updated 2004 Liquid Waste Management Plan (LWMP). This joint stewardship approach to stormwater management was thus initiated to compliment the regulatory approach addressed under the LWMP. The studies, partially funded by RMOW, involved joint field coordination and monitoring, as well as reporting to both the Resort Municipality and the Ministry.

Whistler waterbodies may be at risk from urban rainwater and snowmelt runoff, as storm sewers convey water and potential pollutants directly into ditches, stormwater ponds, and streams, which ultimately lead to larger creeks and lakes that have high fisheries and recreational values. Common contaminants in both types of runoff include nutrients, bacteria, metals, hydrocarbons, and suspended sediments. Additional contaminants in snowmelt runoff include potential components of road salt: chloride, ferrocyanide (anti-clumping agent), urea (ammonia), and trace elements, or impurities (mostly phosphorus, sulphur, nitrogen, copper and zinc).

The goal of both the storm event and snowmelt studies was to determine whether land use and winter road maintenance practices in the Whistler, Crabapple, and Fitzsimmons Creek watersheds were leading to water quality impacts in downstream locations. As part of RMOW's stormwater management plan, Whistler Village runoff is first directed to a 100-m long biofiltration pond along Blackcomb Way just north of the Village. An additional goal of the overall water quality assessment was to assess water quality in the biofiltration pond and its discharge during periods of high runoff, and to determine the pond's effectiveness in removing potential pollutants during these periods.

Findings of the rainwater quality study in Whistler (Section 3.0), Crabapple (Section 4.0), and Fitzsimmons Creeks (**Section 5.0**) showed that they were all receiving non-point source pollution during periods of high runoff that was primarily caused by high suspended sediment and turbidity levels during the first two weeks of October 2007. Sediment-associated copper, iron and zinc levels were also elevated in lower creek reaches and at times exceeded British Columbia Approved Water Quality Guidelines (B.C. AWQGs) for the protection of aquatic life. Activities in the Whistler and Crabapple Creek watersheds, including yearly summer service road maintenance, the 2010 Winter Olympic ski run construction in 2006/07, and bike park operation on Whistler Mountain, all likely contributed to the observed turbidity and sediment levels in October 2007. Excessive turbidity indicates significantly impaired conditions for clear water fishes, which can reduce fish growth rate, habitat size, or both. Significant sources of suspended sediments in Fitzsimmons Creek are likely originating from the Fitzsimmons Slip, although urban runoff from the Whistler Village and further downstream neighbourhoods are contributing elevated levels of both sediments and associated metals during periods of high runoff.

Findings of the snowmelt study (**Section 6.0**) showed that snowmelt runoff contributed to elevated levels of chloride, some metals, and turbidity to creeks in urban areas. Whistler and Fitzsimmons Creeks appeared to be relatively well buffered from snowmelt runoff impacts, as heavy metal and sediment concentrations increased minimally in downstream locations. Crabapple Creek, however, with nearly 30% of its natural drainage arising from stormwater drainage, appears to be more affected by either the high flows associated with snowmelt or practices such as snow storage within its stream banks along lower reaches. Elevated levels of turbidity, cadmium, copper and zinc were observed in Crabapple Creek throughout May 2008, which exceeded B.C. AWQGs at times and were likely derived from sediment and road sources. Additionally, snowmelt runoff from the snow storage area in Day Lot 5 had particularly high levels of suspended sediments, copper and iron. Copper was also found to be elevated in leaching tests of the raw road salt and sand material used in winter road maintenance, which may be contributing low level, but chronic, guideline exceedances in Whistler waterways.

Findings of the biofiltration pond monitoring study (**Section 7.0**) showed that the pond was receiving pollutants from urban stormwater runoff that exceeded B.C. AWQGs at times. Elevated levels of suspended sediments, turbidity, *E. coli*, and metals (cadmium, copper and zinc) were observed during periods of high runoff, i.e. first flush events and early snowmelt runoff. Ammonia was also elevated during the snowmelt period, likely due to the use of urea in the road salt mixture. In October 2007, the biofiltration pond was particularly effective in reducing higher levels of suspended sediments and associated metals (total copper, iron and zinc), while turbidity was only somewhat effectively removed. In May 2008, total copper was effectively reduced and there was some evidence that turbidity, total iron, nitrate and total phosphorus were effectively reduced. Conversely, cadmium and lead did not appear to be effectively removed by the pond in May 2008. The pond was not as effective in removing turbidity, total Fe and total Zn during the snowmelt period, likely due to the relatively lower levels of these parameters compared to the stormwater period of October 2007.

Recommendations to improve water quality during both runoff periods included conducting evaluations of current erosion and sediment control measures on summer maintenance roads and the bike park on Whistler Mountain, in particular. Completion and evaluation of re-vegetation following Creekside soil disturbance in 2006/07 was also recommended prior to September 1, 2008. Optimization of source controls in neighbourhoods surrounding Whistler creeks and the biofiltration pond is also recommended, so that the impact of urban stormwater runoff can be minimized. Examples of source control can include low-impact development (LID) and increased infiltration. **Additional recommendations to improve water quality during snowmelt periods** included using only appropriate amounts of road salt and sand, as well as avoiding storage of excess snow near or within stream banks, the biofiltration pond, and Day Lot 5 (due to its proximity to Fitzsimmons Creek). **Recommendations to improve the biofiltration pond's ability to remove contaminants** during high flow periods were to conduct upgrades, if necessary, as well as to periodically remove and properly dispose of accumulated sediment from the sediment deposition area at the inlet of the pond.

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1.0 INTRODUCTION

The BC Ministry of Environment (MoE), in partnership with the Resort Municipality of Whistler (RMOW), conducted water quality monitoring programs in three urbanized Whistler watersheds during high precipitation (October 2007) and snowmelt (May 2008) periods. Whistler waterbodies may be at risk from urban rainwater and snowmelt runoff, as storm sewers in the municipality drain directly into ditches, stormwater ponds, and streams. Water and potential pollutants are then conveyed to larger creeks and lakes that have high fisheries and recreational values. Thus, the **overall objective was to assess the current water quality conditions in Whistler, Crabapple, and Fitzsimmons Creeks during these periods of high runoff. An additional objective was to assess the effectiveness of a biofiltration pond in treating runoff from Whistler Village that discharges to Fitzsimmons Creek.**

This partnership achieves both regulatory and stewardship goals that are beneficial to both parties. The RMOW has developed a comprehensive community sustainability plan, *Whistler2020*, which includes a Water Strategy under the key priority of Protecting the Environment. Under this strategy, there is a commitment to '*effective stormwater management*' as well as maintaining '*healthy streams, rivers, lakes and wetlands that support thriving populations of fish, wildlife and aquatic organisms*'. *Whistler2020* also sets targets within each Strategy that are to be met through measurable and reportable actions. This partnership assists the MoE in meeting our goal of "clean and safe water, land and air through enhanced protection and stewardship of our water resources". Findings from each study are designed to support RMOW's ongoing Stormwater Management planning, a new regulatory requirement under the municipality's updated 2004 Liquid Waste Management Plan.

The primary goal of the high precipitation study was to determine whether land use practices in the Whistler, Crabapple, and Fitzsimmons Creek watersheds were leading to water quality impacts in downstream locations (Figure 1.1). The primary goal of the snowmelt study was to determine whether winter road maintenance practices were leading to water quality impacts in the same creeks. Land use practices of concern include development and maintenance of alpine ski areas and urban areas in Whistler Valley. Upstream reaches of both Whistler and Crabapple Creeks flow through portions of the Whistler Blackcomb Ski Resort area, where activities such as summer service road maintenance, bike park operations (Crabapple Creek watershed) and ongoing ski hill development may be impacting water quality.

As part of RMOW's stormwater management plan, biofiltration of Whistler Village runoff was implemented as a best management practice in the fall of 2004 through the use of a 100-m long natural wetland along Blackcomb Way just north of the Village. The primary goal of this study was to assess water quality in the biofiltration pond and its discharge during periods of high runoff, and to determine whether the biofiltration pond was effective in removing potential pollutants during these periods.

Information on rainwater and winter road maintenance concerns is included in **Section 2.0.** Information on the study area; methods and data analysis; results and discussion; as well as conclusions and recommendations for each study are then divided into sections which focus on each creek for the high precipitation period (**Sections 3.0 to 5.0**), on the snowmelt period for all creeks (**Section 6.0**), and finally on the performance of the biofiltration pond during both runoff periods (**Section 7.0**). Appendices specific to each study are included with the relevant sections, while appendices relevant to all sections are included in the Master Appendices.

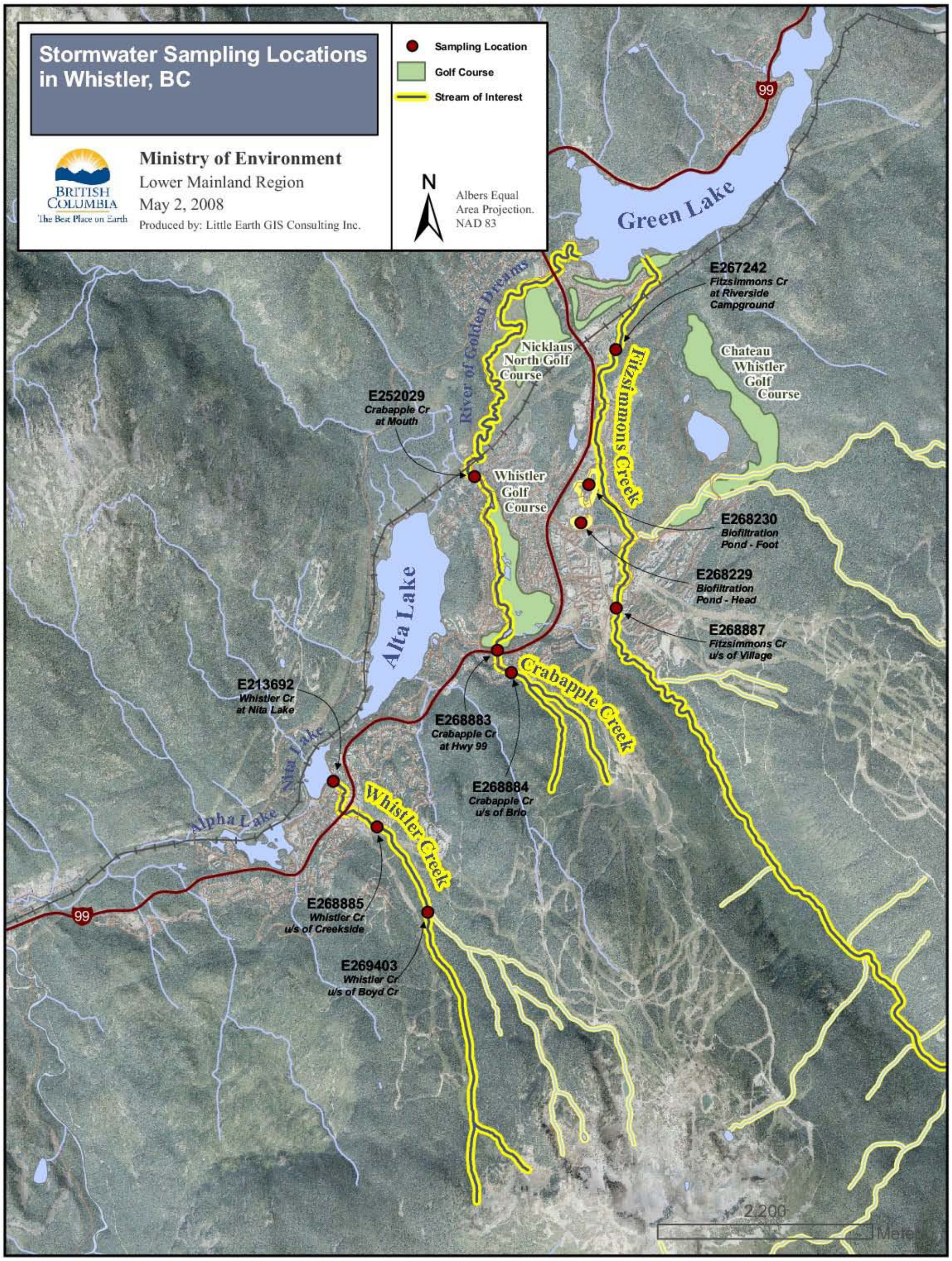


Figure 1.1. Water quality sampling site locations in Whistler, Crabapple and Fitzsimmons Creeks in Whistler, B.C.

2.0 RAINWATER & WINTER ROAD MAINTENANCE CONCERNS

2.1 Rainwater Concerns

In Whistler, storm sewers drain into creeks and ditches, which ultimately lead to local streams and lakes that support both aquatic life and recreational use. This is a concern as rainwater flowing over impervious surfaces, such as parking lots, roads, roofs, and compacted lawns can accumulate contaminants and convey them to natural waterbodies. An additional concern in ski resort communities is the steep terrain and land clearing that occurs for ski run development and adjacent accommodation. A recent study in the northeastern US comparing a pristine watershed to a developed alpine ski resort watershed, with an impervious surface area of 17%, found that annual sediment yields were 2.5 times higher in the developed watershed (Wemple *et al.*, 2007). Fluxes of sodium and calcium were also an order of magnitude higher in the developed watershed, which were due to deicing salt use, where elevated levels of chloride persisted throughout the year despite only winter application of road salt (Wemple *et al.*, 2007).

Whistler also depends on its natural beauty for summer tourism, which now exceeds winter tourism, making up approximately 52% of the estimated 2.1 million visitors a year to Whistler (Tourism Whistler, 2008). If stream and lake water quality were to degrade significantly for both aquatic life and recreational uses, Whistler's economic viability as a recreational destination could be impacted. **Common contaminants in rainwater runoff include nutrients, bacteria, metals, hydrocarbons, and suspended sediments.** Sources and potential impacts of these contaminants are summarized in Table 2.1.

2.2 Winter Road Maintenance Concerns

Current practices within the RMOW include application of road salt (containing NaCl, KCl, and urea) and sand to road and parking lot surfaces annually to aid in snow and ice removal at a ratio of 1:12 (salt:sand). Liquid calcium chloride ($CaCl_2$) is also added to the salt/sand mixture prior to application, to promote better 'stickiness' to surfaces, which allows for less road salt to be used annually (approximately 250 tonnes). Prior to the addition of $CaCl_2$ in 2003, approximately 500 tonnes of road salt were used annually (T. Brooksbank, RMOW, October 20, 2008, personal communication). Current practices also include storage of excess snow near or within stream banks, as well as in one of Whistler's day parking lots (Lot 5), near Fitzsimmons Creek (see Photo Series 2.1). Melting snow along roads and parking lots and within stream channels can contribute significant amounts of salts and sediments, as well as contaminants from road surfaces such as heavy metals (Table 2.1). These contaminants can be conveyed either directly to nearby creeks and ditches or via storm sewers, which is a concern as the creeks and lakes they drain to support both aquatic life and recreational use.

Many studies from various locations have shown that a high percentage of deicing salts are delivered to streams and rivers from surface runoff (Blasius and Merritt, 2002). Several studies have shown that use of road salt can lead to elevated levels of sodium, and particularly chloride in streams and rivers (Godwin *et al*., 2003), as well as small lakes (Hoffman *et al*., 1981). While chloride is directly toxic to aquatic life at relatively high levels (>1000 mg/L), it may also enhance the toxicity of urban pollutants through increased leaching and bioavailability [e.g. dissolved cadmium (Marsalek, 2003)]. Still other studies have found that invertebrate numbers and diversity were lower in streams receiving drainage from salted and sanded roads, although increased fine sediments may have been more important than salt (Molles, 1980 and Demers, 1992; in Mattson and Godfrey, 1994).

Table 2.1. Potential contaminants in snowmelt and rainwater runoff, their sources, and impacts to aquatic life and recreational uses of water

Contaminant	Sources	Potential Impacts to Aquatic Life & Recreation Uses
Metals – cadmium (Cd), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), zinc (Zn)	Road surfaces & vehicular traffic (Mayer et al., 2008), i.e. tire wear (Cd, Pb, Zn), engine wear (Cr, Cu, Fe, Mn), brake lining wear (Cd, Cr, Cu, Pb, Hg, Ni); disturbed soils, paint, preserved wood	**Aquatic life:** - Toxic at low concentrations - Bioconcentrate[a] (bioaccumulate) in food chain (i.e. Cd, Pb, Cu, Ni, Zn) - Some metals biomagnify[b] in food chain [i.e. Cd, Mn] **Recreation:** Poor aesthetics (i.e. iron staining & promotion of iron bacteria)
Suspended sediments (SS) and turbidity	Disturbed soils and winter sand application and snow storage practices (near & within stream channels)	**Aquatic life:** **- Suspended sediments** can transport other attached pollutants (e.g. metals) & can smother both invertebrate & fish spawning habitat on stream and lake bottoms - **Turbidity**, or reduced visual clarity, can cause physiological (gill trauma, osmoregulation, blood chemistry, reproduction & growth), behavioural (avoidance, territoriality, foraging and predation, homing and migration), and habitat (reduction in spawning & benthic invertebrate habitat, damage to redds) effects beginning at 10-30 NTU (Newcombe, 2003; Bash et al., 2001; Henley et al., 2000) **Recreation:** Reduced recreational opportunities from reduced fish populations and poor aesthetics (reduced visual clarity)
Nutrients - nitrogen, phosphorus	Disturbed soils (construction sites), fertilized lawns	**Aquatic life:** - Excessive lake algal growth, leading to DO depletion from increased bacterial decomposition of dead algae. Change in lake trophic status from oligotrophic (nutrient-poor) to eutrophic (nutrient-enriched), which may decrease biodiversity. - Low DO levels affect benthic invertebrate and fish health, growth and survival **Recreation:** Poor aesthetics & possible odour during die-off (algal growth); reduced recreational opportunities (less fish)
Bacteria - *E. coli*, fecal coliforms	Domestic and wild animal excrement, septic field and/or sewage infrastructure leakage	**Recreation:** Swimming beach closures due to risk of intestinal illness, threatens 2° contact recreation (e.g. canoeing)
Hydrocarbons - oil & grease	Road surfaces & vehicular traffic, i.e. leakage from vehicles and equipment, spills, improper disposal of waste oil	**Aquatic life:** Toxic at low concentrations, carcinogenic at chronic, long-term exposures **Recreation:** Poor aesthetics (oil sheen)
Snowmelt: **Salts** (chloride, sodium, calcium), **cyanide, urea** (ammonia), **suspended sediments**	Road salt & sand application	**Aquatic life:** - Chloride is toxic to fish (Nagpal et al, 2003) and amphibians >1,000 mg/L (Collins and Russell, 2008), and benthic invertebrates >2,400 mg/L (Blasius and Merritt, 2002) - Increased leaching & bioavailability of dissolved Cd (Marsalek, 2003)

Notes: [a] bioconcentration is an increase in concentration of a toxin in an organism compared to its concentration in water or sediments, and [b] biomagnification is an increase in concentration of the toxin as it moves up the food web to higher trophic levels.

High levels of chloride can also lead to chemical stratification in stormwater ponds, which inhibits vertical mixing and aeration of bottom layers (Marsalek, 2003). The resulting lack of oxygen in bottom layers, coupled with high chloride levels, can then lead to chemical processes that can stimulate the release of chemicals from bottom sediments. While road salt contains mainly sodium chloride, it may also contain an anti-clumping agent (ferrocyanide), urea (ammonia), and trace elements, or impurities (mostly phosphorus, sulphur, nitrogen, copper and zinc), that can add to the toxicity of chloride-laden stormwater to aquatic life (Marsalek, 2003).

Photo Series 2.1: Snow storage in a) Crabapple Creek channel, at Sunridge Plateau (upper panel, Apr 9/08), and b) Day Lot 5 near Fitzsimmons Creek (bottom left panel, July 19/07; bottom right panel, April 9/08)

2.3 Stormwater Retention Ponds

Stormwater ponds are commonly used in stormwater management as a 'best management practice' to provide flow control (reduction of peak flows) and remove pollutants carried in stormwater runoff. However, their effectiveness in treating both water quantity and water quality has not been extensively studied. An assessment of a stormwater pond/wetland system in Colorado found that its performance in removing many pollutants during storm events was reasonably effective, particularly for total phosphorus (49%), total copper (57%), total zinc (51%), and total suspended solids (78%), although not for nitrate (-85%) (Table 2.2; Anon, 1994).

Oberts (1994) found that ponds were generally effective in removing pollutants during rainfall events (non-winter conditions), but not during snowmelt periods, where there was a marked reduction in performance of removal of suspended solids, phosphorus, nitrogen, and total lead, in particular (Table 2.2). Two reasons cited for poor winter performance was reduced biological activity and the formation of an ice layer (Oberts, 1994). The latter has the effect of eliminating permanent storage volume needed for effective treatment of incoming runoff, as well as creating a physical barrier for settling when early snowmelt runoff is forced to flow over the top of the ice.

Table 2.2. Average removal rates for a) a stormwater pond during 36 storm events in Colorado, 1990-92 (Anon, 1994), and b) four stormwater ponds in Minnesota during rainfall events and snowmelt conditions (Oberts, 1994)

Parameter	a) % Removed by pond	b) % Removed by ponds (approximate)	
	Rainfall events	Rainfall events	Snowmelt conditions
Total phosphorus	49	55	17
Nitrate-nitrogen	-85	29	12
Total copper (Cu)	57	-	-
Total lead (Pb)	-	68	20
Total zinc (Zn)	51	-	-
Total suspended solids (TSS)	78	78	40
Chemical oxygen demand	44	24	12

Most pollutants eventually settle out to form the 'muck layer' of the pond, which are the newly deposited sediments that are soupy in texture, high in organic matter, and a distinctive grey to black colour. The muck layer is effective in trapping nutrients (particularly phosphorus) and trace metals, which follow a consistent pattern and distribution that is nearly identical to reported concentrations in urban stormwater runoff: Zn>Pb>>Cr=Ni=Cu>Cd (TRS, 1994). Additionally, younger ponds tend to accumulate more Zn than Pb in the muck layer, while the reverse is true for older ponds (TRS, 1994). Once in the muck layer, pollutants are removed mainly through five processes:

- binding to sediment particles (which remain fixed within the muck layer)
- sediment diagenesis (decomposition through physical, chemical, and biological process)
- wetland plant uptake (nutrients and metals)
- export from the pond (flushing out during subsequent rain events)
- sediment clean-outs (ultimate removal by excavation)

3.0 WHISTLER CREEK WATER QUALITY DURING RAIN EVENTS IN OCTOBER 2007

3.1 Study Area

Whistler Creek (Figure 3.1) is initially a high-gradient glacial-fed creek, originating in mountain hemlock forests on Whistler Mountain (Rebellato 2006). Along with receiving glacial meltwater, the creek also displays a *hybrid* runoff regime at lower elevations, where higher flows occur during both the i) rainy season, from October-December (with rainfall becoming snowfall in November/December), and ii) again during snowmelt from April to June (Rodenhuis *et al*., 2007). Low flows are typically experienced in winter (Dec-Mar) and July/August. The creek drains an area of 8.57 km^2, 0.79 km^2 (9.2%) of which can be attributed to stormwater drainage area (Golder Associates, 2007). The creek then flows through portions of the Creekside ski area, and into the lower gradient and highly urbanized Creekside subdivision on both sides of Hwy 99 (see Photo Series 3.1). The creek finally enters Nita Lake, which is 11.4 ha in size and forms part of the headwaters for the Cheakamus River to the south (Figure 3.1).

Nita Lake is an important recreational resource for RMOW in the summer, used mainly for secondary contact recreation such as canoeing, kayaking, and fishing (Photo Series 3.2). The lake's trophic status is currently considered to be oligotrophic (total phosphorus 4-10 µg/L), or low in nutrients and thus productivity, based on Environment Canada's Guidance Framework for the management of phosphorus (Environment Canada 2005).

Aquatic species of concern in the Whistler Creek watershed and Nita Lake include coastal tailed frogs (*Ascaphus truei*), a blue-listed species in B.C. (species of special concern), which are known to occur as tadpoles in Boyd Creek, upstream of Hwy 99. Tailed frogs, which were discovered during Boyd Creek surveys in 2006 prior to re-alignment, typically occur in fast-flowing, steeper gradient headwater streams. Both the creek and lake also have important fisheries values, providing spawning and rearing habitat for rainbow trout (*Oncorhynchus mykiss*) and kokanee salmon (*O. nerka*) populations. All three aquatic species are considered to require clear water conditions for survival.

Photo Series 3.1: Developed Creekside area, showing Whistler Creek and Nita Lake (May 13, 2008)

It should be noted that much of the Whistler Creek streambed is channelized and experiences high bedload movements, as indicated by the large gravel fan at the creek's mouth (Taylor and Swiatkiewicz 1972, in Rebellato 2006). Much of the lower creek was re-routed in 1999 for Creekside urban development, and there are plans to re-divert the creek again in 2008. More recently, in 2006/07, the Vancouver Olympic Organizing Committee (VANOC) oversaw reconstruction of portions of the Creekside ski runs for the 2010 Winter Olympic Games. Portions of Boyd Creek, a tributary to Whistler Creek, were re-aligned during this construction effort which led to areas of exposed soil that were not adequately re-vegetated prior to the fall rainy seasons in 2006 and 2007. This was noted in the October and November 2006 Monitoring Memoranda by the on-site Environmental Monitor, Cascade Environmental Resource Group Ltd. (CERG). In the October 2006 Memo, it was noted that '*earthworks continued into mid October, where late re-vegetation prevented efficient grass growth*'. In the November 2006 Memo, it was further noted that '*increased turbidity levels in Crabapple and Whistler Creeks during record rainfalls in early November resulted in some surface erosion from non-vegetated work areas*'. It was also noted in the same Memo that '*ski run areas that were re-vegetated prior to Sept 30 did not experience the same level of erosion from surface water as those areas that were re-vegetated after Oct 1, 2006*'.

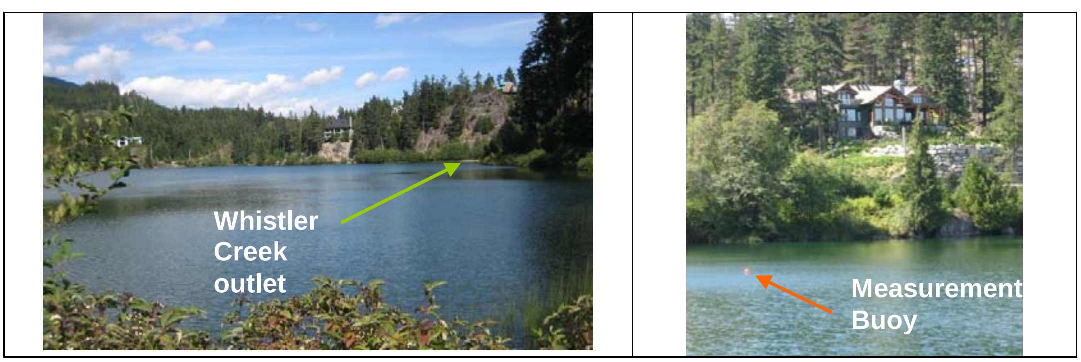


Photo Series 3.2: Nita Lake, showing Whistler Creek inflow area (left panel) and buoy where Secchi depth is measured (right panel) (September 6, 2007)

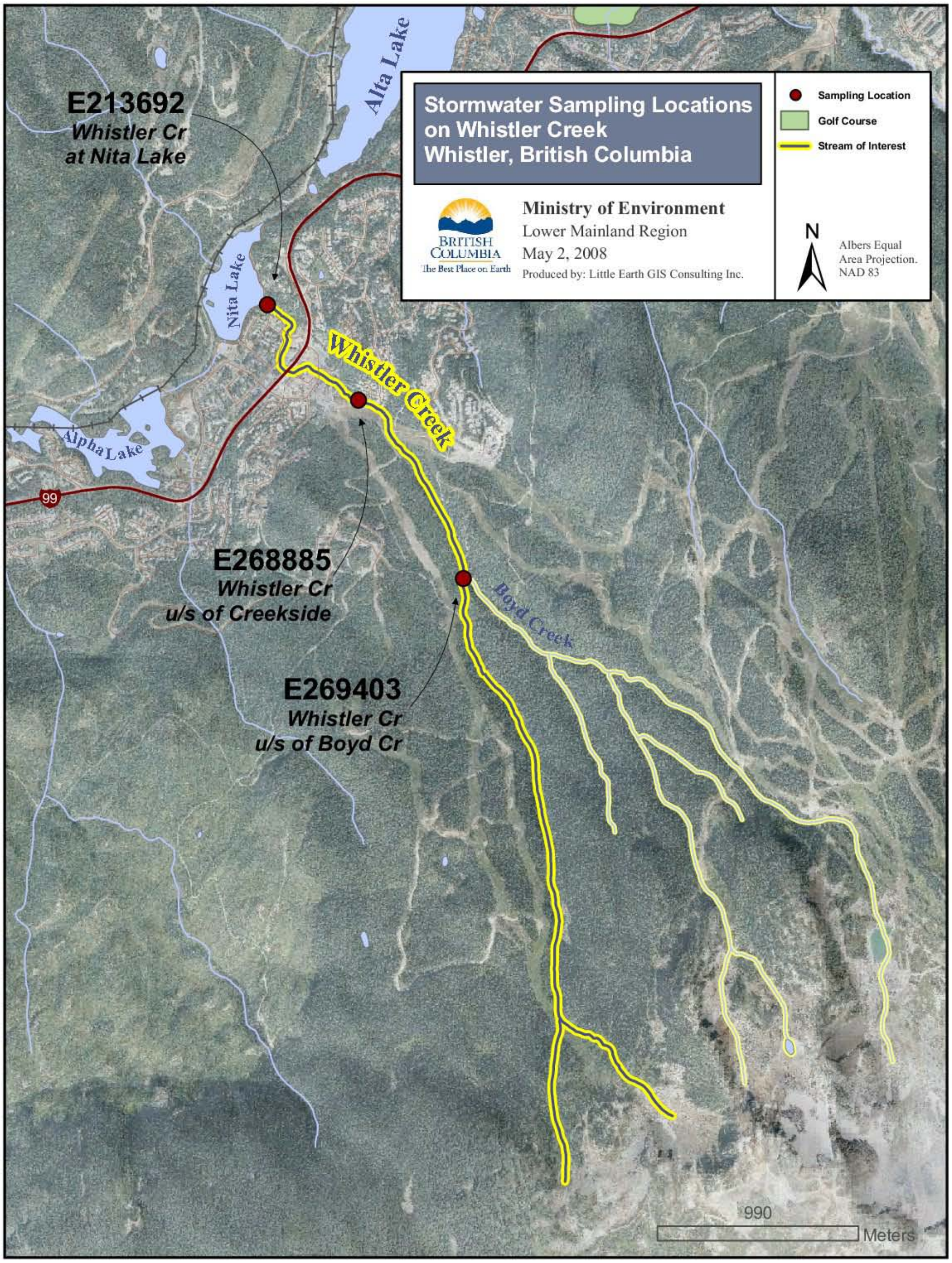


Figure 3.1. Sampling site locations in Whistler Creek, Whistler, B.C.

3.2 Methods & Data Analysis

Site selection

Site locations were chosen along a development gradient to assess cumulative impacts of urban rainwater runoff. Two sites were chosen (see Photo Series 3.3): an upstream reference site (E268885; downstream of ski hill development but upstream of urban development) and a downstream site (E213692; downstream of all development, near the mouth). Ski hill operations were not initially assumed to have a significant impact on the upstream reference site (E268885) originally selected at the study outset. When significant sedimentation and turbidity were observed at this location on October 2 and 10, a new upstream reference site above the Boyd Creek confluence (E269403) was selected on October 17/07. The original upstream site (E268885) then became the midstream site (downstream of ski hill development).

Grab sampling

Summer low flow sampling at the downstream site (E213692) was conducted in August 2007, at a frequency of 5 times in 30 days to satisfy statistical requirements for several British Columbia Approved Water Quality Guidelines (B.C. AWQGs). Grab sampling captured significant rain events (Oct 2, 10 and 22), as well as low flow conditions (Oct 17 and Nov 1) at the downstream site.

Water samples were collected and analyzed for bacteria (fecal coliforms, *E. coli*), total suspended solids (TSS), turbidity, oil and grease, nutrients, and metals (total and dissolved). A replicate sample and field blank were also collected during each sampling event to satisfy the quality assurance/quality control component of the sampling program, generally 10-20% of the total samples collected. The results were compared to B.C. AWQGs for the protection of aquatic life, generally the most sensitive water use, or to Canadian Environmental Quality Guidelines (CCME) if B.C. guidelines were not available. Field measurements of dissolved oxygen (DO), temperature, specific conductance, and pH were also collected using a calibrated YSI 556 Multi-Probe System (YSI Environmental) on each sampling date, and compared to the appropriate guidelines.

Automated turbidity monitoring

An automated monitoring station (sonde) at the most downstream location (E213692) in Whistler Creek has been collecting DO, temperature, specific conductance, pH, turbidity and water level data at 15 min intervals since September 2007. This station is designed to capture both baseline and high flow (rain event/snowmelt) data, and was used in this study to determine if fish were being exposed to excessive turbidity during the month of October 2007. A total of 3262 data points were used from analysis from September 27 to October 31, with five outliers removed using a trimming tool in Aquarius 2.4 software (Aquatic Informatics Inc., 2008).

Newcombe (2003) proposed a method to assess potential 'severity of ill effects' (SEV) to clear water fishes using both magnitude and duration of turbidity events, as impacts may be felt both at higher magnitudes over shorter durations, or at lower magnitudes over longer durations. This model, which provides threshold turbidity levels, is useful as a tool to determine the onset of ill effects caused by excessive turbidity to clear water fishes, as well as to determine the rate at which serious ill effects are likely to escalate (Newcombe, 2003). SEV scores can be calculated and used to determine whether water conditions are *ideal* ($0 \leq SEV < 0.5$), *slightly impaired* ($0.5 \leq SEV < 3.5$), *significantly impaired* ($3.5 \leq SEV < 8.5$), or *severely impaired* ($SEV \geq 8.5$) for fish. An SEV event score of 0 has no effect while an event of 14 would lead to 100% mortality.

Boyd Creek 	**Upstream Location** (E269403, upstream of Boyd Creek) May 13, 2008
	**Midstream Location** (E268885, upstream of developed Creekside area) Oct 10/07 (turbidity of 57.4 NTU)
	**Downstream and Automated Sampler Location** (E213692, at the mouth near Nita Lake) Oct 10/07 (turbidity of 78.1 NTU)

Photo Series 3.3: Whistler Creek sampling sites, showing upstream, midstream, and downstream locations

A magnitude-duration matrix table adapted from Newcombe (2003), including the appropriate equations for calculating SEV scores, is shown in Master Appendix B. Research has shown that physiological and behavioural effects can occur in salmonids at turbidity levels starting from 10-30 NTU (see Master Appendix C, Bash *et al*., 2001). For the purposes of this study, a turbidity threshold of 16 NTU was chosen to define the start and end of turbidity events, as it is fairly conservative within this range of effects. It is also a compromise between Newcombe's matrix table and the B.C. Water Quality Guidelines for turbidity, for the protection of aquatic life (see Master Appendix A). Newcombe's table was initially used to estimate turbidity levels that could lead to impacts for fish, at a duration that could reasonably mimic precipitation events and resulting periods of high runoff in Whistler area creeks that tend to respond quickly to rain events. Thus, at a duration of two days, a sustained level of 7 NTU would have to occur for slightly impaired conditions to begin to occur for fish, i.e. SEV=1 (see Master Appendix B).

While this may be an appropriate threshold to use from a fish health perspective, it is unlikely that 'natural' background turbidity levels are 0 NTU during periods of high flow from steeper gradient streams in the Whistler area, and particularly where previous land use practices, such as logging, have altered the landscape.

The B.C. turbidity guideline during turbid flow periods states that 'induced turbidity should not exceed background levels by more than 8 NTU at any time when background turbidity levels are moderate, i.e. 8-80 NTU (see Master Appendix A). Thus, in the absence of concurrent background turbidity data due to limited resources, it can reasonably be assumed that a background turbidity level of 8 NTU could occur in Whistler Creek during turbid flow periods. Taking this guideline into consideration, this would allow for downstream levels to reach 16 NTU before exceeding the guideline (an increase of 8 NTU over background). Averages and durations were then calculated for each whole turbidity event, starting and ending at 16 NTU, and lasting for at least one hour (Newcombe's first time interval), which were then used to calculate an SEV score. It should be stated that this is an interim approach to characterize the impacts of turbidity to clear water fishes, which can be refined at a later date if concurrent background turbidity data can be collected. It is still considered to be a useful tool to describe the overall condition of the water to fish, whether upstream or downstream of impacts.

Turbidity events were further organized into sub-events (as described in Fleming *et al*. 2005) using three data ranges (16-150, 151-400 and >400 NTU) that followed the general turbidity thresholds in Newcombe's Table. Averages and durations were calculated for each sub-event, which were used to calculate a sub-event SEV score. The sub-event with the highest SEV score was then used as the 'new' turbidity event for descriptive purposes (Fleming *et al*. 2005). The sub-event SEV scores were compared to whole event SEV scores to determine if scores differed greatly. SEV values differed for only four events where the 150 NTU threshold was exceeded, although the values did not differ significantly and more importantly did not change the classification of the event (see Table 3.3). Thus, it was decided that the whole turbidity event could reasonably be used to characterize potential harm to fish from chronic and excessive turbidity, although sub-event SEVs were used for graphical purposes to show the variable nature of turbidity events.

Secchi depth measurements in Nita Lake
As part of a lake water quality monitoring program in Whistler in 2007, the Secchi depth, which measures water clarity, was recorded in both Alpha and Nita Lakes on July 18, September 4, and October 9, 2007. The Secchi depth was taken by first lowering the Secchi disk over the shaded side of the canoe, in the deepest part of the lake (see Photo Series 3.2) until the black and white pattern was no longer visible. The depth of this distance was recorded and the disk was pulled up again until the black and white pattern reappeared, at which time the depth was again recorded. The Secchi depth is the average of these two measurements in metres.

3.3 Results & Discussion

3.3.1 Summer grab sampling – August 2007

Results from grab sampling at the most downstream Whistler Creek site (E213692) in August 2007, during low flow conditions, indicated that parameters met B.C. Approved Water Quality Guidelines (AWQGs) for the protection of aquatic life (see Appendix 3.1). It should be noted, however, that the laboratory reportable detection limits (RDLs) for several biologically important metals (i.e. cadmium, chromium, copper, lead, selenium and silver) were higher than current guidelines, so it is not known whether these metals met guidelines protective of aquatic life. RDLs for metals improved in mid October 2007, allowing for better comparison to guidelines. Mean total suspended solids (TSS) and turbidity levels were low, or 4.6 mg/L and 0.8 NTU, respectively (n=5, Appendix 3.1).

3.3.2 Fall grab sampling – October 2007

It should be noted that the Creekside site (E268885) was originally chosen as the upstream reference site, but another reference site, upstream of the Boyd Cr confluence (E269403), was added on October 17, 2007 when high turbidity and suspended sediments were observed at the Creekside site on both October 2 and 9. The Creekside site was subsequently treated as the midstream site. It was not initially clear what was causing the turbidity, although heavy machinery could be heard upstream in the Boyd Creek watershed area in October 2007. It has also been noted in Section 3.1 that construction activities occurred in the upper Boyd Creek watershed in 2006 and 2007. **Exceedances in total copper, total iron, TSS, and turbidity** occurred to varying degrees and on at least one occasion at each Whistler Creek site, which will be discussed in the following sections.

i) Total copper

At the upstream site (E269403), maximum total copper guidelines for the protection of aquatic life, which are hardness dependent, were met on both sampling dates, October 17 and 22. At the midstream site (E268885), however, **maximum copper guidelines** (hardness adjusted to 4.6-6 µg/L) **were exceeded on all rain event dates** (Oct 2, 10 and 22), with concentrations of 6, 8 and 19.8 µg/L, respectively (Figure 3.2 and Appendix 3.2). **At the downstream site (E213692), both mean and maximum copper guidelines were also exceeded**. Maximum copper guidelines (hardness adjusted to 4.8-5.6 µg/L) were exceeded on the first two rain event dates, October 2 and 10, with concentrations of 14 and 8 µg/L, respectively. The mean total copper guideline of 2 µg/L was also exceeded at the downstream site, with a mean of 5.3 µg/L (n=5). The toxicological effects of Cu on aquatic life are described in Master Appendix D. While aquatic life may have been exposed to sublethal concentrations of Cu in the creek at times in October 2007, the impacts from Cu alone were likely short-term.

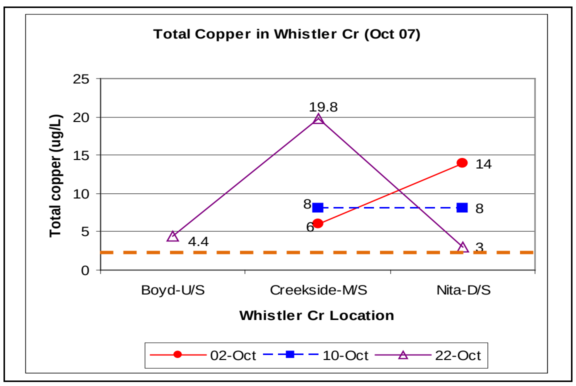


Figure 3.2. Total copper (µg/L) at upstream (U/S), midstream (M/S), and downstream (D/S) Whistler Creek sites during three rain events in October 2007 (orange-dashed mean Cu guideline shown)

ii) Total iron

At the upstream site (E269403), the maximum guideline of 1000 µg/L (1 mg/L) for **total iron** was exceeded on October 22, with a concentration of 1470 µg/L. At the midstream site (E268885), this iron guideline was exceeded on two rain event dates, October 10 and 22, with concentrations of 1670 and 6520 µg/L, respectively (Figure 3.3 and Appendix 3.2). At the downstream site (E213692), the iron guideline was exceeded on two rain event dates, October 2 and 10, with concentrations of 2270 and 1650 µg/L, respectively, and approached exceedance on October 22 with a concentration of 914 µg/L. It should be noted that at the midstream site, dissolved iron concentrations were relatively consistent between rain events and non-storm events (35-48 µg/L, n=4), while total iron was significantly elevated during rain events (808-6520 µg/L, n=3) (Figure 3.3, note scale differences). This indicates that total iron was likely associated with sediments, which were also elevated. This was also observed at the downstream site, where dissolved iron concentrations were consistent between rain events and non-events (55-73 µg/L, n=5), while total iron was significantly elevated during rain events (914-2270 µg/L, n=3). The toxicological effects of Fe on aquatic life are described in Master Appendix D. While aquatic life may have been exposed to elevated Fe levels in the creek at times in October 2007, the impacts from Fe alone were likely short-term and minimal.

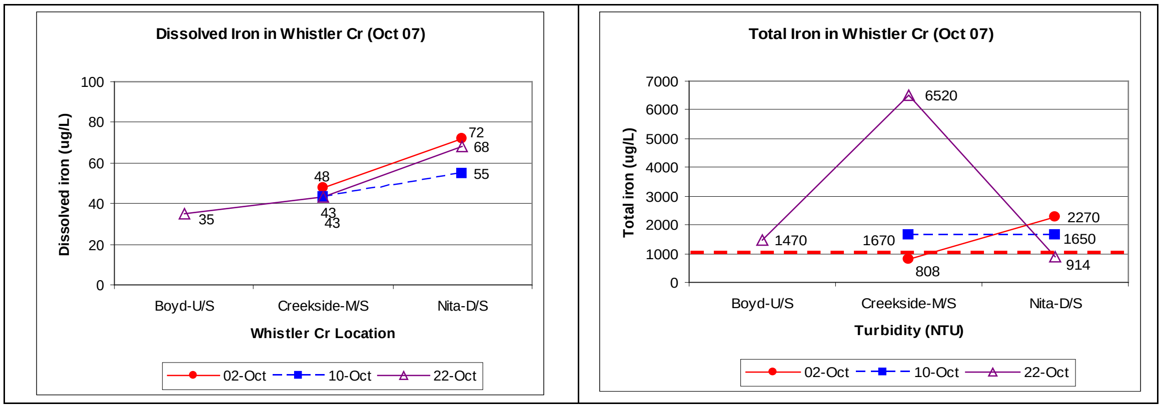


Figure 3.3. Dissolved and total iron (µg/L, note differences in scale between graphs and red-dashed maximum guideline line) at upstream (U/S), midstream (M/S), and downstream (D/S) Whistler Creek sites during three rain events in October 2007

iii) Suspended solids and turbidity

During the non-storm events, low levels of **total suspended solids (TSS) and turbidity** were found at all three sites (Table 3.1), which met B.C. AWQGs for clear flow periods. Several significant precipitation events occurred in October, including on October 2 (18.8 mm), October 7 (23.5 mm), October 9-10 (26.3 mm), and October 21-22 (19.1 mm), which coincided with sampling events. High levels of TSS and turbidity were recorded at the mid- and downstream sites (see Figure 3.4 and Table 3.1). TSS and turbidity were the highest on both October 2 and 10 at the downstream Whistler Creek site compared to the midstream site, which may indicate cumulative impacts from urban development in the watershed. The high turbidity and sediment loading that was observed in Whistler Creek on October 2 and 10 also coincided with a significant sediment plume observed in Nita Lake at the creek outlet following the first heavy rains of October 2007. This was noted as an ongoing condition during field work in October, which led to discolouration throughout Nita Lake, likely due to increased turbidity from Whistler Creek (see field note observations in Appendix 3.3).

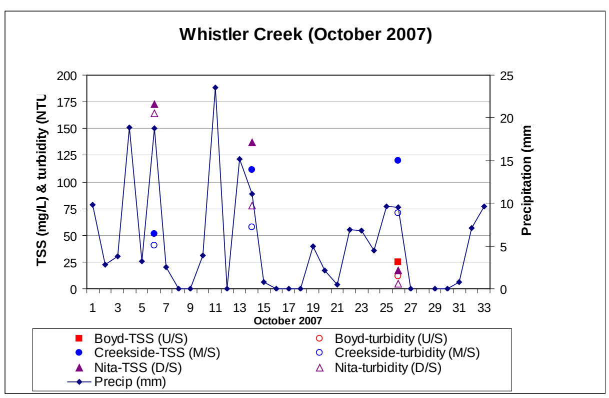


Figure 3.4. Total suspended solids (TSS, mg/L) and turbidity (NTU) at upstream (U/S), midstream (M/S), and downstream (D/S) Whistler Creek sites, plotted with precipitation (mm) at the Blackcomb Mountain base station (659m, Environment Canada) from September 27 (Day 1) to October 29, 2007 (Day 33).

TSS and turbidity concentrations (25 mg/L and 11.5 NTU, respectively) at the upstream site were used as background levels to which the midstream and downstream levels could be compared to on October 22. On October 22, the highest TSS and turbidity levels were found at the midstream location (120 mg/L and 70.5 NTU, respectively), which were 5 and 6 times higher, respectively, than background levels at the upstream site (Table 3.1 and Figure 3.5). Thus, **TSS and turbidity levels at the midstream site exceeded B.C. AWQGs on October 22** for the protection of aquatic life during turbid flow periods (see also Master Appendix A), which states:

> **TSS** – induced suspended sediment (SS) concentrations should not exceed background SS levels by more than 25 mg/L at any time when background is 25-250 mg/L;
> **Turbidity** - induced turbidity should not exceed background turbidity levels by more than 8 NTU at any time when background is 8-80 NTU.

Table 3.1. Total suspended solids (TSS) and turbidity results during storm (Oct 2, 10, 22) and non-storm (Oct 17, Nov 1) events for Whistler Creek sites in 2007, showing B.C. Water Quality Guideline (WQG) comparisons with background levels on October 22.

Storm Event Sampling - Whistler Creek						
	Event 1	**Event 2**	**Event 3**	**BC WQG (Oct 22)**		
Whistler Cr US Boyd Cr (E269403) - Upstream					**Non-storm**	
	Oct 2/07	Oct 10/07	Oct 22/07	Background	Oct 17/07	
TSS (mg/L)	n/a	n/a	25	**25**	<4	
Turbidity (NTU)	n/a	n/a	11.5	**11.5**	2.3	
Whistler Cr US Creekside (E268885) - Midstream					**Non-storm**	
	Oct 2/07	Oct 10/07	Oct 22/07	WQG	Oct 17/07	
TSS (mg/L)	51	111	120	**50**	<4	
Turbidity (NTU)	40.1	57.4	70.5	**19.5**	2.3	
Whistler Cr at Nita Lake (E213692) - Downstream					**Non-storm events**	
	Oct 2/07	Oct 10/07	Oct 22/07	WQG	Oct 17/07	Nov 1/07
TSS (mg/L)	173	137	17	**50**	<4	<4
Turbidity (NTU)	164	78.1	5	**19.5**	1.8	0.7

Highlighted cells show guideline exceedences

Thus, on October 22, TSS and turbidity should not have been higher than 50 mg/L and 19.5 NTU, respectively, at downstream sites (Table 3.1 and Figure 3.5). While this condition was met at the furthest downstream site, it was not met at the midstream site. Downstream of the midstream site, Whistler Creek takes a sharp S-turn before crossing Hwy 99, from a northwest to west direction, which may allow for sediment deposition during lower flow regimes, such as those towards the end of October. This may explain why elevated turbidity was not observed at the downstream site on October 22. A majority (97.1 mm or 64%) of the month's precipitation (150.7 mm) fell in early October, from September 30 to October 10, which accounted for higher flows and thus higher sediment and turbidity levels at the downstream site compared to the midstream site. These are typically referred to as 'first flush' events, which occur following the first significant rainfalls in the fall rainy season in the Pacific Northwest, and which also generally contain the highest contaminant concentrations.

TSS and turbidity guidelines were exceeded at the midstream site possibly due to activities occurring in the Boyd Creek watershed in 2006 and 2007, as well as from maintenance practices of the summer service road by the Whistler Blackcomb Ski Resort. Cascade Environmental Resource Group Ltd. (CERG), the Environmental Monitor for this venue during 2006 and 2007, noted that i) much of the construction activity was occurring near Boyd Creek, and not in the Whistler Creek watershed above the

Boyd Creek confluence, and ii) that service road maintenance practices may be the largest contributor to sediment loading in Whistler Creek during rain events (J. Turner, CERG, personal communication, Oct. 17/07).

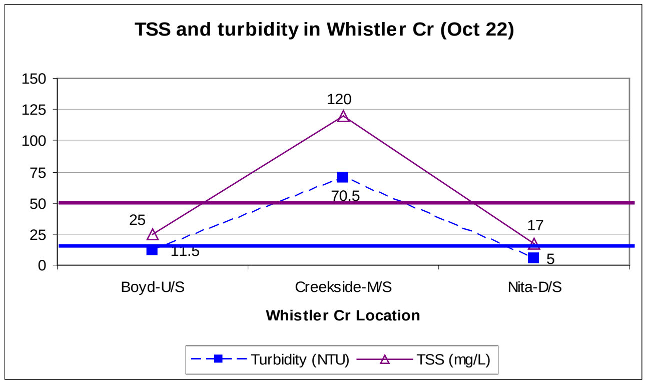


Figure 3.5. Total suspended solids (TSS) and turbidity (NTU) at upstream (U/S), midstream (M/S), and downstream (D/S) Whistler Creek sites on October 22, 2007, showing B.C. AWQG induced allowances over background (Boyd-U/S)

Construction activities related to the 2010 Creekside venue that may have contributed to significant turbidity and sediment loading in Whistler Creek included re-alignment of portions of Boyd Creek that occurred in both 2006 and 2007. Improper installation of snow making pipes in early June 2007 was also cited in a CERG Incident Report as having led to a significant turbidity event in Crystal and Boyd Creeks, both tributaries to Whistler Creek (see CERG Memorandum dated June 11, 2007 Re: Incident Report – June 4, 2007). In this instance, the contractor (Whistler Blackcomb) and subcontractor, manipulated drainage ditches to facilitate drainage of the area directly into Crystal Creek, a small tributary to Whistler Creek. Turbidity levels were recorded at 1000+ NTU in Crystal Creek and 428 NTU in Boyd Creek on June 5, 2007 (Turner, 2007). Photographs in the Incident Report also show significant soil disturbance on June 4, 2007, which may not have been adequately re-vegetated as noted in previous CERG Memoranda. Such activities, in upper reaches of the Whistler Creek watershed, are of concern in terms of causing turbidity and sedimentation impacts to downstream fish-bearing reaches and Nita Lake during significant rain events and snowmelt periods.

3.3.3 Automated turbidity monitoring

Automated water quality data, including turbidity, DO, pH, specific conductance, and temperature, were collected every 15 min at the most downstream Whistler Creek site (E213692) during the month of October 2007. The 'severity-of-ill-effects' (SEV) scale, water condition and effects of excessive turbidity on clear water fishes proposed by Newcombe (2003) are shown in Table 3.2 (see also Master Appendix B). The SEV scores for turbidity sub-events and whole events in Whistler Creek, which exceeded 16 NTU and 1h in duration, are shown in Table 3.3. A total of 26 turbidity events were recorded, where three were classified as moderate, 17 were minor, and 6 were nil, or ideal for fish. A minor rating indicates slightly impaired conditions, where feeding and other behaviours begin to change; while a moderate rating indicates significantly impaired conditions where fish growth rate and habitat size can be reduced.

Turbidity reached very high levels (>400 NTU) four times during three significant precipitation events on October 2, 7 and 9-10. On October 2 and 7, maxima of 869 NTU were reached; while between October 9-10, two maxima of 562 NTU (Oct 9) and 747 NTU (Oct 10) were reached. These events were also significant in that along with being high in magnitude at times, they lasted for relatively long periods of time, i.e. 14.25 h (Oct 2), 11.25 h (Oct 7) and 31.25 h (Oct 9-10) hours (Figure 3.6). The SEV scores (4.9, 6.0, and 6.3 on October 2, 7, and 9-10, respectively) for these three events indicated that they were 'moderate' (Table 3.3). The October 22 event, which was classified as 'minor' (SEV=2.4), is also shown in Figure 3.6 for comparison purposes as it was sampled.

Table 3.2: Severity-of-ill-effect (SEV) scale, condition, and potential effects of turbidity on clear water fishes (Newcombe, 2003)

SEV scale	Water condition	Effect on clear water fish
0 ≤ nil < 0.5	Ideal	Best for adult fishes that must live in a clear water environment most of the time
0.5 ≤ minor < 3.5	Slightly impaired	Feeding and other behaviours begin to change: severity of effect increases with duration
3.5 ≤ moderate < 8.5	Significantly impaired	Marked increase in water cloudiness could reduce fish growth rate, habitat size, or both
8.5 ≤ severe < 14.5	Severely impaired	Profound increases in water cloudiness could cause poor 'condition' or habitat alienation

The 'moderate' turbidity events on October 2, 7, and 9-10 suggest that conditions were significantly impaired for fish, where there would be a 'marked increase in water cloudiness that could reduce fish growth rate, habitat size, or both' (see Table 3.2). The B.C. *Environmental Management Act* (*EMA*, Master Appendix E) states that pollution means the 'presence of substances or contaminants that substantially alter or impair the usefulness of the environment'. Thus, **these three events, in particular, can be defined as having caused pollution under *EMA*.** Suspended solids could also be defined as a 'deleterious' substance under the Federal Fisheries Act, 'that if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water' (see Master Appendix F). In Section 36(3) of the Act, it further states that 'no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance may enter any such water'.

Table 3.3: Severity-of-ill-effect (SEV) scores for turbidity events in Whistler Creek in October 2007, including average turbidity (NTU) and duration (h) of whole and sub-events (see methods). Events are colour-coded green (nil, or ideal), yellow (minor, or slightly impaired), and orange (moderate, or significantly impaired) to indicate potential impairment of each turbidity event on clear water fishes (Newcombe, 2003).

		Whole Turbidity Event			Turbidity Sub-event			
Event	**Start Date**	**Average Turbidity (NTU)**	**Duration (h)**	**SEV**	**Average Turbidity (NTU)**	**Duration (h)**	**Highest SEV**	**Event Classification**
1	27-Sep	37.12	6	2.16	same			minor
2	30-Sep	18.07	3.25	0.10	same			nil
3	1-Oct	24.69	3.25	0.75	same			minor
4	1-Oct	46.47	5.5	2.54	same			minor
5	2-Oct	96.20	14.25	4.93	568.5	0.5	5.53	moderate
6	3-Oct	34.11	2.25	1.08	same			minor
7	4-Oct	40.54	1.5	1.06	same			minor
8	4-Oct	50.45	2.25	1.89	same			minor
9	5-Oct	36.73	1.25	0.69	same			minor
10	6-Oct	24.23	1.75	0.14	same			nil
11	7-Oct	43.14	5	2.30	same			minor
12	7-Oct	180.82	11.25	6.02	617.48	0.75	6.08	moderate
13	9-Oct	131.74	31.25	6.30	597.18	0.75	6.01	moderate
14	11-Oct	24.10	1.75	0.13	same			nil
15	13-Oct	45.98	2	1.59	same			minor
16	15-Oct	77.82	4.5	3.43	54.14	2.75	2.37	minor
17	16-Oct	35.88	2.5	1.28	same			minor
18	16-Oct	52.33	2.75	2.15	same			minor
19	18-Oct	32.57	3.5	1.39	same			minor
20	21-Oct	22.30	1.75	0.00	same			nil
21	22-Oct	44.85	0.75	0.64	same			minor
22	22-Oct	32.98	11.5	2.51	same			minor
23	23-Oct	30.32	6.5	1.81	same			minor
24	24-Oct	54.84	4.5	2.70	same			minor
25	28-Oct	22.23	1.25	0.00	same			nil
26	29-Oct	18.89	2	0.00	same			nil

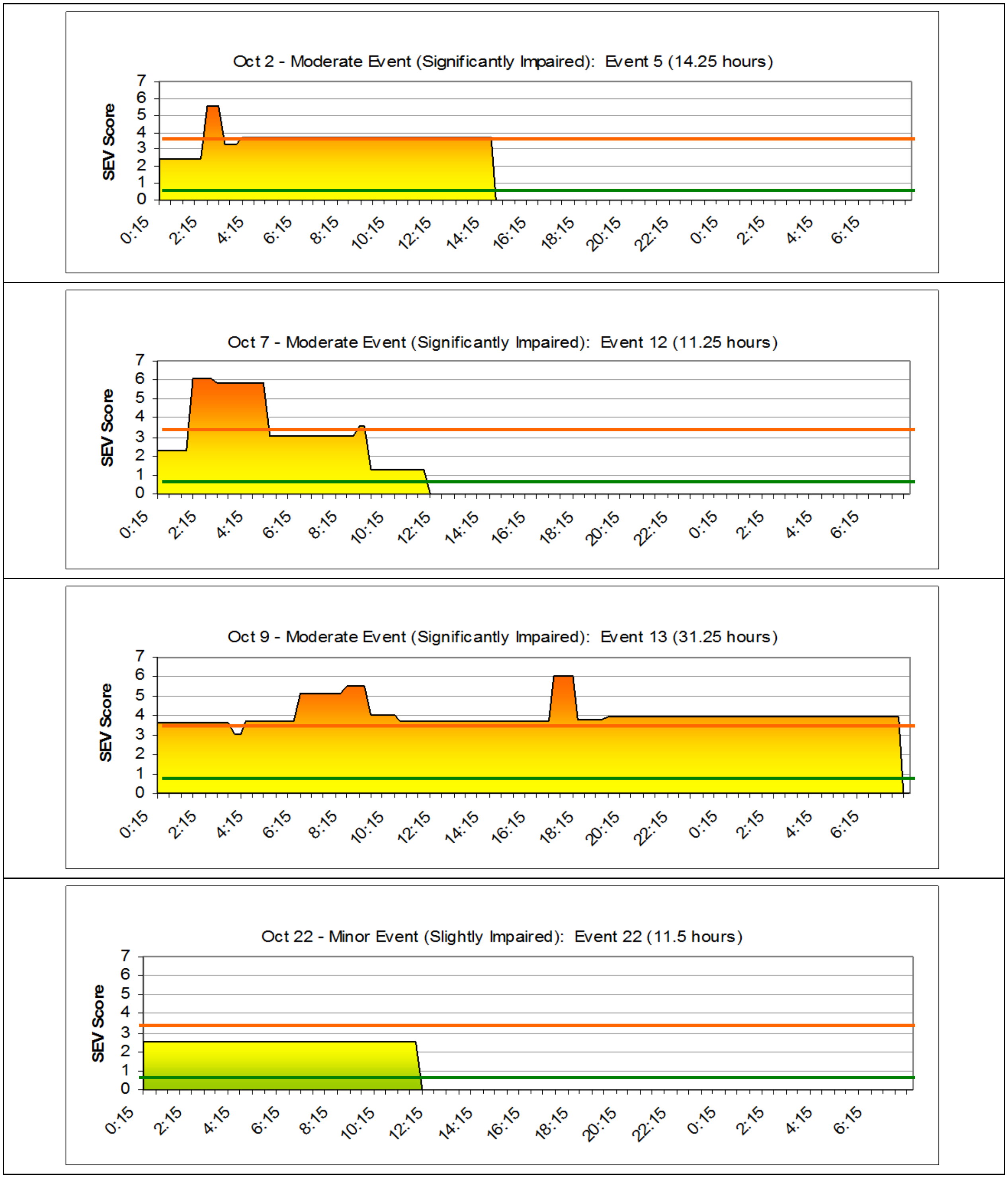


Figure 3.6. Moderate (Oct 2, 14.25h; Oct 7, 11.25h; and Oct 9, 31.25h) and minor (Oct 22, 11.5h) turbidity events at the downstream Whistler Creek site (E213692) in 2007, showing duration of each sub-event by SEV score (see methods). Moderate events (3.5≤SEV<8.5) indicate significantly impaired, and minor events (0.5≤SEV< 3.5) slightly impaired, conditions to clear water fishes from excessive turbidity.

It is also important to consider the **cumulative impacts of excessive turbidity events** during the whole month of October. Cumulative effects of sediment and turbidity on fish are difficult to capture, but factors that mediate their effect include duration of exposure; frequency of exposure; toxicity; temperature; life stage of fish; angularity, size and type of particle; severity/magnitude of pulse; natural background turbidity (e.g. watershed position and legacy, or historical land use practices); other stressors and general condition of biota; and availability of, and access to, refugia (Bash *et al*., 2001). Figure 3.7 shows the 26 turbidity events >16 NTU, and longer than 1h in duration, that occurred starting on September 27 and ending on October 29. It is also important to note that the combination of the three largest turbidity events, along with several minor events, occurred within the space of approximately one week in October 2007 (Oct 2-10). This could have had prolonged effects on fish in Whistler Creek, in terms of reduced fish growth rate and habitat size, or both.

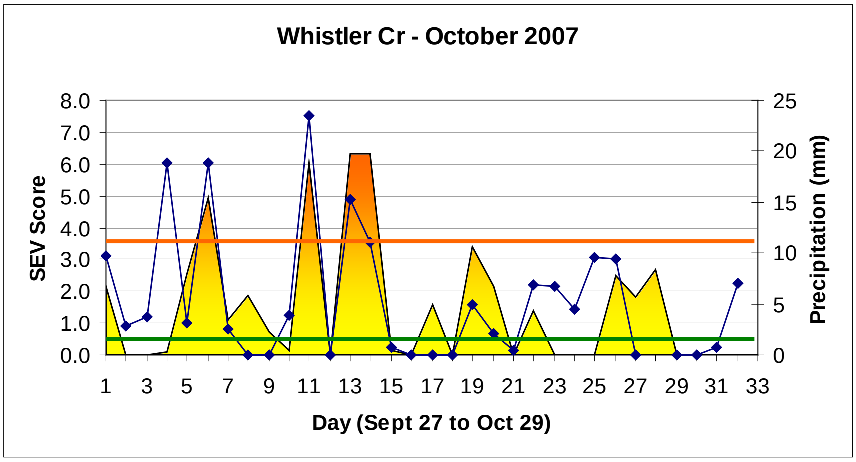


Figure 3.7. Turbidity events at the downstream site in Whistler Creek (E213692) in October 2007, showing 'severity-of-ill-effect' (SEV) score for the whole event (left axis) and precipitation (mm) on that day (right axis). Turbidity events were defined as >16 NTU and >1 hour in duration, and are shown in order, from September 27 (Day 1) to October 29, 2007 (Day 33). SEV scale: 0 ≤nil< 0.5; 0.5 ≤minor< 3.5; 3.5 ≤moderate< 8.5; 8.5≤ severe< 14.5 (Newcombe, 2003).

3.3.4 Nita Lake Secchi depth in October 2007

Secchi depths are used as a measure of visual clarity in lakes, which is influenced primarily by algal growth (productivity), but also by sediment-derived turbidity; lower readings indicate turbid water and higher readings indicate clear water. A lake's productivity, measured in combination with Secchi depth, nutrient levels, and chlorophyll *a* (green photosynthetic pigment of algae), determines its 'trophic status'. Lakes of low productivity are referred to as **oligotrophic** lakes as they are typically clear, with low nutrient levels (total phosphorus (TP) 4-10 µg/L), sparse plant life, and low fish production. Lakes with intermediate productivity are termed **mesotrophic** (TP 10-20 µg/L); while highly productive lakes are known as **eutrophic** (TP 35-100 µg/L) and tend to have abundant plant life, including algae. Elevated algal levels in lakes are a concern due to depletion of oxygen levels for aquatic organisms and the general lack of recreational appeal.

Pollution tends to reduce water clarity, through increased turbidity, often in watersheds where development and poor land use practices cause increased erosion, which in turn can cause increases in suspended solids during periods of high runoff. Increased turbidity also limits light penetration in lakes which can reduce photosynthesis, or primary productivity, which in turn can trigger a cascade of negative impacts from one trophic level to the next involving phytoplankton, zooplankton, and fish (Newcombe, 2003; Henley *et al*., 2000). Photosynthesis is also important for the production of oxygen that is necessary for aquatic life.

Limited water quality sampling of Nita Lake by MoE in 2007 determined that it may currently be an oligotrophic lake, with low TP (<2-10 µg/L), relatively high clarity (Secchi depth 5.4m, Sept 4), and low chlorophyll *a* levels (0.7-0.8 µg/L) (unpublished data). What is of concern is that Secchi depths were similar in both Nita and Alpha Lake on all dates except October 9, where the Secchi depth was measured at 1.6 m in Nita Lake, less than half that of Alpha Lake (3.7 m) (Table 3.4). The main difference between the two lakes is that Whistler Creek, which flows into the smaller Nita Lake, contributes significant flows to the lake, particularly during periods of high runoff. As noted in the previous section, several excessive turbidity events occurred in Whistler Creek during the first few weeks of October 2007. Field observations during the month also indicated that a large sediment plume was visible, extending from the creek's mouth on October 2 and 10, and that continued turbidity was visible in the whole lake on October 17 (see field note observations in Appendix 3.3).

Table 3.4. Secchi depths (m) and differences, between Nita and Alpha Lakes in 2007

Date	Nita Lake	Alpha Lake	Difference (m)
July 18	2.8	3.0	-0.2
Sept 4	5.4	5.0	+0.4
Oct 9	**1.6**	**3.7**	**-2.1**

It should also be noted that the Secchi depth was taken at the opposite end of the lake from the mouth of Whistler Creek, thus indicating the pervasive extent of turbidity following the first large rainfall on October 2. It is not believed that chlorophyll *a* would have contributed significantly to a decreased Secchi depth, as the lake is known to be nutrient-poor (oligotrophic) and the fall time period is not typically a time of high primary productivity, due to lower water temperatures and shorter daylight periods.

3.4 Conclusions

Results from several sampling methods in October 2007 provide 'lines of evidence' that **Whistler Creek was receiving non-point source pollution during periods of high runoff**. This water quality assessment shows that pollution, as defined by the B.C. *Environmental Management Act*, was **primarily caused by high TSS and turbidity** levels in the creek during the first two weeks of October 2007. Elevated TSS and turbidity are also deleterious substances under the Federal *Fisheries Act* during this period**.** Excessive turbidity during this time likely caused significantly impaired conditions for clear water fishes during three events (Oct 2, Oct 7, and Oct 9-10), according to Newcombe (2003). Differences in TSS and turbidity were observed along the Whistler Creek gradient on October 22, 2007. TSS and turbidity were 5 and 6 times higher, respectively, at the midstream (Creekside) site compared to the newer upstream reference site (upstream of Boyd Creek) on October 22, which exceeded the BC Water Quality Guidelines for TSS and turbidity (for the protection of aquatic life) during turbid flow periods. **High TSS levels also likely led to elevated sediment-associated iron and copper levels in lower creek reaches at times in October 2007, which may have impacted on aquatic organisms for short periods.**

This study was not able to adequately determine the state of stormwater quality due to land use practices in the upper Whistler Creek watershed that were contributing significant amounts of sediments and associated metals to the creek. While it is not clear how much of the current human activity contributed to elevated TSS and turbidity levels in Whistler Creek in October 2007, ski hill maintenance operations may be contributing significant amounts of sediment to Whistler Creek and Nita Lake during periods of high runoff. This may have had significant short-term as well as long-term impacts on aquatic life in both waterbodies, which in turn can affect overall health and recreational opportunities in Nita Lake. **Short-term impacts may include decreased fish growth and survival, as well as reduced spawning habitat and invertebrate food resources.** Long-term impacts may include declining fish populations and reduced recreational fishing opportunities in Nita Lake.

Operations, including yearly summer service road maintenance on Whistler Mountain and recent Creekside area ski run construction activities near Boyd Creek, may have been contributing factors to the observed pollution in October 2007. These operations and activities should be examined carefully so that actions can be taken to prevent future pollution events into Whistler Creek and Nita Lake, particularly prior to the fall rainy season in 2008. It also appears that appropriate sediment control measures, including re-seeding of disturbed slopes related to VANOC site construction did not occur in a timely manner, i.e. prior to September 1 in both 2006 and 2007. This may have been a significant contributor to the observed turbidity and sediment levels in Whistler Creek and Nita Lake. There is an opportunity to learn lessons from inappropriate construction practices that may be leading to downstream impacts that should be passed on to local contractors and developers. While no regulatory actions were taken as a result of these findings, actions may need to be taken in the future if conditions do not improve.

Climate change is another important factor to consider, as precipitation and temperature patterns will change, which will influence stormwater flows in the fall and winter in the future. A warming climate is predicted to 'promote the shift of streams from *hybrid* (rain/snowmelt) to *pluvial* (rain-dominated) systems', as well as having increased potential for winter floods in *pluvial* systems (Rodenhuis *et al.*, 2007). This has implications for Whistler Creek, which is currently a *hybrid* flow system, but could experience higher proportions of rainfall compared to snowfall in the October-December rainy season. Higher flows during this time period will increase stormwater runoff and thus potential impacts to aquatic life from poor water quality. Thus, it will become even more important to ensure good stormwater quality, to prevent potential impacts to downstream creek reaches and lakes.

3.5 Recommendations

It is recommended that an evaluation of current **erosion and sediment control measures** on summer maintenance roads be conducted by Whistler Blackcomb on both Whistler and Blackcomb Mountains, as many creeks flow through the ski hill area and have the potential to convey sediments and associated metals to downstream fish-bearing stream reaches and lakes. Current construction practices should also be evaluated, so that future activities can include proper erosion and sediment controls. **Re-vegetation of disturbed ski slopes**, resulting from historical disturbance and VANOC's construction activities in 2006 and 2007 in the Creekside area, should also be immediately addressed and completed prior to September 1, 2008. If slopes were re-vegetated in 2007, they should be monitored for effective growth in 2008.

Follow-up stormwater quality monitoring should be conducted by Whistler Blackcomb and/or VANOC during the fall rainy period in 2008, to evaluate the effectiveness of measures taken to ameliorate the current concerns regarding elevated suspended sediments and turbidity during high runoff periods. An automated water sampler, maintained in partnership with RMOW, will also continue to monitor turbidity during low and high flow periods, such as snowmelt and high precipitation periods.

The Ministry would like to continue addressing water quality issues in a collaborative manner. Ministry staff could present these findings to the various parties, address any questions, and work with them to ensure that remedial measures are effective in addressing the identified issues. **It is therefore recommended that a meeting of key stakeholders be organized to form an action plan to improve current conditions in the Whistler Creek watershed, so that future impacts to the creek and Nita Lake can be prevented.**

Optimization of source controls should be implemented in the Creekside area, so that the impact of urban stormwater runoff on Whistler Creek and Nita Lake can be minimized. Examples of source control can include low-impact development (LID) and increased infiltration.

APPENDIX 3.1 – WATER QUALITY RESULTS: AUGUST 2007

WHISTLER CR AT NITA LAKE (E213692) - August 2007								BC Water Quality Guideline (Aquatic Life)		
Downstream										
	RDL	**02-Aug**	**09-Aug**	**13-Aug**	**22-Aug**	**29-Aug**	**30-d Mean**	30-day mean	max	Notes
Field Measurements										
Temperature (dec C)		9.7	8.99	8.45	9.97	10.3	**9.48**		10.0-18.0	rainbow optimum
pH		6.48	6.82	7.03	7.25	7.34	**6.98**		6.5-9.0	
Dissolved oxygen (DO, mg/L)		11.61	10.16	10.03	6.1	7.63	**9.11**	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		54	64	65	69	70	**64**			
Organics & Inorganics (mg/L)										
Total Organic Carbon (C)	0.5	<0.5	<0.5	<0.5	0.6	<0.5	**0.52**			
Total Hardness (CaCO3)	0.5	28.5	29.5	29.4	31.8	32	**30.2**			
Total Suspended Solids	4	7	<4	<4	<4	<4	**4.6**	see text	see text	
Turbidity (NTU)	0.1	0.5	1.4	0.8	0.7	0.7	**0.8**	see text	see text	
Conductivity (uS/cm)	1	60	65	67	69	73	**66.8**			
Dissolved Chloride (Cl)	0.5	<0.5	0.8	0.6	1	0.6	**0.8**	150	600	
Nutrients (mg/L)										
Total Nitrogen (N)	0.02	0.09	0.06	0.08	0.11	0.07	**0.08**			
Total Kjeldahl Nitrogen	0.02	0.05	0.03	0.03	0.07	0.04	**0.04**			
Total Organic Nitrogen (N)	0.02	0.05	0.03	0.03	0.07	0.04	**0.04**			
Nitrate (N)	0.002	0.038	0.03	0.045	0.042	0.034	**0.04**	40	200	
Nitrite (N)	0.002	<0.002	<0.002	<0.002	<0.002	<0.002	**<0.002**	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	**<0.005**	1.9-2.0	26.5-27.5	pH & T dependent
Total Phosphorus (P)	0.002	0.005	0.003	0.006	<0.002	0.036	**0.010**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.002	0.002	0.003	0.003	0.003	**0.003**			
Selected Metals (ug/L)										
Dissolved Aluminum (Al)	20	<20	<20	<20	<20	<20	**<20**	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	<2	<2	<2	**<2**		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	<5	<5	<5	**<5**		1.0 (Cr(VI))	CCME
Total Copper (Cu)	5	<5	<5	<5	<5	<5	**<5**	2	4.7-5.0	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	18	17	24	22	25	**21**	n/a	350	draft guideline
Total Iron (Fe)	5	139	121	68	57	71	**91**	n/a	1000	draft guideline
Total Lead (Pb)	30	<30	<30	<30	<30	<30	**<30**	4	18	H=30 mg/L
Total Manganese (Mn)	1	13	13	11	10	12	**12**	700	800	H=25 mg/L
Total Molybdenum (Mo)	5	<5	<5	<5	<5	<5	**<5**	1000	2000	
Total Selenium (Se)	30	<30	<30	<30	<30	<30	**<30**	2	n/a	
Total Silver (Ag)	10	<10	<10	<10	<10	<10	**<10**	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	<5	<5	<5	<5	<5	**<5**	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)										
E.coli	1	2	2	2	5	22	**4**	77	n/a	geomean, primary
Fecal coliforms	1	2	3	2	5	22	**4**	200	n/a	contact

RDL = Reportable Detection Limit

APPENDIX 3.2 – WATER QUALITY RESULTS: OCTOBER 2007

WHISTLER CR U/S OF BOYD CR (E269403) - Oct 2007 Reference				BC Water Quality Guideline (Aquatic Life)		
	RDL	Oct 17 Non-event	Oct 22 Event 3	30-day mean	max	Notes
Field Measurements						
Temperature (deg C)		2.78	2.82		10.0-18.0	rainbow optimum
pH		6.34	6		6.5-9.0	
Dissolved oxygen (DO, mg/L)		11.82	11.42	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		64	63			
Organics & Inorganics (mg/L)						
Total Oil and grease	1	n/a	2			
Total Organic Carbon	0.5	1.7	2.1			
Total Hardness (CaCO3)	0.5	28.3	27.9			
Total Suspended Solids	4	<4	25	see text	see text	
Turbidity (NTU)	0.1	2.3	11.5	see text	see text	
Conductivity (uS/cm)	1	63	60			
Dissolved Chloride (Cl)	0.5	<0.5	<0.5	150	600	
Nutrients (mg/L)						
Total Nitrogen (N)	0.02	0.1	0.11			
Total Kjeldahl Nitrogen (Calc)	0.02	0.06	0.05			
Total Organic Nitrogen (N)	0.02	0.06	0.05			
Nitrate (N)	0.002	0.048	0.046	40	200	
Nitrite (N)	0.002	<0.002	0.006	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005	2	27.5	pH & T dependent
Total Phosphorus (P)	0.002	0.008	0.055		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.004	0.01			
Selected Metals (ug/L)						
Dissolved Aluminum (Al)	1	25	44	50	100	pH ≥ 6.5
Total Cadmium (Cd)	0.01	<0.01	0.01		0.017	CCME (interim)
Total Chromium (Cr)	1	<1	<1		1.0 (Cr(VI))	CCME
Total Copper (Cu)	0.2	0.8	4.4	2	4.6	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	25	35	n/a	350	draft guideline
Total Iron (Fe)	5	99	1470	n/a	1000	draft guideline
Total Lead (Pb)	0.2	<0.2	0.4	4	18	H=30 mg/L
Total Manganese (Mn)	1	14	51	700	800	H=25 mg/L
Total Molybdenum (Mo)	1	<1	<1	1000	2000	
Total Selenium (Se)	0.1	0.1	0.1	2	n/a	
Total Silver (Ag)	0.02	<0.02	<0.02	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	<5	6	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)						
E. coli	1	<1	3	77	n/a	geomean, primary contact
Fecal coliforms	1	<1	18	200	n/a	

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines

Highlighted cells show exceedences of guidelines

WHISTLER CR AT CREEKSIDE (E268885) - October 2007							BC Water Quality Guideline (Aquatic Life)		
Midstream									
	RDL	Oct 2 Event 1	Oct 10 Event 2	RDL*	Oct 17 Non-event	Oct 22 Event 3	30-day mean	max	Notes
Field Measurements									
Temperature (deg C)		5.41	5.6		3.35	3.51		10.0-18.0	rainbow optimum
pH		5.93	5.93		5.74	6.39		6.5-9.0	
Dissolved oxygen (DO, mg/L)		13.21	n/a		11.79	11.12	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		71	55		74	75			
Organics & Inorganics (mg/L)									
Total Oil and grease	1	<1	<1		n/a	2			
Total Organic Carbon	0.5	3.3	4.4		1.6	3			
Total Hardness (CaCO3)	0.5	32.8	28		32.5	42.6			
Total Suspended Solids	4	51	111		<4	120	see text	see text	
Turbidity (NTU)	0.1	40.1	57.4		1.3	70.5	see text	see text	
Conductivity (uS/cm)	1	72	57		71	72			
Dissolved Chloride (Cl)	0.5	1	0.9		0.8	1.5	150	600	
Nutrients (mg/L)									
Total Nitrogen (N)	0.02	0.23[a]	0.6		0.11	0.13			
Total Kjeldahl Nitrogen (Calc)	0.02	0.16[a]	0.51		0.05	<0.02			
Total Organic Nitrogen (N)	0.02	0.16[a]	0.51		0.05	<0.02			
Nitrate (N)	0.002	0.066	0.071		0.065	0.096	40	200	
Nitrite (N)	0.002	0.006	0.014		<0.002	0.041	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005		<0.005	<0.005	1.9-2.0	26.5-27.5	pH & T dependent
Total Phosphorus (P)	0.002		0.079		0.005	0.231		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.01	0.013		0.004	0.041			
Selected Metals (ug/L)									
Dissolved Aluminum (Al)	20	30	60	1	24	60	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	0.01	<0.01	0.06		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	1	<1	2		1.0 (Cr(VI))	CCME
Total Copper (Cu)	5	6	8	0.2	0.8	19.8	2	4.6-6.0	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	48	43	5	35	43	n/a	350	draft guideline
Total Iron (Fe)	5	808	1670	5	127	6520	n/a	1000	draft guideline
Total Lead (Pb)	30	<30	<30	0.2	<0.2	2	4	18	H=30 mg/L
Total Manganese (Mn)	1	69	118	1	25	181	700	800	H=25 mg/L
Total Molybdenum (Mo)	5	<5	<5	1	<1	<1	1000	2000	
Total Selenium (Se)	30	<30	<30	0.1	0.1	0.2	2	n/a	
Total Silver (Ag)	10	<10	<10	0.02	<0.02	0.04	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	7	8	5	<5	21	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)									
E. coli	1	45	9		<1	18	77	n/a	geomean, primary contact
Fecal coliforms	1	45	13		<1	79	200	n/a	

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines

* RDL changed for metals due to lab method improvements

[a] Blank concentrations were 0.13 mg/L

Highlighted cells show exceedences of guidelines

WHISTLER CR AT NITA LAKE (E213692) - October 2007 Downstream									BC Water Quality Guideline (Aquatic Life)		
	RDL	Oct 2 Event 1	Oct 10 Event 2	RDL*	Oct 17 Non-event	Oct 22 Event 3	Nov 1 Non-event	30-d Mean	30-day mean	max	Notes
Field Measurements											
Temperature (deg C)		5.96	5.69		3.71	4.15	2.45	**4.39**		10.0-18.0	rainbow optimum
pH		6.76	n/a		5.7	5.64	7.47	**6.23**		6.5-9.0	
Dissolved oxygen (DO, mg/L)		10.33	n/a		10.75	11.04	12.7	**11.21**	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		83	64		81	82	78.4	**78**			
Organics & Inorganics (mg/L)											
Total Oil and grease	1	1[b]	<1			2					
Total Organic Carbon	0.5	5.4	5.6		1.6	2.1	1.3[c]	**3.7**			
Total Hardness (CaCO3)	0.5	38.8	29.8		34.1	33.8	35.7	**34.4**			
Total Suspended Solids	4	173	137		<4	17	<4	**67.0**	see text	see text	
Turbidity (NTU)	0.1	164	78.1		1.8	5	0.7	**49.9**	see text	see text	
Conductivity (uS/cm)	1	82	63		80	79	86	**78**			
Dissolved Chloride (Cl)	0.5	2.5	1.9		2.8	3.1	2.5	**2.6**	150	600	
Nutrients (mg/L)											
Total Nitrogen (N)	0.02	0.57[a]	0.48		0.17	0.12	0.15	**0.272**			
Total Kjeldahl Nitrogen (Calc)	0.02	0.48[a]	0.39		0.16	0.04	0.06	**0.2**			
Total Organic Nitrogen (N)	0.02	0.48[a]	0.39		0.16	0.04	0.06	**0.2**			
Nitrate (N)	0.002	0.072	0.071		0.018	0.07	0.086	**0.063**	40	200	
Nitrite (N)	0.002	0.017	0.019		<0.002	0.002	<0.002	**0.008**	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005		<0.005	<0.005	<0.005	**<0.005**	1.9-2.0	26.5-27.5	pH & T dependent
Total Phosphorus (P)	0.002		0.062		0.005	0.036	0.004	**0.027**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.027	0.015		0.004	0.006	0.005	**0.011**			
Selected Metals (ug/L)											
Dissolved Aluminum (Al)	20	50	80	1	23	33	16	**40.4**	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	0.01	<0.01	0.01	<0.01	**<2**		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	1	<1	<1	<1	**<5**		1.0 (Cr(VI))	CCME
Total Copper (Cu)	5	14	8	0.2	0.9	3	0.7	**5.32**	2	4.8-5.6	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	72	55	5	68	68	73	**67.2**	n/a	350	draft guideline
Total Iron (Fe)	5	2270	1650	5	137	914	139	**1022**	n/a	1000	draft guideline
Total Lead (Pb)	30	<30	<30	0.2	<0.2	0.2	<0.2	**<30**	4	18	H=30 mg/L
Total Manganese (Mn)	1	181	119	1	28	53	27	**81.6**	700	800	H=25 mg/L
Total Molybdenum (Mo)	5	<5	<5	1	<1	<1	<1	**<5**	1000	2000	
Total Selenium (Se)	30	<30	<30	0.1	<0.1	0.1	0.1	**<30**	2	n/a	
Total Silver (Ag)	10	<10	<10	0.02	<0.02	<0.02	<0.02	**<10**	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	12	9	5	<5	11	14	**10**	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)											
E. coli	1	70	17		1	12	<1	**7**	77	n/a	geomean, primary
Fecal coliforms	1	230	25		1	400	<1	**19**	200	n/a	contact

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines

* RDL changed for metals due to lab method improvements

[a] Blank concentrations were 0.13 mg/L

[b] Blank concentration was 1 mg/L

[c] Blank conentration was 1 mg/L

Highlighted cells show exceedences of guidelines

APPENDIX 3.3 – FIELD NOTE OBSERVATIONS: OCTOBER 2007

Observations from Field Notes – October 2007

Date	Location	Field Notes
Oct 2	Creekside (E268885) – M/S	- very turbid (brown) & fast flowing
	Nita (E213692) – D/S	- very turbid & moderate flow - large sediment plume can be seen entering Nita Lake from Whistler Creek (extends approx 25-30m out from mouth)
Oct 10	Creekside (E268885) – M/S	- turbid & fast flowing
	Nita (E213692) – D/S	- turbid & high flow - still large sediment plume into Nita Lake
Oct 17	Boyd (E269403) – U/S	- added this site as upstream reference site following site visit with Jonathan Turner (CERG) on Oct 17 - relatively clear & moderate flow
	Creekside (E268885) – M/S	- clear & moderate flow
	Nita (E213692) – D/S	- slight turbidity & moderate flow - Nita Lake still quite turbid overall (pale in colour), improved clarity of Whistler Cr not adding additional turbidity to lake
Oct 22	Boyd (E269403) – U/S	- slightly turbid & fast flowing (steep gradient)
	Creekside (E268885) – M/S	- quite turbid (brown) & fast flowing
	Nita (E213692) – D/S	- moderately turbid & fast flowing
Nov 1	Nita (E213692) – D/S	- clear (no turbidity) & moderate flow

4.0 CRABAPPLE CREEK WATER QUALITY DURING RAIN EVENTS IN OCTOBER 2007

4.1 Study Area

Crabapple Creek (Figure 4.1), also known as Archibald Creek, originates on Whistler Mountain (1,600m elevation) and displays a *hybrid* runoff regime, where higher flows occur during both the i) rainy season, from October to December (with rainfall becoming snowfall in November/December), and ii) snowmelt season from April to June (Rodenhuis *et al*., 2007). Low flows are typically experienced in July/August, once snowmelt at higher elevations has ceased. The creek drains an area of 4.14 km^2, 1.22 km^2 (29.6%) of which can be attributed to stormwater drainage area (Golder, 2007).

From its headwaters on Whistler Mountain, the creek flows through portions of the popular Whistler Bike Park area, which boasts more than 200 km of lift-serviced descending mountain bike trails and is open from mid-May to mid-October (see map in Appendix 4.1). The creek then flows through the Sunridge Plateau and Brio neighbourhoods upstream of Hwy 99, before running through the Whistler Golf Club (WGC) course and Blueberry Hill neighbourhood downstream of Hwy 99 (Figure 4.1). The creek finally enters the River of Golden Dreams (ROGD) near Lorimer Rd., which empties into Green Lake to the north, and is part of the headwaters for the Lillooet River to the southeast. ROGD supports popular secondary recreational activities (canoeing, kayaking) and kokanee and rainbow trout populations. The Crabapple Creek discharge near the confluence of the ROGD is estimated to be 1.05 m^3/s (Symko, 2000).

Crabapple Creek flows through three sedimentation ponds in the golf course. The first pond (Pond 1) the creek flows into upon entering the property is the main sediment-capturing pond (Figure 4.2). The creek then runs through the golf course and out along the northwest side of the property. Dredging of the ponds occurred in 1992, 1998 and 2007, with removal of 300-400 cubic yards of material each time, most of which has come from Pond 1 (S. Carmichael, Whistler Golf Course, personal communication, June 10, 2008).

Land use practices that have disturbed the upper Crabapple Creek headwaters in the past include extensive logging in the 1950s and 60s, followed by the development of the Whistler Mountain ski area (Symko, 2000). More recent changes to the creek's main stem include diversion of its channel to the west side of its floodplain in the WGC, to accommodate construction of the golf course (Symko, 2000). It was also noted that the new channel remains 'unnatural', with few pool/riffle steps and even fewer meanders, and that concern remains about reduced channel drainage capacity.

Concerns have also been expressed that the proximity and maintenance practices of both the bike park and the summer service road to the creek may be having significant impacts on the creek from sediment inputs during periods of high runoff. These concerns were outlined in a 2007 Upper Crabapple Creek Walk Survey Report (Rebellato and Young, 2007), in which freshly dug trenches in the bike park and ditching along the service road were cited as likely sources of sediment into the creek. Summer service road maintenance has also been cited as being potentially the largest contributor to sediment loading in affected creeks during rain events (J. Turner, CERG, personal communication, Oct. 17, 2007).

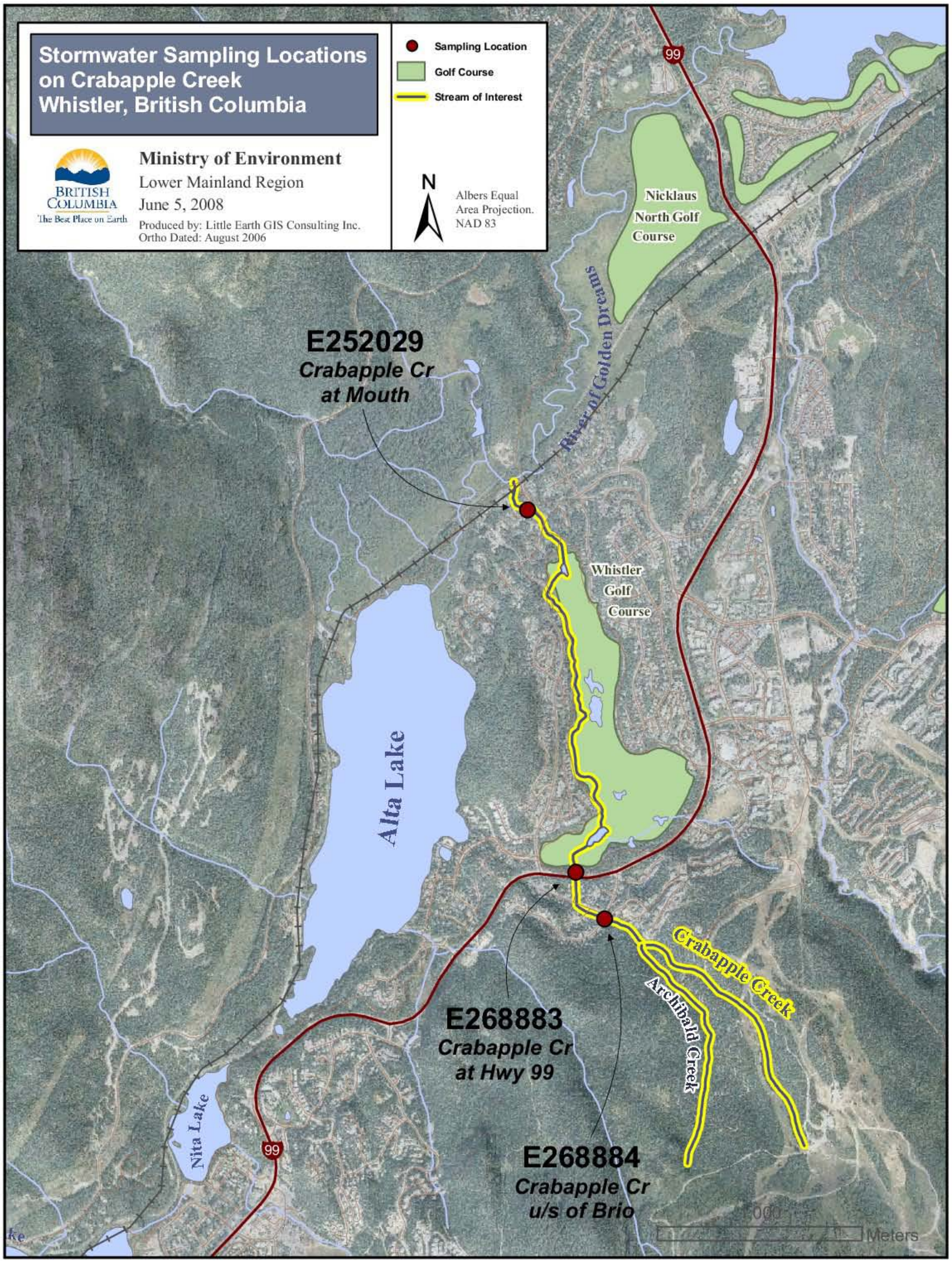


Figure 4.1. Sampling site locations in Crabapple Creek, Whistler, B.C.

More recently, in 2006 and 2007, the Vancouver Olympic Organizing Committee (VANOC) oversaw reconstruction of some ski runs on Whistler Mountain for the 2010 Winter Olympic Games. These construction efforts left areas of exposed soil that were not adequately re-vegetated prior to the fall rainy seasons in both years, which was noted by the on-site independent Environmental Monitor, Cascade Environmental Resource Group Ltd. (CERG). For instance, in the October 2006 Monitoring Memo, it was noted that '*earthworks continued into mid October, where late re-vegetation prevented efficient grass growth*' (Lunn and Turner, 2006a). In the November 2006 Monitoring Memo, it was further noted that '*increased turbidity levels in Crabapple and Whistler Creeks during record rainfalls in early November resulted in some surface erosion from non-vegetated work areas*'. It was also noted in the same Memo that '*ski run areas that were re-vegetated prior to Sept 30 did not experience the same level of erosion from surface water as those areas that were re-vegetated after Oct 1, 2006*' (Lunn and Turner, 2006b).

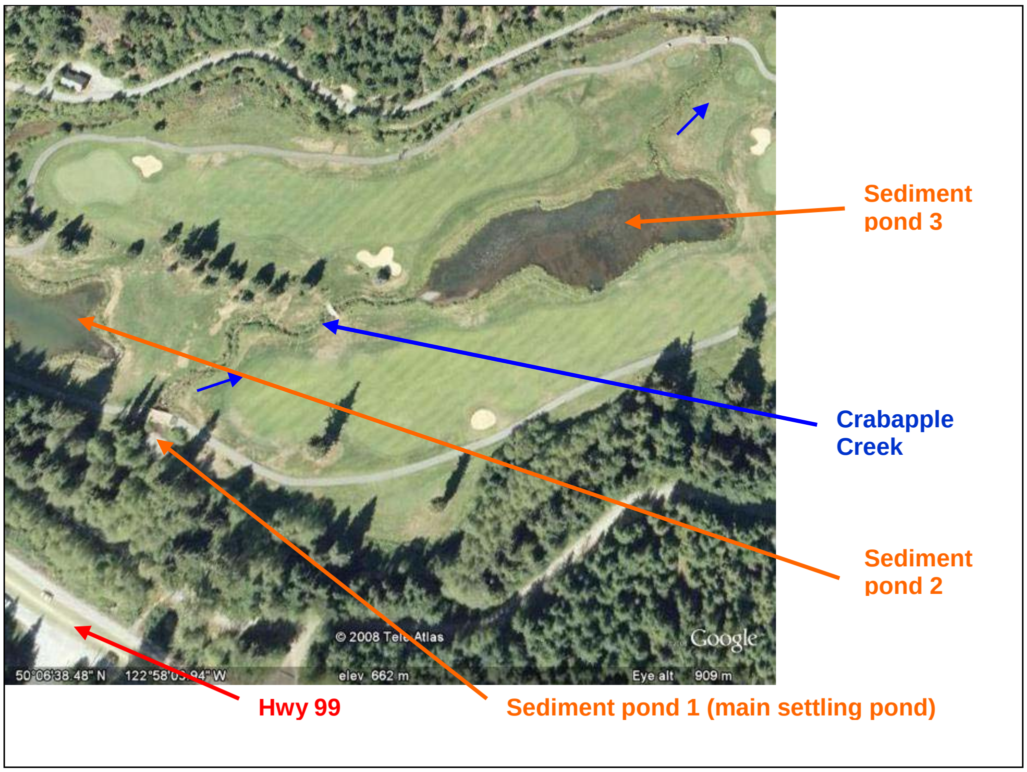


Figure 4.2. Crabapple Creek, as it enters the Whistler Golf Course, showing the two sediment ponds it goes through at the start of the golf course (Google Earth Maps)

Aquatic species of concern in the Crabapple Creek watershed include coastal tailed frogs (*Ascaphus truei*), a blue-listed species in B.C. (species of special concern), in upper reaches, and fish populations in the lower reaches. Fish species in lower creek reaches include rainbow trout (*Oncorhynchus mykiss*, resident and spawners from Alta Lake), kokanee salmon (*O. nerka*, spawners), threespine stickleback (*Gasterosteus aculeatus*), and sculpin (Order Scorpaeniformes). This creek is considered one of the most productive of the Whistler Valley creek systems, particularly for rainbow trout, and is an important spawning and rearing channel for Alta and Green Lake fish (Symko, 2000). It should also be noted that the lowest reach, between the golf course and the mouth, is particularly productive due to availability of spawning and rearing habitat (H. Beresford, Resort Municipality of Whistler, personal communication, May 27, 2008). Tailed frogs inhabit fast-flowing, steeper gradient headwater streams, and along with the fish species, are known to require clear water conditions for survival.

4.2 Methods & Data Analysis

Site selection

Site locations were chosen along a development gradient to assess cumulative impacts of urban rainwater runoff. Three sites were chosen (see Photo Series 4.1): an **upstream reference location (E268884)**, downstream of the ski hill but upstream of golf course and most urban development; a **midstream location (E268883)** just downstream of Hwy 99 and some urban development, but upstream of golf course; and a **downstream location (E252029)**, which was downstream of all development and golf course, near the mouth. An automated water sampler is also operated by MoE at this downstream location. It should be noted that for the purposes of assessing urban stormwater quality in Crabapple Creek, ski hill operations, i.e. the bike park and summer service road, were not initially assumed to have an influence on the upstream reference site (E268884).

Grab sampling

Water samples were collected and analyzed as described in Section 3.2, where summer low flow sampling (Aug 2007) and non-event sampling (Oct 2007) were also conducted at the downstream site (E252029) in Crabapple Creek.

Automated turbidity monitoring

An automated monitoring station (sonde) at the most downstream location (E252029) in Crabapple Creek has been collecting DO, temperature, specific conductance, pH, turbidity and water level data at 15 min intervals since 2002. This station is designed to capture both baseline and high flow (rain event/snowmelt) data over the long-term. At the study outset, the turbidity from September 27 to October 31 was to be used to determine if fish were being exposed to excessive turbidity during the month. However, several problems (see Appendix B) with the data were observed when the data were downloaded and it was determined that the data could not be used to accurately describe turbidity in the Crabapple Creek reach between the golf course and River of Golden Dreams.

Newcombe proposed a method to assess potential 'severity of ill effects' (SEV) from suspended sediments (SS) (Newcombe and Jensen, 1996) and turbidity (Newcombe, 2003) to clear water fishes using both magnitude and duration, as impacts may be felt both at higher magnitudes over shorter durations, or at lower magnitudes over longer durations. These models, which provide threshold SS and turbidity levels, are useful tools to determine the onset of ill effects caused by excessive levels to clear water fishes, as well as to determine the rate at which serious ill effects are likely to escalate (Newcombe; 1996, 2003). Magnitude-duration matrix tables, including appropriate equations for calculating the respective SEV scores, are provided in the appendices for **suspended solids** (Appendix 4.5; Newcombe and Jensen, 1996) and **turbidity** (Master Appendix B; Newcombe, 2003).

Grab sample TSS and turbidity data from the three sampling sites were initially used in the respective model equations, using various example durations ranging from 0.5 to 48 hours, to illustrate the possible range of effects on clear water fishes from excessive levels. Additionally, the durations of the five largest high flow events were estimated using the available turbidity and stream level data, which were then also generally compared to Whistler Creek turbidity event durations determined by sonde data during the same time period (see Appendix 4.2). General conclusions could thus be drawn on the likely impacts of excessive TSS and turbidity on clear water fishes in the context of expected duration of each event. This approach was also, in fact, necessary to address the discrete reaches of Crabapple Creek due to the golf course features including i) settling ponds and closed culvert under Hwy 99, which largely limit fish populations to downstream reaches, and ii) accounting for the differences in sediment and turbidity levels in up- and downstream reaches due to the sediment ponds in the golf course that act to moderate high sediment levels during periods of high runoff in downstream reaches. Thus, even with a sonde collecting accurate data, it may be beneficial to augment the automated data set with grab sample data from the various reaches, as resources are not available to have automated samplers in each reach.

	**Upstream Location** (E268884, upstream Brio) Oct 10/07 (turbidity of 52.7 NTU)
	**Midstream Location** (E268883, just downstream of Hwy 99 but upstream of Whistler Golf Course) Oct 10/07 (turbidity of 45.6 NTU)
	**Downstream and Automated Sampler Location** (E252029, at mouth) Oct 10/07(turbidity of 77.8 NTU)

Photo Series 4.1: Crabapple Creek sampling sites showing upstream, midstream and downstream locations

4.3 Results & Discussion

4.3.1 Summer grab sampling – August 2007

Results from grab sampling at the most downstream site (E252029) in August 2007, during low flow conditions, indicated that most parameters met B.C. Approved Water Quality Guidelines (AWQGs) for the protection of aquatic life except dissolved aluminum (Al) and total zinc (Zn). Mean guidelines for both zinc (7.5 µg/L) and aluminum (50 µg/L) were slightly exceeded, with concentrations of 7.6 µg/L and 72 μg/L, respectively at the downstream site (see Appendix 4.3). It should be noted, however, that the lab reportable detection limits (RDLs) for several biologically important metals (i.e. cadmium, chromium, copper, lead, selenium and silver) were higher than the guidelines, so it is not known whether these metals of concern met guidelines protective of aquatic life. RDLs for these metals improved in mid October 2007, allowing for better comparison of October data to guidelines. Mean total suspended solids (TSS) and turbidity levels were low, or 4.8 mg/L and 2.4 NTU, respectively (Appendix 4.3).

4.3.2 Fall grab sampling – October 2007

Several significant precipitation events occurred in October (Oct 2, 18.8 mm; Oct 7, 23.5 mm; Oct 9-10, 26.3 mm; and Oct 21-22, 19.1 mm), which coincided with sampling events on Oct 2, 10 and 22. **Exceedances of both maximum and mean BC AWQGs occurred for TSS, turbidity, dissolved aluminum, total cadmium, total copper, total iron, and total zinc** to varying degrees and on at least one occasion at each Crabapple Creek site, which will be discussed in the following sections.

i) TSS and turbidity

During the two non-storm sampling events, low levels of TSS (<4 mg/L) and turbidity (0.6 and 3.3 NTU) levels were found at the downstream site (Table 4.1). During the high precipitation events in October 2007, the highest levels of TSS and turbidity were recorded at the upstream 'reference' site on October 2 (605 mg/L and 452 NTU, respectively; Table 4.1 and Figure 4.3), which was problematic for guideline interpretation. These levels were considered to be excessive, but due to the limitations of the guidelines, i.e. that induced downstream levels are compared to appropriate background levels, these levels could not be stated to exceed guidelines. At the outset of the study, it was assumed that upstream influences on TSS and turbidity would not be significant, but this was not the case. The excessive levels on October 2 at the upstream site likely occurred due to upstream land use practices and the creek's 'first flush' response following the first significant rain events of the fall season, which can also contain the highest contaminant concentrations. In fact, a majority (97.1 mm, or 64%) of the month's precipitation (150.7 mm) fell in early October, from September 30 to October 10, which accounted for the observed higher flows and resulting high sediment and turbidity levels on October 2 and 10 (see Photo Series 4.1).

Table 4.1: Total suspended solids (TSS) and turbidity results during storm (Oct 2, 10 and 22) and non-storm (Oct 17 and Nov 1) events for Crabapple Creek sites in 2007

Storm Event Sampling - Crabapple Cr			
	Event 1	Event 2	Event 3
Crabapple Cr US Brio (E268884) - upstream			
	Oct 2/07	Oct 10/07	Oct 22/07
TSS (mg/L)	605	107	22
Turbidity (NTU)	452	52.7	8.4
Crabapple Cr at Hwy 99 (E268883) - midstream			
	Oct 2/07	Oct 10/07	Oct 22/07
TSS (mg/L)	222	95	24
Turbidity (NTU)	210	45.6	8.1
Crabapple Cr at Mouth (E252029) - downstream			
	Oct 2/07	Oct 10/07	Oct 22/07
TSS (mg/L)	113	143	51
Turbidity (NTU)	84.5	77.8	1.9

Non-storm events	
Oct 17/07	Nov 1/07
<4	<4
3.3	0.6

Highlighted cells show guideline exceedences during turbid flow periods

Following the first flush event on October 2, the highest TSS levels were observed at the downstream site on October 10 (107 mg/L and 52.7 NTU) and October 22 (TSS only, 51 mg/L) (Table 4.1 and Figure 4.3), which exceeded the BC AWQGs during turbid flow periods. This was determined using the upstream 'background' levels for guideline comparison on October 10 and 22, which were 107 and 22 mg/L, while turbidity was 52.7 and 8.4 NTU, respectively. Thus, on October 10, TSS and turbidity should not have been higher than 132 mg/L and 60.7 NTU, respectively, at downstream sites. While this condition was met at the midstream site, it was not met at the downstream site. On October 22, TSS and turbidity should not have been higher than 47 mg/L and 16.4 NTU, respectively, at the downstream sites. This condition was not met for TSS at the downstream site. Thus, **B.C. AWQGs for TSS and turbidity levels were exceeded at the downstream site on both October 10 (both) and 22 (TSS only).** This may be indicative of cumulative impacts from urban development practices in the watershed, particularly in light of the fact that stormwater drainage area contributes to 30% of the creek's total drainage area.

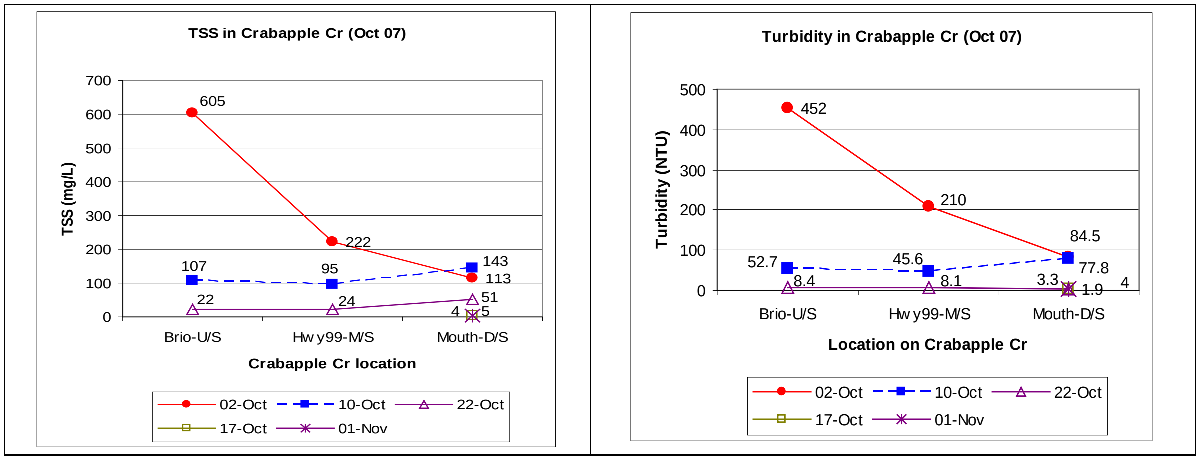


Figure 4.3. Total suspended solids (TSS) and turbidity (NTU) at upstream (U/S), midstream (M/S), and downstream (D/S) Crabapple Creek sites during three rain events in October 2007

These guidelines were also likely exceeded due to both bike park and summer service road maintenance practices by the Whistler Blackcomb Ski Resort, as well as the Olympic-related construction on Whistler Mountain in 2006 and 2007. Cascade Environmental Resource Group Ltd. (CERG), the Environmental Monitor for this venue during 2006 and 2007, noted that service road maintenance practices may be the largest contributor to sediment loading in Whistler Creek during rain events (J. Turner, CERG, personal communication, Oct. 17/07), while Olympic ski run construction was cited by Whistler Blackcomb to be a significant contributor to sediment increases in Crabapple Creek (A. DeJong, WB, personal communication, Jun 19, 2008). Cumulative impacts from urban stormwater runoff downstream of the golf course may have also contributed to elevated levels of TSS and turbidity in lower creek reaches, following the first flush conditions of early October. Thus, activities in the upper portions of the Crabapple Creek watershed are the main concern at this time in terms of impacting tailed frogs in upper reaches, and fish in lower reaches, due to elevated turbidity and sedimentation during periods of high runoff.

The biological impacts of increased sediment and turbidity are varied, but are generally recognized to be magnitude and duration dependent. Additionally, sediments are of concern at high levels as they are considered to be reservoirs, or sinks, for metals which can increase availability for uptake by aquatic biota (Singleton, 1987). Newcombe and Jensen (1996) have summarized the range of effects of excessive suspended sediments (SS) to fish, which range from behavioural, to sublethal and lethal effects depending on levels and duration of exposure (see Appendix 4.5). A recent review has also shown that physiological and behavioural effects can occur in salmonids at turbidity levels starting from 10-30 NTU (summarized in Master Appendix C, Bash *et al*., 2001).

An analysis of the potential 'severity-of-ill-effects' (SEV) scores for several durations using grab data for both SS and turbidity are shown in Tables 4.2 and 4.3. This analysis was performed to highlight potential impacts to fish in the reach downstream of the golf course, which is known to be the most productive area for spawning in Crabapple Creek (H. Beresford, RMOW, personal communication, May 27, 2008). Conditions for tailed frogs in upper creek reaches are also of concern, but impacts of TSS and turbidity to this species have not been as rigorously assessed. The SEV scoring systems differ slightly, where SEV scores for SS (SEV_{SS}) correspond to specific physiological effects described in Newcombe and Jensen (1996). SEV_{SS} range from nil (SEV_{SS}=0), to behavioural (SEV_{SS} 1-3), sublethal (SEV_{SS} 4-8) and lethal/paralethal (SEV_{SS} 9-14) effects (see Appendix 4.5). Turbidity SEV scores (SEV_{turb}) indicate whether water conditions are *ideal* (0≤SEV_{turb}<0.5), *slightly impaired* (0.5≤ SEV_{turb} <3.5), *significantly impaired* (3.5≤ SEV_{turb} <8.5), or *severely impaired* (SEV_{turb} ≥8.5) for fish (see Master Appendix B). An SEV_{turb} event score of 0 has no effect while an event of 14 would lead to 100% mortality.

Fish could have experienced sublethal effects (SEV_{SS} 4-6) from elevated suspended sediments in downstream creek reaches near the mouth on October 2, 10 and 22, assuming that sustained grab sample TSS concentrations occurred for 0.5-7 h (Table 4.2). Possible effects could have ranged from short-term reduction in feeding rates and feeding success (SEV_{SS}=4), to moderate habitat degradation and impaired homing (SEV_{SS}=7) (Appendix 4.5). Durations of high flow events above rainy season baseflows, which also likely experienced elevated sediment and turbidity inputs, could be approximated from the sonde's depth data. Such high flow events occurred on October 2, 10 and 22 and were estimated to occur for 20, 29, and 17 h, respectively (see Appendix 4.2).

Table 4.2: Severity (SEV_{SS}) of ill effect scores and for suspended sediment (SS) grab data in Crabapple Creek on October 2, 10 and 22, 2007 (see score interpretation in Appendix 4.5)

Total suspended sediments (TSS)			SEV_{SS} Scores						
			Theoretical Duration (h)						
Date	**Site**	**TSS (mg/L)**	**0.5**	**1**	**2**	**3**	**7**	**24**	**48**
02-Oct	Brio	605	5	6	6	7	7	8	8
	Hwy 99	222	5	5	5	6	6	7	7
	Mouth	113	4	5	5	5	6	6	7
10-Oct	Brio	107	4	5	5	5	6	6	7
	Hwy 99	95	4	4	5	5	6	6	7
	Mouth	143	4	5	5	5	6	7	7
22-Oct	Brio	22	3	3	4	4	5	5	6
	Hwy 99	24	3	3	4	4	5	5	6
	Mouth	51	4	4	4	5	5	6	6

Fish likely experienced slightly different impacts from excessive turbidity on these dates near the creek's mouth. The most severe impacts were likely felt on October 2, where water conditions were likely slightly impaired (SEV_{turb} 1.6-3.2) for 0.5-3 h, or possibly significantly impaired (SEV_{turb}=4) at 7 h if sustained grab sample turbidity levels occurred at the downstream site (Table 4.3). Slightly impaired conditions indicate that feeding and other behaviours begin to change, while significantly impaired conditions indicate a marked increase in water cloudiness, which could reduce fish growth rate, habitat size, or both (see Master Appendix B). At sustained levels of grab sample turbidity on October 10, the same trend may have occurred at the downstream sites up to 7 h; while on October 22 conditions may have been ideal for fish (Table 4.3). It should be noted, however, that turbidity event analysis (>16 NTU) at the most downstream site in nearby Whistler Creek, with similar land use practice concerns, showed that significantly impaired conditions from excessive turbidity occurred for fish on October 2 and 10, lasting 14.25 and 31.25 h, respectively (see Appendix 4.2). Slightly impaired conditions occurred on October 22 in Whistler Creek for 11.5 h.

Table 4.3: Severity (SEV_{turb}) of ill effect scores for grab turbidity data in Crabapple Creek on October 2, 10 and 22, 2007 (see score interpretation in Master Appendix B)

Turbidity			SEV_{turb} Scores						
			Theoretical Duration (h)						
Date	**Site**	**Turbidity (NTU)**	**0.5**	**1**	**2**	**3**	**7**	**24**	**48**
02-Oct	Brio	452	5.1	5.7	6.3	6.7	7.5	8.6	9.3
	Hwy 99	210	3.5	4.1	4.7	5.1	5.9	7	7.7
	Mouth	84.5	1.6	2.2	2.9	3.2	4.0	5.1	5.8
10-Oct	Brio	52.7	0.6	1.2	1.9	2.2	3.0	4.2	4.8
	Hwy 99	45.6	0.3	0.9	1.6	1.9	2.7	3.9	4.5
	Mouth	77.8	1.4	2.0	2.7	3.1	3.8	5.0	5.6
22-Oct	Brio	8.4	0	0	0	0	0	0.3	1.0
	Hwy 99	8.1	0	0	0	0	0	0.3	0.9
	Mouth	1.9	0	0	0	0	0	0	0

Thus, elevated turbidity conditions likely occurred to different degrees in all three reaches on these dates, which may have impacted both tailed frogs in upper reaches and fish in lower reaches, despite the moderating influence of the golf course settling ponds. The sediment control ponds may have been effective in controlling upstream sediment inputs to Crabapple Creek on October 2, as indicated by the decreasing sediment and turbidity levels along the stream gradient. However, levels increased along the stream gradient on October 10 and 22, with the highest levels at the mouth, indicating possible cumulative inputs from urban stormwater runoff. Thus, variable sources of sediments, including point sources from ski hill activities and non-point sources from stormwater inputs are both leading to non-attainment of B.C. AWQGs and likely impacts to aquatic life.

It should also be noted that elevated suspended solids could be considered to constitute pollution under Section 6 (4) of the B.C. *Environmental Management Act* (*EMA*, Master Appendix E), as well as be defined as a 'deleterious' substance under the Federal Fisheries Act (Master Appendix F). The *EMA* states that '*a person must not introduce waste into the environment in such a manner or quantity as to cause pollution*', where pollution means the '*presence of substances or contaminants that substantially alter or impair the usefulness of the environment*'. Under the Federal Fisheries Act, a 'deleterious' substance is defined as any substance 'that if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water' (Master Appendix F). In Section 36(3) of the Act, it further states that 'no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance may enter any such water'. The data presented here indicates that both Acts were likely violated with respect to excessive TSS and turbidity at times in Crabapple Creek in October 2007.

It is also **important to consider the cumulative impacts of excessive sediment and turbidity events on fish**, which are difficult to capture and not addressed in the B.C. AWQGs. Factors that mediate their effect on fish include duration of exposure; frequency of exposure; toxicity; temperature; life stage of fish; particle angularity, particle size and type; severity/magnitude of pulse; natural background turbidity (e.g. watershed position and legacy, or historical land use practices); other stressors and general condition of biota; and availability of, and access to, refugia (Bash *et al*., 2001). Automated turbidity data from nearby Whistler Creek showed that three moderate turbidity events occurred from October 2-10, which likely caused significant impairment for fish [see Section 3.3, part c)]. A similar scenario likely occurred in Crabapple Creek, which also responds quickly to significant rain events. These events, along with minor turbidity events that occurred within the space of approximately one week in October 2007 (Oct 2-10), may have had a prolonged impact on ability of fish to catch prey due to excessive cloudiness. This may have had implications for fish growth and survival in lower reaches of Crabapple Creek at the time.

ii) Dissolved aluminum (Al)

The maximum dissolved aluminum (Al) guideline of 100 µg/L was exceeded at the up- and midstream sites on both October 10 and 22, ranging from 180–252 µg/L (Figure 4.4). At the downstream site, this guideline was exceeded only on October 22 (114 µg/L), and was only half the level of the mid- and upstream sites. The mean Al guideline of 50 µg/L was also exceeded at the downstream site, which was almost twice as high, with a mean of 97.5 µg/L.

It is also interesting to note that dissolved Al concentrations increased at the up- and midstream sites during the month of October, from 60 µg/L on October 2, to a range of 180–252 µg/L at these sites on October 10 and 22. Sources of total Al, and thus dissolved Al, include disturbed soil which could have accounted for the increased levels of dissolved Al over the month upstream of the golf course, as more and more sediment entered Crabapple Creek following the first flush event on October 2. The apparent effectiveness of the golf course sediment ponds in trapping significant amounts of sediment may explain why dissolved Al levels decreased at the downstream location compared to upstream locations, as Al-associated sediment and thus dissolved Al were prevented from reaching lower creek reaches. The toxicological effects of Al on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Al levels in the creek at times in October 2007, the impacts from Al alone were likely short-term.

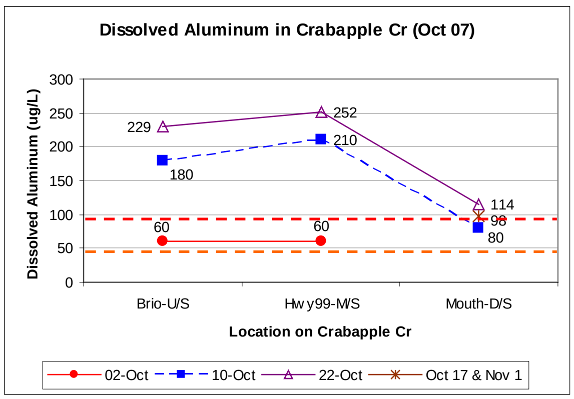


Figure 4.4. Dissolved aluminum (µg/L) at upstream (U/S), midstream (M/S) and downstream (D/S) Crabapple Creek sites during three rain events in October 2007, showing maximum (100 µg/L, red-dashed) and mean (50 µg/L, orange-dashed) B.C. AWQG lines

iii) Total cadmium

In the absence of a B.C. AWQG for total cadmium (Cd), the maximum Canadian Environmental Quality Guideline of 0.017 µg/L (freshwater aquatic life) was used for comparison. Once lab reportable detection limits (RDLs) improved in mid October, total Cd was found to exceed this guideline at all three sites on October 22 (0.09-0.19 µg/L), as well as at the downstream site on October 17 (0.16 µg/L) and Nov 1 (0.15 µg/L). It is not known whether Cd is naturally elevated or related solely to stormwater runoff, as low level results were not available during the October 2 and 10 first flush events. There were also not enough data to determine whether a gradient exists along the creek's development gradient.

iv) Total copper

Maximum total copper (Cu) guidelines, adjusted for hardness, ranged from 5.7-11.6 µg/L; while the mean copper guideline is 2 µg/L. At the upstream site, maximum Cu guidelines were not met on October 2 (32 µg/L) and October 10 (9 µg/L) (Figure 4.5). At the midstream site, total Cu concentrations also exceeded maximum guidelines on October 2 and 10, with concentrations of 20 and 11 µg/L, respectively. At the downstream site, Cu concentrations were high on all rain event dates (Oct 2, 10 and 22), and exceeded maximum guidelines, with concentrations of 22, 21 and 13.5 µg/L, respectively. The mean guideline was also exceeded at the downstream site, with a mean total Cu concentration of 13.3 µg/L (n=5).

Sources of total Cu were most likely derived from sediment inputs from upstream mountain activities, particularly during the October 2 first flush event, but may have also included cumulative urban stormwater inputs, as observed on October 10 and 22. On these dates, an increasing concentration gradient in Cu levels can be seen from upstream to downstream along the urban development gradient, where Cu levels were 2-4 times higher than B.C. AWQGs at the mouth. The toxicological effects of Cu on aquatic life are described in Master Appendix D. While aquatic life may have been exposed to sublethal concentrations of Cu in the creek at times in October 2007, the impacts from Cu alone were likely short-term.

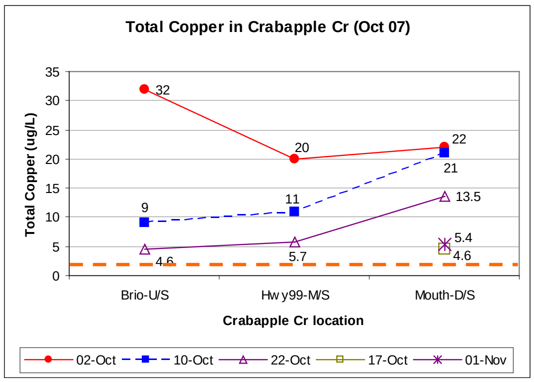


Figure 4.5. Total copper (µg/L) at upstream (U/S), midstream (M/S), and downstream (D/S) Crabapple Creek sites during three rain events in October 2007, showing the mean (2 µg/L, orange-dashed) B.C. AWQG line

v) Total iron

The mean dissolved iron (Fe) guideline of 350 µg/L was not exceeded at the downstream site, while the maximum total Fe guideline of 1000 µg/L (1 mg/L) was exceeded at all three sites. At the upstream site, the maximum guideline for total Fe was exceeded on October 2 and 10, with concentrations of 2460 µg/L and 1320 µg/L, respectively (Figure 4.6). At the midstream site, this iron guideline was exceeded on all rain event dates, ranging from 1150 to 2690 µg/L. At the downstream site, the highest iron levels were detected on each rain date and exceeded the maximum guideline, ranging from 2270 to 2780 µg/L. As with total Cu concentrations, total Fe can be seen to be increasing along the urban development gradient, from upstream to the mouth.

It should be noted that while dissolved Fe concentrations at the downstream site were relatively stable between rain events and non-events (50-115 µg/L, n=4), total iron was significantly elevated during rain events (2270-2780 µg/L, n=3) compared to non-events (455-480 µg/L, n=2) (Figure 4.6, note scale differences). This indicates that total Fe was likely associated with elevated sediment inputs during rain events. The toxicological effects of Fe on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Fe levels in the creek at times in October 2007, the impacts from Fe alone were likely short-term and minimal.

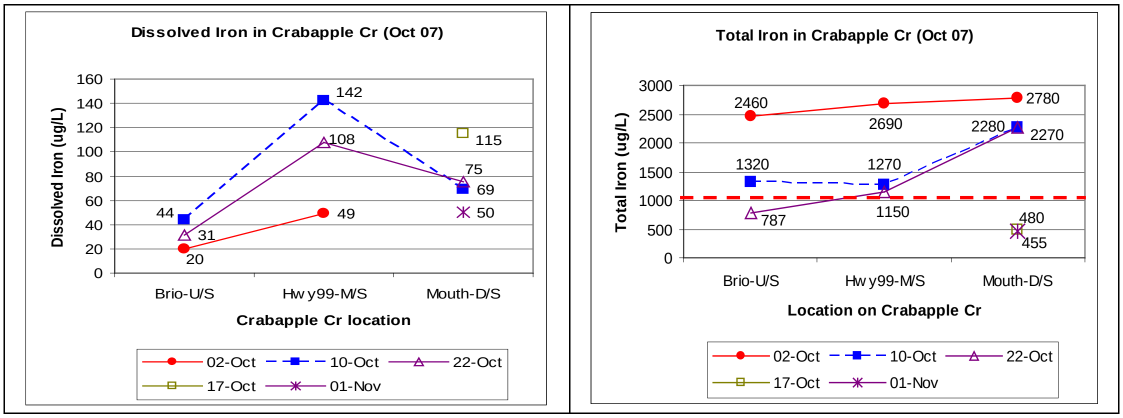


Figure 4.6. Dissolved and total iron (µg/L, note differences in scale between graphs and 1 mg/L draft guideline line for total iron**)** at upstream (U/S), midstream (M/S), and downstream (D/S) Crabapple Creek sites during three rain events in October 2007, showing and maximum (1000 µg/L, red-dashed) B.C. AWQG line (mean AWQG is 350 µg/L and was not exceeded)

vi) Total zinc

Total zinc (Zn) levels in Crabapple Creek at the mouth were low in August 2007 (mean of 7.6 µg/L, max of 9 µg/L) and met the maximum (33 µg/L, hardness≤90 mg/L), while slightly exceeding the mean guideline (7.5 µg/L, hardness≤90 mg/L) for total Zn (Appendix 4.3). In October 2007, however, with higher flows and the ensuing higher sediment loadings, the maximum Zn guideline was exceeded at all three sites on October 2 (40-55 µg/L), as well as at the downstream site on October 10 (39 µg/L) and October 22 (36 µg/L) (Figure 4.7). The mean guideline was also exceeded at the downstream site, which was three times higher at 34 µg/L. As with Cu and Fe, Zn can bind to particulate matter, which may have accounted for the observed higher levels in the creek and along the stream gradient, from upstream to the mouth. The toxicological effects of Zn on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Zn levels in the creek at times in October 2007, the impacts from Zn alone were likely short-term.

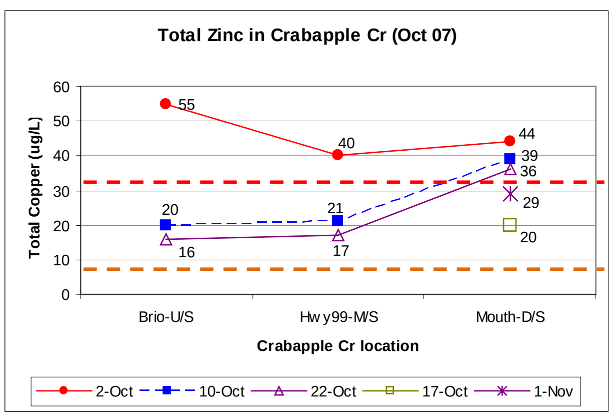


Figure 4.7. Total zinc (µg/L) at upstream (U/S), midstream (M/S) and downstream (D/S) Crabapple Creek sites during three rain events in October 2007, showing maximum (33 µg/L, red-dashed) and mean (7.5 µg/L, orange-dashed) B.C. AWQG lines

4.4 Conclusions

Results from grab sampling during storm events in October 2007 show that **Crabapple Creek was receiving non-point source pollution during periods of high runoff**. **This water quality assessment shows that pollution, as defined by the B.C. *Environmental Management Act*, was caused by high TSS and turbidity levels, as well as the resulting increase in sediment-associated metals (copper, iron, cadmium and zinc)** in the creek during October 2007. Elevated TSS, turbidity, and metals could also be considered to be deleterious substances under the Federal *Fisheries Act* during this period**.** It should also be noted that these metals may have additive or synergistic effects (i.e. increased toxicities in combination) on aquatic life which are important to consider. Excessive TSS and turbidity also likely caused significantly impaired conditions for clear water fishes at times from October 2 to 11, leading to reduced feeding success and physiological stress.

This study was able to show that specific sources, i.e. land use practices on the ski hill, as well as variable sources, i.e. stormwater inputs, are likely contributing to elevated levels of both sediments and associated metals in Crabapple Creek during periods of high runoff. The former was the main factor impacting the creek on October 2, while the latter also impacted the creek towards the end of October. While sediment and turbidity levels would be expected to be elevated to some degree in steeper gradient streams during periods of high runoff in the Whistler area, it is felt that levels were excessive and likely derived from anthropogenic sources. **The common non-attainment of metals also highlights the sediment runoff problems**.

Operations, including bike park and yearly summer service road maintenance, as well as recent 2010 Olympic ski run construction on Whistler Mountain, were all likely contributing factors to the observed pollution in Crabapple Creek in October 2007. These operations and activities should be examined carefully so that actions can be taken to prevent future sediment impacts to Crabapple Creek, particularly prior to the fall rainy season in 2008. It also appears that appropriate sediment control measures, including re-vegetating of disturbed slopes related to Olympic site construction did not occur in a timely manner, i.e. prior to Sept 1 in both 2006 and 2007. This may have contributed to the observed increases in turbidity and sediment levels in Crabapple Creek.

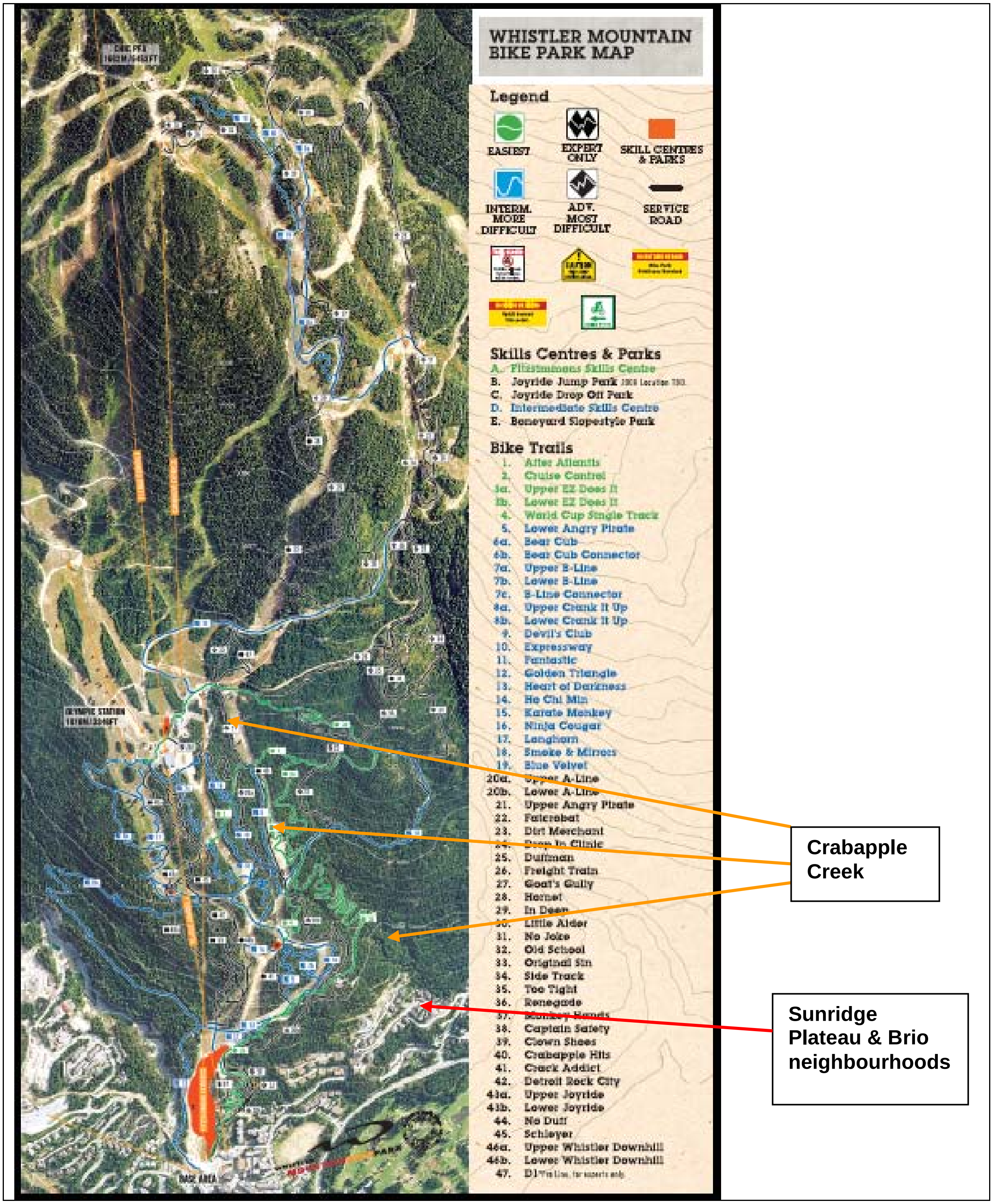
Climate change is another important factor to consider, as precipitation and temperature patterns will change, which will influence stormwater flows in the fall and winter in the future. A warming climate is predicted to ‘promote the shift of streams from *hybrid* (rain/snowmelt) to *pluvial* (rain-dominated) systems’, as well as having increased potential for winter floods in *pluvial* systems (Rodenhuis *et al.*, 2007). This has implications for Crabapple Creek, which is currently a *hybrid* flow system, but could experience higher proportions of rainfall compared to snowfall in the October-December rainy season. Higher flows during this time period will increase stormwater runoff and thus potential impacts to aquatic life from poor water quality. Thus, it will become even more important to ensure good stormwater quality, to prevent potential impacts to downstream creek reaches and lakes, and the aquatic life and recreational activities associated with them.

4.5 Recommendations

It is recommended that:

- **An evaluation of current erosion and sediment control measures in the bike park and on summer maintenance roads be conducted** by Whistler Blackcomb on both mountains, as many creeks flow through the ski hill area and have the potential to convey sediments and associated contaminants to downstream fish-bearing stream reaches and lakes.
- **Current construction practices should also be evaluated**, so that future activities can include proper erosion and sediment controls. The lessons learned from inappropriate construction practices should be shared with local contractors and developers to prevent future impacts.
- **Re-vegetation of disturbed slopes on Whistler Mountain**, whether from historical disturbance or VANOC's construction activities in 2006 and 2007, **should be completed prior to September 1, 2008** as recommended by the Environmental Monitor. If slopes were re-vegetated in 2007, they should be monitored for effective growth in 2008.
- **Follow-up stormwater quality monitoring should be conducted** by Whistler Blackcomb during the fall rainy period in 2008, to evaluate the effectiveness of measures taken to ameliorate the current concerns regarding elevated suspended sediments and turbidity during high runoff periods. A more appropriate upstream site that measures background levels during turbid flow periods should also be located, if possible. An automated water sampler in Crabapple Creek will also continue to monitor turbidity during low and high flow periods.
- **A meeting of key stakeholders be held to form an action plan to improve current conditions in the Crabapple Creek watershed, so that future impacts to the creek can be minimized.** The Ministry would like to continue addressing water quality issues in a collaborative manner. Ministry staff could present these findings to the various parties, address any questions, and work with them to ensure that remedial measures are effective in addressing the identified issues.
- **Optimization of source controls be implemented in neighbourhoods surrounding Crabapple Creek**, so that the impact of urban stormwater runoff on the creek can be minimized. Examples of source control can include low-impact development (LID) and increased infiltration.

APPENDIX 4.1 – WHISTLER MOUNTAIN BIKE PARK MAP



APPENDIX 4.2 – CRABAPPLE CREEK DATA PROBLEMS

Description of Problems with Crabapple Creek Automated Data from October 2007

On October 31, 2007 MoE was on-site to pick up the Crabapple Creek sonde for calibration. It was noted that i) new gravel was deposited in the creek near the deployment tube, and ii) significant 'fouling' of the sonde, or coating of the probe with fine sediment, was observed. This was reflected by comparison measurements from a side-by-side "in-situ" sonde which recorded turbidity of 2.9 NTU on October 31, compared to 380 NTU recorded by the sonde in its deployment tube. This fouling was visually verified by fine sediment found in the sensor guard. After reviewing the data for the deployment period, it was noted that the Crabapple Creek sonde was likely fouled six times in this manner, which was also corroborated by depth data from the sonde (relative to stream gauge) that corresponded to the six highest peaks in stream depths up to October 29 (Table I). Turbidity event data from nearby Whistler Creek, which also originates from Whistler Mountain, is also provided for comparison as the automated turbidity data was reliable (Bull, 2008). This data lends additional support to the likely occurrence of significant sedimentation/turbidity events in Crabapple Creek, as five of the same events were ranked among the highest that occurred in Whistler Creek. However, due to the sensor fouling in Crabapple Creek, these events could not be quantified accurately for both the magnitude and duration since the data was not representative of the true turbidity in the creek. The deployment tube is being modified to avoid future impacts to the sonde during large sedimentation events.

Table I. Crabapple Creek automated sampler data, showing date and time of turbidity and depth peaks of the five largest high flow events during October 2007

	Crabapple Creek		**Whistler Creek Turbidity Event Comparison (from Bull, 2008)**		
Start Date	Approximate length of turbidity & depth event (h)	Approximate peak stream depth reached during turbidity event (m)	Length of turbidity & depth event >16 NTU (h)	Max turbidity reached (NTU)	Event Classification (Impact to fish)
Oct 2 (first flush)	20.00	0.38	14.25	868.5	Significantly impaired
07-Oct	22.00	0.58	11.25	869.4	Significantly impaired
10-Oct	29.00	0.77	31.25	747	Significantly impaired
22-Oct	17.00	0.67	11.50	83	Slightly impaired
23-Oct			6.50	96	Slightly impaired
24-Oct	6.50	0.59	Analysis threshold of 16 NTU not reached, i.e. not a significant turbidity event		

APPENDIX 4.3 – WATER QUALITY RESULTS: AUGUST 2007

CRABAPPLE CR AT MOUTH (E252029) - August 2007 Downstream								BC Water Quality Guidelines		
	RDL	**2-Aug**	**9-Aug**	**13-Aug**	**22-Aug**	**29-Aug**	**30-d mean**	30-d mean	max	Notes
Field Measurements										
Temperature (deg C)		11.7	11.4	9.8	10.7	11.5	**11**		10.0-18.0	rainbow optimum
pH		6.7	7.15	7.1	7.3	7.4	**7.1**		6.5-9.0	
Dissolved oxygen (DO, mg/L)		9.76	10.03	9.69	8.06	n/a	**9.39**	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		225	195	204	213	217	**211**			
Organics & Inorganics (mg/L)										
Total Hardness (CaCO3)	0.5	91.5	94.1	94	103	102	**96.9**			
Total Organic Carbon (C)	0.5	1.2	0.9	2.1	1.1	0.6	**1.18**			
Dissolved Hardness (CaCO3)	0.5	92	89.1	98.2	103	98.7	**96.2**			
Total Suspended Solids	4	<4	<4	8	<4	<4	**4.8**	see text	see text	
Turbidity (NTU)	0.1	0.9	2.7	4.9	2	1.4	**2.38**	see text	see text	
Conductivity (uS/cm)	1	192	196	202	209	221	**204**			
Dissolved Chloride (Cl)	0.5	5	4.1	6.5	5.5	5.9	**5.4**	150	600	
Nutrients (mg/L)										
Total Nitrogen (N)	0.02	0.16	0.14	0.17	0.19	0.14	**0.16**			
Total Kjeldahl Nitrogen (Calc)	0.02	0.09	0.07	0.09	0.12	0.07	**0.088**			
Total Organic Nitrogen (N)	0.02	0.09	0.07	0.09	0.1	0.07	**0.084**			
Nitrate (N)	0.002	0.071	0.069	0.081	0.075	0.065	**0.0722**	40	200	
Nitrite (N)	0.002	0.002	0.002	0.004	0.004	0.002	**0.0028**	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005	<0.005	0.015	0.005	**0.007**	1.81-1.84	14.1-23.5	
Total Phosphorus (P)	0.002	0.023	0.005	0.01	0.003	0.005	**0.0092**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.007	0.005	0.006	0.007	0.005	**0.006**			
Selected Metals (ug/L)										
Dissolved Aluminum (Al)	20	90	60	70	80	60	**72**	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	<2	<2	<2	**<2**		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	<5	<5	<5	**<5**		1.0 (Cr(VI))	CCME
Total Cobalt (Co)	5	<5	<5	<5	<5	<5	**<5**	4	110	
Total Copper (Cu)	5	<5	<5	<5	<5	<5	**<5**	2	10.6-11.7	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	66	56	61	96	74	**70.6**	n/a	350	Draft guidelines
Total Iron (Fe)	5	196	275	361	278	246	**271.2**	n/a	1000	Draft guidelines
Total Lead (Pb)	30	<30	<30	<30	<30	<30	**<30**	4	18	H=30 mg/L
Total Manganese (Mn)	1	49	66	98	78	65	**71.2**	700	800	H=25 mg/L
Total Selenium (Se)	30	30	<30	<30	<30	<30	**<30**	2	n/a	
Total Silver (Ag)	10	<10	<10	<10	<10	<10	**<10**	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	7	7	9	8	7	**7.6**	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)										
Fecal coliform	1	13	26	31	780	58	**54**	77	n/a	geomean,
E.coli	1	13	26	10	300	44	**34**	200	n/a	primary contact

RDL = Reportable Detection Limit

Highlighted cells show exceedences of guidelines

APPENDIX 4.4 – WATER QUALITY RESULTS: OCTOBER 2007

CRABAPPLE CR U/S OF BRIO (E268884) - Oct 2007 Upstream Reference						BC Water Quality Guidelines		
	RDL	Oct 2 - Event 1	Oct 10 - Event 2	RDL*	Oct 22 - Event 3	30-d mean	max	Notes
Field Measurements								
Temperature (deg C)		5.9	6.15		4.54		10.0-18.0	rainbow optimum
pH		7.53	n/a		6.15		6.5-9.0	
Dissolved oxygen (DO, mg/L)		11.67	n/a		10.6	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		126	66		111			
Organics & Inorganics (mg/L)								
Total Oil and grease	1	<1	<1		2			
Total Organic Carbon	0.5	3.8	4.9		2.5			
Total Hardness (CaCO3)	0.5	71.1	39.4		51.9			
Total Suspended Solids	4	605	107		22	see text	see text	
Turbidity (NTU)	0.1	452	52.7		8.4	see text	see text	
Conductivity (uS/cm)	1	128	82		110			
Dissolved Chloride (Cl)	0.5	2.9	1.8		1.5	150	600	
Nutrients (mg/L)								
Total Nitrogen (N)	0.02	0.5[a]	0.69		0.17			
Total Kjeldahl Nitrogen (Calc)	0.02	0.28[a]	0.27		0.05			
Total Organic Nitrogen (N)	0.02	0.28[a]	0.27		0.05			
Nitrate (N)	0.002	0.187	0.402		0.121	40	200	
Nitrite (N)	0.002	0.035	0.012		0.003	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005		<0.005	1.92-1.94	13.3-26.8	
Total Phosphorus (P)	0.002		0.039		0.042		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.049	0.015		0.007			
Selected Metals (ug/L)								
Dissolved Aluminum (Al)	20	60	180	1	229	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	0.01	0.09		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	1	<1		1.0 (Cr(VI))	CCME
Total Cobalt (Co)	5	7	<5	0.5	2	4	110	
Total Copper (Cu)	5	32	9	0.2	4.6	2	5.7-8.7	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	20	44	5	31	n/a	350	Draft guidelines
Total Iron (Fe)	5	2460	1320	5	787	n/a	1000	Draft guidelines
Total Lead (Pb)	30	40	<30	0.2	0.7	4	18	H=30 mg/L
Total Manganese (Mn)	1	399	149	1	108	700	800	H=25 mg/L
Total Selenium (Se)	30	<30	<30	0.1	0.1	2	n/a	
Total Silver (Ag)	10	<10	<10	0.02	<0.02	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	55	20	5	16	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)								
E. coli	1	37	22		3	77	n/a	geomean, primary
Fecal coliforms	1	45	26		7	200	n/a	contact

RDL = Reportable Detection Limit

* RDL changed for metals due to lab method changes

[a] Blank concentrations were 0.13 mg/L

Highlighted cells show exceedences of guidelines

CRABAPPLE CR D/S OF HWY 99 (E268883) - Oct 2007						BC Water Quality Guidelines		
Midstream								
	RDL	Oct 2 - Event 1	Oct 10 - Event 2	RDL*	Oct 22 - Event 3	30-d mean	max	Notes
Field Measurements								
Temperature (deg C)		5.99	6.35		5.04		10.0-18.0	rainbow optimum
pH		7.13	n/a		5.8		6.5-9.0	
Dissolved oxygen (DO, mg/L)		9.55	n/a		10.73	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		121	85		112			
Organics & Inorganics (mg/L)								
Total Oil and grease	1	<1	<1		1			
Total Organic Carbon	0.5	4.3	5.2		2.7			
Total Hardness (CaCO3)	0.5	62.9	39.2		48.4			
Total Suspended Solids	4	222	95		24	see text	see text	
Turbidity (NTU)	0.1	210	45.6		8.1	see text	see text	
Conductivity (uS/cm)	1	121	84		110			
Dissolved Chloride (Cl)	0.5	3.7	1.9		1.8	150	600	
Nutrients (mg/L)								
Total Nitrogen (N)	0.02	0.55[a]	0.67		0.18			
Total Kjeldahl Nitrogen (Calc)	0.02	0.33[a]	0.27		0.06			
Total Organic Nitrogen (N)	0.02	0.33[a]	0.25		0.06			
Nitrate (N)	0.002	0.203	0.391		0.118	40	200	
Nitrite (N)	0.002	0.015	0.012		0.002	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	0.026		<0.005	1.92-1.94	19.9-26.8	
Total Phosphorus (P)	0.002		0.061		0.032		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.024	0.016		0.009			
Selected Metals (ug/L)								
Dissolved Aluminum (Al)	20	60	210	1	252	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	0.01	0.12		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	1	<1		1.0 (Cr(VI))	CCME
Total Cobalt (Co)	5	<5	<5	0.5	2.1	4	110	
Total Copper (Cu)	5	20	11	0.2	5.7	2	5.7-6.5	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	49	142	5	108	n/a	350	Draft guidelines
Total Iron (Fe)	5	2690	1270	5	1150	n/a	1000	Draft guidelines
Total Lead (Pb)	30	<30	<30	0.2	0.8	4	18	H=30 mg/L
Total Manganese (Mn)	1	299	138	1	124	700	800	H=25 mg/L
Total Selenium (Se)	30	<30	<30	0.1	0.1	2	n/a	
Total Silver (Ag)	10	<10	<10	0.02	<0.02	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	40	21	5	17	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)								
E. coli	1	96	12		1	77	n/a	geomean, primary
Fecal coliforms	1	96	15		4	200	n/a	contact

RDL = Reportable Detection Limit

* RDL changed for metals due to lab method changes

[a] Blank concentrations were 0.13 mg/L

Highlighted cells show exceedences of guidelines

CRABAPPLE CR AT MOUTH (E252029) - Oct 2007 Downstream									BC Water Quality Guidelines		
	RDL	Oct 2 Event 1	Oct 10 Event 2	RDL*	Oct 17 Non-storm	Oct 22 Event 3	Nov 1 Non-storm	**30-d mean**	30-d mean	max	Notes
Field Measurements											
Temperature (deg C)		6.9	6.61		4.82	5.3	3.49	**5.42**		10.0-18.0	rainbow optimum
pH		6.86	n/a		6.19	5.6	7.19	**6.46**		6.5-9.0	
Dissolved oxygen (DO, mg/L)		9.35	n/a		10.5	10.42	12.18	**10.61**	8.0-11.0	5.0-9.0*	* minimum
Specific conductivity (uS/cm)		179	117		236	190	224.7	**189.34**			
Organics & Inorganics (mg/L)											
Total Oil and grease	1	1[b]	<1			1		**1**			
Total Organic Carbon	0.5	3.9	6.2		2.5	2.9	2.4[c]	**3.4**			
Total Hardness (CaCO3)	0.5	78.4	53		102	78.1	98	**81.9**			
Total Suspended Solids	4	113	143		<4	51	5	**63.2**	see text	see text	
Turbidity (NTU)	0.1	84.5	77.8		3.3	1.9	4	**34.3**	see text	see text	
Conductivity (uS/cm)	1	179	114		231	180	230	**186.8**			
Dissolved Chloride (Cl)	0.5	8	3.6		8.1	7.5	8.8	**7.2**	150	600	
Nutrients (mg/L)											
Total Nitrogen (N)	0.02	0.62[a]	1.04		0.26	0.25	0.25	**0.46**			
Total Kjeldahl Nitrogen (Calc)	0.02	0.43[a]	0.7		0.09	0.13	0.1	**0.26**			
Total Organic Nitrogen (N)	0.02	0.43[a]	0.7		0.07	0.12	0.07	**0.25**			
Nitrate (N)	0.002	0.179	0.315		0.165	0.119	0.149	**0.1854**	40	200	
Nitrite (N)	0.002	0.008	0.018		0.002	0.005	0.002	**0.007**	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005		0.025	0.008	0.033	**0.0152**	1.9-1.97	18.8-26.8	
Total Phosphorus (P)	0.002		0.085		0.008	0.07	0.015	**0.0445**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.018	0.02		0.007	0.011	0.01	**0.0132**			
Selected Metals (ug/L)											
Dissolved Aluminum (Al)	20	n/a	80	1	98	114	98	**97.5**	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	0.01	0.16	0.19	0.15	**0.17[d]**		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	1	<1	<1	<1	**<1**		1.0 (Cr(VI))	CCME
Total Cobalt (Co)	5	7	<5	0.5	2	3.1	2.1	**3.8**	4	110	
Total Copper (Cu)	5	22	21	0.2	4.6	13.5	5.4	**13.3**	2	7-11.6	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	n/a	69	5	115	75	50	**77.3**	n/a	350	Draft guidelines
Total Iron (Fe)	5	2780	2280	5	480	2270	455	**1653**	n/a	1000	Draft guidelines
Total Lead (Pb)	30	<30	<30	0.2	0.2	1.3	0.4	**0.63**	4	18	H=30 mg/L
Total Manganese (Mn)	1	287	239	1	186	189	175	**183.3**	700	800	H=25 mg/L
Total Selenium (Se)	30	<30	<30	0.1	0.1	0.2	0.1	**0.13**	2	n/a	
Total Silver (Ag)	10	<10	<10	0.02	<0.02	0.03	<0.02	**0.02**	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	44	39	5	20	36	29	**33.6**	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)											
E. coli	1	170	330		3	10	10	**28**	77	n/a	geomean,
Fecal coliforms	1	260	350		3	54	14	**46**	200	n/a	primary contact

RDL = Reportable Detection Limit
* RDL changed for metals due to lab method changes
[a] Blank concentrations were 0.13 mg/L
[b] Blank concentration was 1 mg/L
[c] Blank conentration was 1 mg/L
[d] Mean of 3 detectable values
Highlighted cells show exceedences of guidelines

APPENDIX 4.5 – IMPACT ASSESSMENT MODEL FOR SUSPENDED SEDIMENT EFFECTS

Impact Assessment Model for Effect of Suspended Sediments (SS) on Juvenile and Adult Salmonids (Newcombe, 1996)

Severity-of-ill-effect Scores (SEV) - Potential

SEV = 1.064 + 0.607(ln ED) + 0.738(ln SS)

SS (mg/L)	1	3	7	1	2	6	2	7	4	11	30	$\log_e$SS (mg/L)
	Hours			Days			Weeks		Months			
162755	10	11	11	12	12	13	14	14				12
59874	9	10	10	11	12	12	13	13	14			11
22026	8	9	10	10	11	11	12	13	13	14		10
8103	8	8	9	10	10	11	11	12	13	13	14	9
2981	7	8	8	9	9	10	11	11	12	12	13	8
1097	6	7	7	8	9	9	10	10	11	12	12	7
403	5	6	7	7	8	9	9	10	10	11	12	6
148	5	5	6	7	7	8	8	9	10	10	11	5
55	4	5	5	6	6	7	8	8	9	9	10	4
20	3	4	4	5	6	6	7	8	8	9	9	3
7	3	3	4	4	5	6	6	7	7	8	9	2
3	2	2	3	4	4	5	5	6	7	7	8	1
1	1	2	2	3	3	4	5	5	6	7	7	0

ED is exposure duration, SS is supended sediment

Notes: diagonal terraced lines denote thresholds of sublethal effects (lower left) & lethal effects (middle diagonal); shaded areas represent extrapolations beyond empirical data which are capped at 14 (although higher values are possible)

Scale of the severity (SEV) of ill effects associated with excess suspended sediment

SEV	Description of effect
	Nil effect
0	No behavioural effects
	Behavioural effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal effects
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in rate of coughing; increased respiration rat
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
	Lethal and paralethal effects
9	Reduced growth rate; delayed hatching; reduced fish density
10	0-20% mortality; increased predation; moderate to severe habitat degradation
11	>20-40% mortality
12	>40-60% mortality
13	>60-80% mortality
14	>80-100% mortality

5.0 FITZSIMMONS CREEK WATER QUALITY DURING RAIN EVENTS IN OCTOBER 2007

5.1 Study Area

Fitzsimmons Creek (Figure 5.1) is a glacial fed creek, originating from the Platform, Curtain, Macbeth, Fitzsimmons and Overlord Glaciers at 2683 m elevation, that flows from south-east to north-west between Whistler and Blackcomb Mountains (Golder Associates, 2007). The main stem flows out onto a large fan on the valley floor and is joined by Blackcomb and Horstman Creeks before flowing into Green Lake at 632 m elevation. While the main source of water throughout the year is glacial meltwater, the creek also displays a *hybrid* (rain/snowmelt) runoff regime at lower elevations. Low flows are typically experienced in the winter months (Dec-Mar) and again in August/September, once higher elevation melt has eased. The Fitzsimmons Creek watershed is the largest in Whistler, with the creek (including the Blackcomb and Horstman Creek sub-basins) draining an area of 94 km^2, 4 km^2 (4.2%) of which is attributed to stormwater drainage area, or the modified catchment area where stormwater is collected and redirected (Golder Associates, 2007).

While upper portions of the watershed lie within a provincial park, lower portions flow between Whistler and Upper Villages, along the Valley Trail, beside the White Gold and Spruce Grove neighbourhoods, and finally through the Nicklaus North Golf Course at Green Lake. Fitzsimmons Creek supports several fish species, including bull trout, as well as secondary recreational activities such as riverball rolling and ziptrekking (over the creek).

Fitzsimmons Creek receives stormwater runoff from Whistler Village and neighbourhoods further downstream via five main discharge outlets along its length. The drainage areas include, from south to north: 1) Village bus loop, 2) Upper Village and Blackcomb Way (near Glacier Drive), 3) Lorimer Road (bridge), 4) Village and Montebello neighbourhood (to biofiltration pond, with bypass to Fitzsimmons Creek), and 5) Spruce Grove neighbourhood and Spruce Grove Way. The biofiltration pond is positioned along Blackcomb Way, just north of the Village, and was created in the fall of 2004 from a natural wetland to receive stormwater runoff from Whistler Village. The pond discharge then mixes with an ‘amenities stream’ that originates from Fitzsimmons Creek further upstream, and enters Fitzsimmons Creek near Nancy Greene Drive. There is also a bypass built into this treatment system where stormwater runoff flows directly to Fitzsimmons Creek during periods of high runoff.

As with other Whistler area watersheds, timber harvesting has occurred since 1969 in the Fitzsimmons Creek watershed. Approximately 3.5 km of forest has been harvested, with no riparian buffer retained, along Fitzsimmons Creek upstream of the fan apex (Golder Associates, 2007). There is also some glacial drift, called the ‘Fitzsimmons Slip’, approximately 2 km upstream of Whistler Village that is moving gradually down-slope and eroding slowly into Fitzsimmons Creek. The slip deposits an estimated 15,000-20,000 m^3 of gravel yearly along the length of the creek, where RMOW extracts 30,000-40,000 m^3 of gravel every two years to address the flood hazard and risk posed by excess debris during storm events (J. Hallisey, personal communication, Resort Municipality of Whistler, March 17, 2009). To protect the rail bridge near the Nicklaus North Golf Course from seasonal flooding, BC Rail also extracts gravel when necessary (see Photo Series 5.1).

More recent activities occurring in and near the creek, approximately 1.5 km upstream of Whistler Village, which may have varying degrees of impacts on creek water quality and quantity, include construction of the 2010 Winter Olympic Sliding Centre (completed in 2007), a debris barrier structure to address debris and flood hazard from the Fitzsimmons Slip (to be completed in 2009), and a 7.5MW Run-of-River Hydroelectric facility (to be completed in 2010). Other activities that may be contributing to water quality problems at times include a small bike park along the bank by the day parking lots and storage of snow (containing sediment, road salt, and contaminants) in Day Lot 5 near the creek (see Photo Series 5.1).

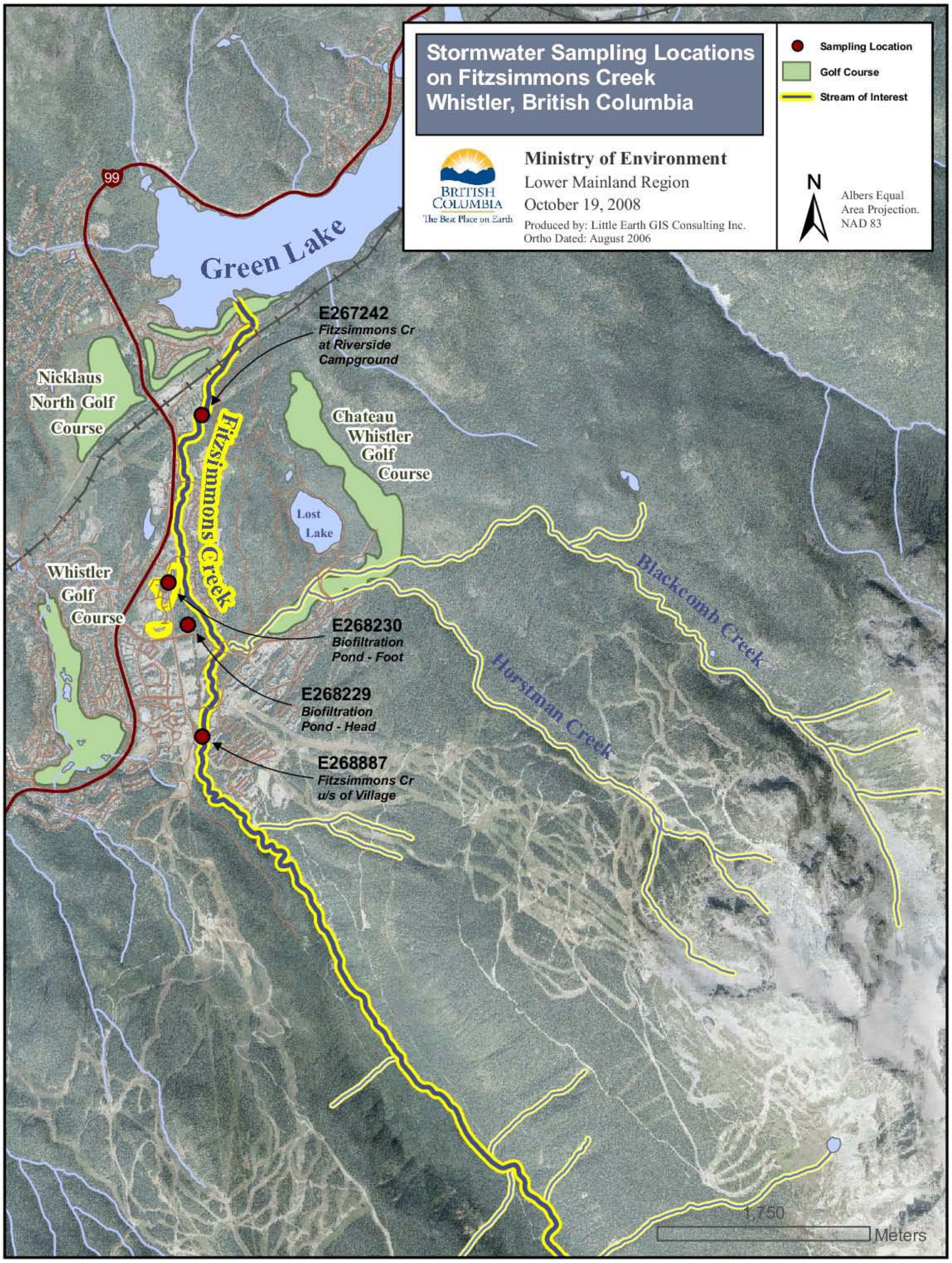


Figure 5.1. Sampling site locations in Fitzsimmons Creek, Whistler, B.C.

Snow storage area in Day Lot 5 near Fitzsimmons Creek (Apr 9/08)

Gravel extraction at BC Rail bridge near Green Lake (Jun 21/07)

Photo Series 5.1: Activities in and near Fitzsimmons Creek that may affect water quality at times

Aquatic species in the Fitzsimmons Creek watershed include bull trout (*Salvelinus confluentus*), rainbow trout (*Oncorhynchus mykiss*, resident and spawners from Green Lake), and sculpin (Order Scorpaeniformes) populations in lower reaches (B. Rebellato, RMOW, July 31, 2007, personal communication). This creek is considered to be very important for bull trout, which are blue-listed in BC (species of special concern), where they are potentially resident, rearing, and traveling through to Blackcomb Creek to spawn. Bull trout are known to be more sensitive to increases in water temperature, poor water quality, and low flow conditions than many other salmonids (U.S. Fish and Wildlife Service, 1998). This species spawns in early September once water temperatures fall below 10°C, in clean gravel and cobble substrate, with fry emerging in early spring after a relatively long incubation period of 4-5 months.

5.2 Methods & Data Analysis

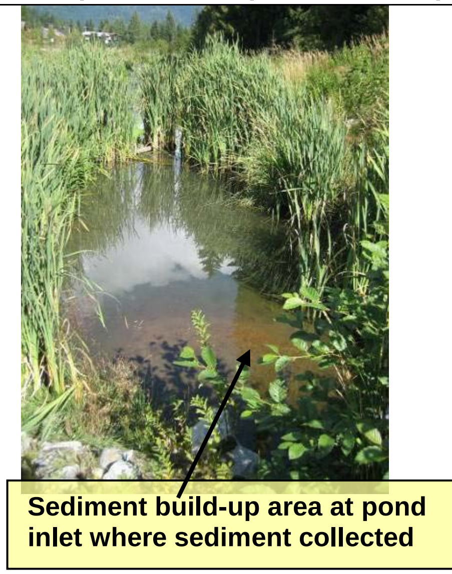
Site selection
Site locations were chosen along a development gradient to assess cumulative impacts of stormwater runoff. Two sites were chosen (see Photo Series 5.2): an upstream (U/S) reference location (E268887), upstream of the Village and most urban development; and a downstream (D/S) location (E267242), which was downstream of most development, at the Riverside Campground.

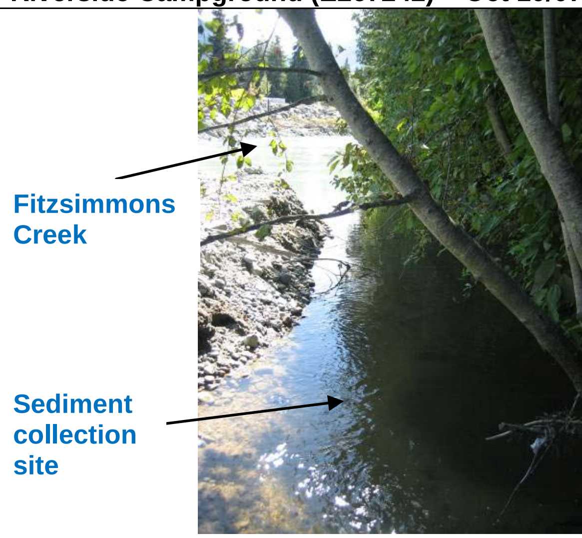
Grab sampling
Water samples were collected and analyzed as described in Section 3.2, where summer low flow sampling (Aug 2007) and non-event sampling (Oct 2007) were also conducted at the downstream site (E267242) in Fitzsimmons Creek.

Sediment sampling
Sediment samples were collected on September 6, 2007 from the inlet of the biofiltration pond and from a small channel entering Fitzsimmons Creek, which conveys the pond discharge mixed with the amenities stream runoff to the creek (Photo Series 5.2, bottom panel). The samples were analyzed for total metals, total organic carbon, and particle size and metal concentrations were compared to applicable B.C. Working Guidelines for Sediment.

Fitzsimmons Creek upstream of Village site (E268887) – Oct 10/07 (Reference site)

Fitzsimmons Creek downstream site, at Riverside Campground (E267242) – Oct 10/07





Fitzsimmons Creek sediment site (lower right area) – Sept 6 07

Photo Series 5.2: Fitzsimmons Creek water sampling sites showing upstream and downstream locations (upper row) and sediment sampling locations in biofiltration pond inlet (bottom left) and outlet of the pond discharge mixed with the 'amenities stream' as it enters Fitzsimmons Creek (bottom right)

5.3 Results & Discussion

5.3.1 Summer grab sampling – August 2007

Results from grab sampling at the downstream site in August 2007, during dry but high glacial runoff conditions, indicated that parameters met B.C. Approved Water Quality Guidelines for the protection of aquatic life (see Appendix 5.1). However, the lab reportable detection limits (RDLs) for several biologically important metals (i.e. cadmium, chromium, copper, and lead) were higher than the guidelines, so it is not known whether these metals met guidelines. RDLs for these metals improved in mid October 2007, allowing for better comparison of October data to guidelines. Turbidity (mean=9 NTU) and total suspended solids (TSS, mean=30.4 mg/L) were elevated at times, which was likely attributable to the elevated glacial silt in the water column occurring during daily glacial melting events in the summer months (Table 5.1).

Table 5.1: Total suspended solids (TSS) and turbidity at the downstream Fitzsimmons Creek site during low flow conditions in August 2007

Fitzsimmons Cr at Riverside Campground (E267242)						
	02-Aug	09-Aug	13-Aug	22-Aug	29-Aug	**Mean**
TSS (mg/L)	19	31	80	9	13	**30.4**
Turbidity (NTU)	5.6	13.2	12.7	8.7	5	**9.0**

5.3.2 Fall grab sampling – October 2007

Several significant precipitation events occurred in October 2007 (Oct 2, 18.8 mm; Oct 7, 23.5 mm; Oct 9-10, 26.3 mm; and Oct 21-22, 19.1 mm), which coincided with grab sampling events on October 2, 10 and 22. **Exceedances of both maximum and mean B.C. Approved Water Quality Guidelines (AWQGs) for the protection of aquatic life occurred for TSS, turbidity, total cadmium, copper, iron, and zinc** to varying degrees and on at least one occasion at both Fitzsimmons Creek sites, which will be discussed in the following sections.

i) TSS and turbidity

During the two non-storm sampling events (Oct 17 and Nov 1), low levels of TSS (<4 mg/L) and turbidity (<1.5 NTU) levels were found at the downstream site in Fitzsimmons Creek (Table 5.2). During high precipitation periods in the Pacific Northwest, elevated suspended sediment and turbidity levels are expected to occur to some degree in creeks and rivers, particularly in steeper gradient creeks. This is reflected in the **B.C. AWQGs for TSS and turbidity during turbid flow periods**, which allows for differences in flow regimes (see Master Appendix A).

Levels of TSS and turbidity were high at the upstream Fitzsimmons Creek site during the first two rain events sampled, and particularly during the second event on October 10, where TSS and turbidity were 200 mg/L and 96 NTU, respectively (Table 5.2 and Figure 5.2). The elevated TSS and turbidity levels on October 2 and 10 at the upstream site are likely naturally derived from the Fitzsimmons Slip area during high precipitation events. However, TSS and turbidity were 488 mg/L and 154 NTU, respectively, at the downstream site, which exceeded guidelines for turbid flow periods (Table 5.2 and Figure 5.2). These increases are likely from urban stormwater runoff entering from the five main discharge points, as well as other diffuse sources along its length. "First flush' events, such as these, often have high sediment and contaminant loads. A majority (97.1 mm, or 64%) of the month's precipitation (150.7 mm) fell in early October, from September 30 to October 10, which accounted for the observed higher flows and resulting high sediment and turbidity levels on October 2 and 10.

Table 5.2: Total suspended solids (TSS) and turbidity results during storm (Oct 2, 10, 17) and non-storm (Oct 17, Nov 1) events for Fitzsimmons Creek in 2007

Fitzsimmons Cr upstream of Village (E268887)				
	Oct 2/07	Oct 10/07	Oct 22/07	**Mean**
TSS (mg/L)	171	200	35	**135**
Turbidity (NTU)	95.8	96.2	4.2	**65**

Fitzsimmons Cr at Riverside Campground (E267242)					Non-storm events	
	Oct 2/07	Oct 10/07	Oct 22/07	**Mean**	Oct 17/07	Nov 1/07
TSS (mg/L)	108	488	22	**206**	<4	<4
Turbidity (NTU)	84.5	154	5.2	**81**	1.0	1.4

Pink cells show guideline exceedances during turbid flow periods

The impacts of increased sediment and turbidity on aquatic life are varied, but are generally recognized to be magnitude and duration dependent. A recent review has also shown that physiological and behavioural effects can occur in salmonids at turbidity levels starting from 10-30 NTU (summarized in Master Appendix C, Bash *et al.*, 2001). Additionally, suspended sediments are of concern at high levels as they are considered to be reservoirs, or sinks, for metals, which can increase availability for uptake by aquatic biota (Singleton, 1987).

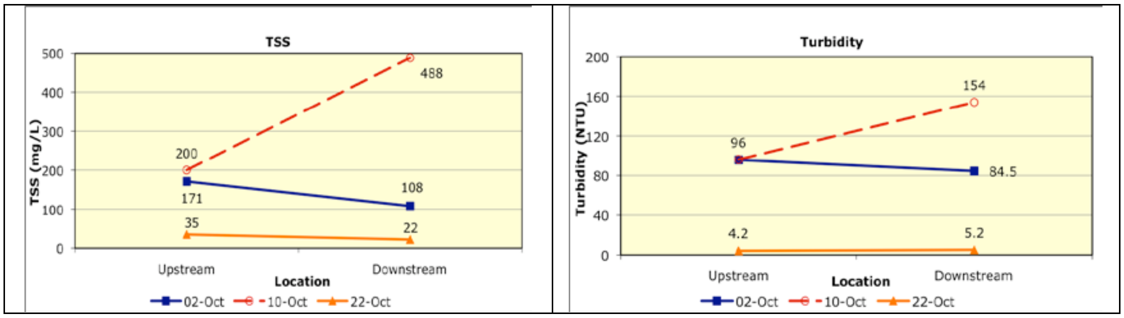


Figure 5.2. Total suspended solids (TSS) and turbidity (NTU) at upstream and downstream Fitzsimmons Creek sites during three rain events in October 2007.

ii) Total cadmium

In the absence of a B.C. AWQG for total cadmium (Cd), the maximum Canadian Environmental Quality Guideline of 0.017 µg/L (freshwater aquatic life) was used for comparison. Once lab reportable detection limits improved in mid October, total Cd was found to slightly exceed this guideline at both sites on October 22 (0.02 µg/L), as well as at the downstream site on October 17 (0.02 µg/L). It is unknown whether Cd is naturally elevated or related solely to stormwater runoff, as the low level results were not available on the October 2 and 10 first flush events.

iii) Total copper

Maximum total copper (Cu) guidelines, adjusted for hardness, ranged from 5.5-8.3 µg/L for the 2007 sampling dates, while the mean guideline is 2 µg/L. In August 2007, the maximum total Cu guidelines were met, but the mean guideline attainment level was not known due to the high reportable detection limit for Cu (Appendix 5.1). During high precipitation events in October 2007, the **mean Cu concentrations exceeded the mean guideline at both sites, where means were 5.5 times higher (11.6 µg/L) at the upstream site, and 7 times higher (14.2 µg/L) at the downstream site** (Appendix 5.2). **Maximum Cu guidelines were also exceeded at both sites on October 2 and 10**, where the Cu concentration at the downstream site (18 µg/L) was only 1.4 times higher than at the upstream site (13 µg/L) on October 2, but was 2.4 times higher at the downstream site (46 µg/L) than at the upstream site (19 µg/L) on October 10 (Figure 5.3). Sources of total Cu were likely derived from upstream suspended sediment inputs, particularly during these first flush events, but were also likely derived from cumulative urban stormwater inputs at the downstream site on October 10. The toxicological effects of Cu on aquatic life are described in Master Appendix D. While aquatic life was exposed to sublethal concentrations of Cu in the creek at times in October 2007, the impacts from Cu alone were likely short-term.

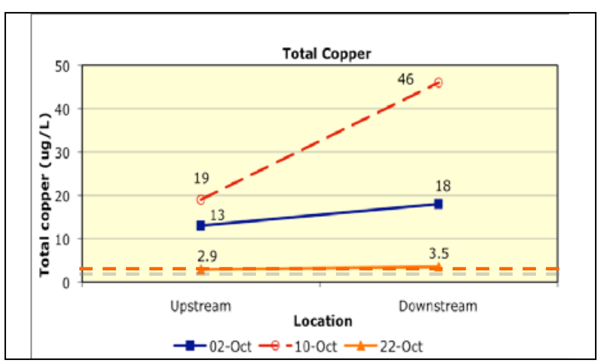


Figure 5.3. Total copper (µg/L) at upstream and downstream Fitzsimmons Creek sites during three rain events in October 2007, showing the mean B.C. AWQG line (2 µg/L, orange-dashed).

iv) Total iron

The maximum total iron (Fe) guideline is 1,000 µg/L (1 mg/L), while the maximum dissolved guideline is 350 µg/L (0.35 mg/L). In August 2007, the dissolved and total Fe guidelines were not exceeded at the downstream (D/S) Fitzsimmons Creek site (dissolved Fe mean=13 µg/L, total Fe mean=306 µg/L; Appendix 5.1). During high precipitation events in October 2007, dissolved Fe concentrations were low at both sites and the guideline was not exceeded (upstream mean=9 µg/L, downstream mean=38 µg/L; Appendix B). The **maximum total Fe guideline**, however, **was exceeded at the upstream site on October 10 (1720 µg/L), and at the downstream site on October 2 (1320 µg/L) and 10 (3680 µg/L)** (Figure 5.4 and Appendix 5.2). As with total Cu concentrations, total Fe can be seen to be increasing with increased suspended sediment concentrations during periods of high runoff, and particularly at the downstream site on October 10 where Fe was 2.1 times higher than at the upstream site. The toxicological effects of Fe on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Fe levels in the creek at times in October 2007, the impacts from Fe alone were likely short-term and minimal.

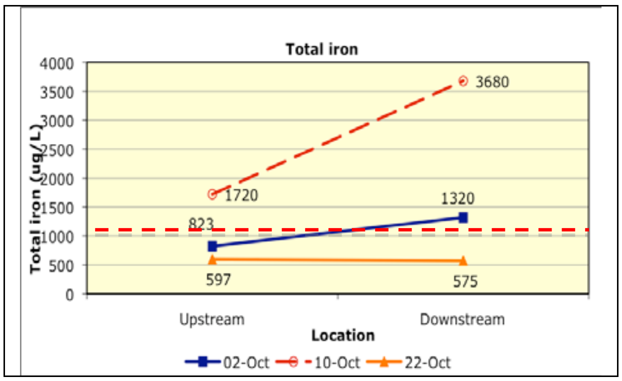


Figure 5.4. Total iron (µg/L, note differences in scale between graphs**)** at upstream and downstream Fitzsimmons Creek sites during three rain events in October 2007, showing maximum total iron B.C. AWQG line (1000 µg/L, red-dashed).

v) Total zinc

The maximum total zinc (Zn) guideline (hardness ≤90 mg/L) is 33 µg/L, while the mean guideline is 7.5 µg/L. In August 2007, these guidelines were not exceeded at the downstream Fitzsimmons Creek site (mean and max of <5 µg/L; Appendix 5.1). During high precipitation events in October 2007, the maximum Zn guideline was met, but **the mean guideline was slightly exceeded at both sites** (upstream mean**=**9 µg/L, downstream mean=9.6 µg/L; Appendix 5.2). As with Cu and Fe, Zn binds to particulate matter and can be seen to be increasing with increased suspended sediment concentrations during high runoff periods, and particularly at the downstream site on October 10 where Zn was 1.6 times higher than at the upstream site (Figure 5.5). The toxicological effects of Zn on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Zn levels in the creek at times in October 2007, the impacts from Zn alone were likely short-term.

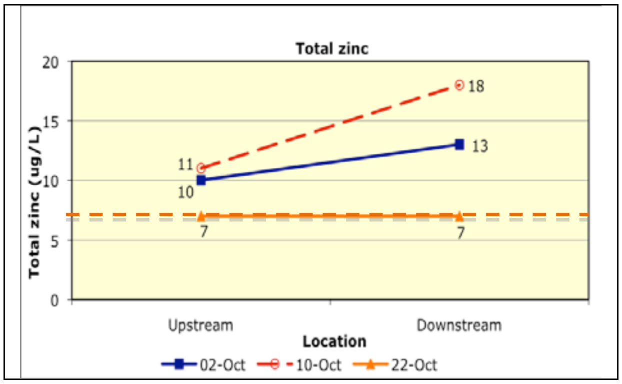


Figure 5.5. Total zinc (µg/L) at upstream and downstream Fitzsimmons Creek sites during three rain events in October 2007, showing mean B.C. AWQG line (7.5 µg/L, orange-dashed).

5.3.3 Sediment metal concentrations

Analysis of a sediment sample taken from the biofiltration pond/amenities **channel outlet to Fitzsimmons Creek**, **showed elevated levels of copper, iron, and manganese** compared to the relevant B.C. Sediment Quality Guidelines (Table 5.3). Iron and manganese are relatively common and co-occur in certain underlying soil types, although the elevated copper levels may be accumulating from stormwater runoff via discharge from the biofiltration pond.

Table 5.3. Metal concentrations in sediment from the biofiltration pond inlet and the outlet to Fitzsimmons Creek, downstream (D/S) of the pond outlet (Sept 6, 2007)

Sediment Samples (Sep 6/07)	RDL	Biofiltration Pond Inlet	Outlet to Fitzsimmons Creek (D/S of pond)	Relevant BC Sediment Quality Guidelines				
				TEL[1]	PEL[1]	ISQG[2]	LEL[3]	SEL[3]
Selected Metals (ug/g)		n=1	n=1					
Total Arsenic (As)	0.2	9.8	3.7		17	5.9		
Total Cadmium (Cd)	0.05	0.61	0.15	0.60	3.50			
Total Chromium (Cr)	1	46	14		90	37		
Total Copper (Cu)	0.5	200	72.9		197	36		
Total Iron (Fe)	100	26,500	22,900				21,200	43,766
Total Lead (Pb)	0.1	29	3.8		91	35		
Total Manganese (Mn)	0.2	423	873				460	1,100
Total Nickel (Ni)	0.8	32.2	11				16	75
Total Zinc (Zn)	1	227	52		315	123		
Organics (ug/g)								
Total Organic Carbon	2	54	7.7					
Particle Size (%)								
Clay (<4 um)		12.2	5.2					
Silt (<63 um)		24.8	18.5					
Sand (<2 mm)		63.0	76.3					

RDL = Reportable Detection Limit
Pink cells indicate exceedences of guidelines

[1] **TEL** = interim threshold effect level, **PEL** = probable effect level
[2] **ISQG** = interim sediment quality guideline
[3] **LEL** = lowest effect level, based on SLC, SEL = severe effect level, based on SLC (SLC is Screening Level Concentration)

Analysis of a sediment sample taken from the inlet of the **biofiltration pond**, where sediment deposition preferentially occurs, **showed elevated levels of arsenic, chromium, copper, iron, nickel and zinc** compared to the relevant B.C. Sediment Quality Guidelines (Table 5.3). These levels are likely accumulating from Whistler Village runoff during high precipitation and snowmelt periods. Copper was also found to be elevated in road salt and sand used in winter road maintenance [see Section 6.3, part a)], which may be accumulating and be of concern for aquatic organisms, particularly those inhabiting the sediment layers in those areas, or those sensitive to copper.

5.4 Conclusions

Results from grab sampling during both dry (August 2007) and wet (October 2007) periods show that **Fitzsimmons Creek is receiving increased suspended sediment loads during periods of high precipitation**. With the increased sediment loads, **there was an observed increase in sediment-associated metals, particularly copper, iron and zinc**. This was particularly true on October 10, when TSS, copper, iron, and zinc were the highest at the downstream site, approximately two times higher than at the upstream site. Significant sources of sediment are likely originating from the Fitzsimmons Slip, although urban runoff from the Whistler Village and further downstream neighbourhoods also appear to be contributing elevated levels of both sediments and associated metals during periods of high runoff. It should also be noted that these metals may have additive or synergistic effects (i.e. increased toxicities in combination) on aquatic life which are important to consider.

Climate change is also important to consider, as precipitation and temperature patterns are likely to change, which will influence stormwater flows in the fall and winter in the future. A warming climate is predicted to 'promote the shift of streams from *hybrid* (rain/snowmelt) to *pluvial* (rain-dominated) systems', as well as having increased potential for winter floods in *pluvial* systems (Rodenhuis *et al.*, 2007). This has implications for Fitzsimmons Creek, which currently has a *glacial* and *hybrid* flow system, but could experience higher proportions of rainfall compared to snowfall in the October-December rainy season. Higher flows during this time period will increase stormwater runoff and thus potential impacts to aquatic life from poor water quality. Thus, it will become even more important to ensure good stormwater quality, to prevent potential impacts to downstream creek reaches and lakes, and the aquatic life and recreational activities associated with them.

5.5 Recommendations

It is recommended that:

- **Additional stormwater infrastructure for 'untreated' runoff not be directed to Fitzsimmons Creek as the creek is prone to natural erosion and high sediment loading which is also leading to increases in sediment-associated metals at times (i.e. Cu, Fe & Zn).** Thus, any additional sources of suspended sediments and sediment-associated metals from untreated urban runoff could exacerbate water quality for aquatic life in the creek.
- **Optimization of source controls be implemented in Whistler Village**, so that the impact of urban stormwater runoff on Fitzsimmons Creek can be minimized. Examples of source control can include low-impact development (LID), increased infiltration, and detention ponds, which can act to 'treat' runoff by reducing suspended sediment and contaminant loading.

APPENDIX 5.1 – WATER QUALITY RESULTS: AUGUST 2007

E267242 FITZSIMMONS CR AT RIVERSIDE CAMPGROUND - AUGUST 2007 Downstream	RDL	02-Aug	09-Aug	13-Aug	22-Aug	29-Aug	Mean (n=5)	BC Water Quality Guideline (Aquatic Life) 30-d mean	max	Notes
Field Measurements										
Temperature (deg C)		7.09	6.9	6.66	6.86	7.67	**7.04**		10.0-18.0	rainbow optimum
pH		6.2	6.52	6.21	7.02	7.38	**6.67**		6.5-9.0	
Dissolved oxygen (DO, mg/L)		12.68	10.94	10.81	9.42	9.49	**10.67**	8.0-11.0	5.0-9.0*	*minimum
Organics & Inorganics (mg/L)										
Total Organic Carbon	0.5	<0.5	<0.5	<0.5	<0.5	<0.5	**<0.5**			
Total Hardness (CaCO3)	0.5	33.4	36.5	42.2	41.1	39.8	**38.6**			
Total Suspended Solids	4	19	31	80	9	13	**30**	see text	see text	
Turbidity (NTU)	0.1	5.6	13.2	12.7	8.7	5	**9.0**	see text	see text	
Conductivity (uS/cm)	1	70	75	85	86	85	**80**			
Dissolved Chloride (Cl)	0.5	0.8	<0.5	<0.5	0.7	<0.5	**0.6**	150	600	
Nutrients (mg/L)										
Total Nitrogen (N)	0.02	0.04	0.03	0.03	0.07	0.02	**0.04**			
Total Kjeldahl Nitrogen (Calc)	0.02	0.02	0.02	<0.02	0.07	<0.02	**0.03**			
Total Organic Nitrogen (N)	0.02	0.02	0.02	<0.02	0.07	<0.02	**0.03**			
Nitrate (N)	0.002	0.022	0.007	0.006	0.005	0.002	**0.008**	40	200	
Nitrite (N)	0.002	<0.002	0.003	0.007	<0.002	0.002	**0.003**	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005	<0.005	<0.005	<0.005	**<0.005**	1.92-1.99	19.9-27.2	pH & T dependent
Total Phosphorus (P)	0.002	0.026	0.016	0.029	0.018	0.003	**0.018**			
Orthophosphate (P)	0.001	0.007	0.004	0.006	0.004	0.003	**0.005**			
Selected Metals (ug/L)										
Dissolved Aluminum (Al)	20	30	20	30	30	50	**32**	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	<2	<2	<2	**<2**		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	<5	<5	<5	**<5**		1.0 (Cr(VI))	CCME
Total Cobalt (Co)	5	<5	<5	<5	<5	<5	**<5**	4	110	
Total Copper (Cu)	5	<5	<5	5	<5	<5	**<5**	2	5.8-7.4	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	14	12	11	16	10	**13**	n/a	350	
Total Iron (Fe)	5	269	524	407	231	100	**306**	n/a	1000	
Total Lead (Pb)	30	<30	<30	<30	<30	<30	**<30**	4	18	H=30 mg/L
Total Manganese (Mn)	1	13	21	22	12	9	**15**	700	800	H=25 mg/L
Total Molybdenum (Mo)	5	<5	<5	<5	<5	<5	**<5**	1000	2000	
Total Selenium (Se)	30	<30	<30	<30	<30	<30	**<30**	2	n/a	
Total Silver (Ag)	10	<10	<10	<10	<10	<10	**<10**	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	<5	<5	<5	<5	<5	**<5**	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)										
E. coli	1	12	4	15	2	3	**5**	385	n/a	geomean,
Fecal coliforms	1	12	5	15	2	3	**6**	n/a	n/a	secondary contact

RDL = Reportable Detection Limit

APPENDIX 5.2 – WATER QUALITY RESULTS: OCTOBER 2007

E268887 FITZSIMMONS CR U/S OF VILLAGE - OCTOBER 2007 Upstream	RDL	Oct 2 Event 1	Oct 10 Event 2	RDL*	Oct 22 Event 3	Mean (n=3)	BC Water Quality Guideline (Aquatic Life) 30-d mean	max	Notes
Field Measurements									
Temperature (deg C)		5.3	4.67		3.76	**4.6**		10.0-18.0	rainbow optimum
pH		7.32	n/a		6.08	**6.7**		6.5-9.0	
Dissolved oxygen (DO, mg/L)		9.72	n/a		10.82	**10.3**	8.0-11.0	5.0-9.0*	*minimum
Specific conductivity (uS/cm)		125	66		124	**105**			
Organics & Inorganics (mg/L)									
Total Oil and grease	1	1	<1		1	**1**			
Total Organic Carbon	0.5	1.4	1.9		0.9	**1.4**			
Total Hardness (CaCO3)	0.5	66.7	37		54.8	**52.8**			
Total Suspended Solids	4	171	200		35	**135**	see text	see text	
Turbidity (NTU)	0.1	95.8	96.2		4.2	**65.4**	see text	see text	
Conductivity (uS/cm)	1	126	67		120	**104**			
Dissolved Chloride (Cl)	0.5	<0.5	0.5		<0.5	**0.5**	150	600	
Nutrients (mg/L)									
Total Nitrogen (N)	0.02	0.1	0.14		0.05	**0.10**			
Total Kjeldahl Nitrogen (Calc)	0.02	0.09	0.09		0.03	**0.07**			
Total Organic Nitrogen (N)	0.02	0.09	0.09		0.03	**0.07**			
Nitrate (N)	0.002	0.004	0.033		0.021	**0.019**	40	200	
Nitrite (N)	0.002	0.008	0.017		0.002	**0.009**	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005		<0.005	**<0.005**	1.94-1.97	16.9-27.2	pH & T dependent
Total Phosphorus (P)	0.002	n/a	0.081		0.056	**0.070**			
Dissolved Phosphorus (P)	0.002	0.018	0.012		n/a	**0.015**			
Orthophosphate (P)	0.001	0.02	0.012		0.007	**0.013**			
Selected Metals (ug/L)									
Dissolved Aluminum (Al)	20	30	50	1	14	**31**	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	0.01	0.02	n/a		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	1	<1	n/a		1.0 (Cr(VI))	CCME
Total Cobalt (Co)	5	<5	<5	0.5	<0.5	n/a	4	110	
Total Copper (Cu)	5	13	19	0.2	2.9	**11.6****	2	5.5-8.3	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	5	38	5	14	**19**	n/a	350	
Total Iron (Fe)	5	823	1720	5	597	**1047**	n/a	1000	
Total Lead (Pb)	30	<30	<30	0.2	0.2	n/a	4	18	H=30 mg/L
Total Manganese (Mn)	1	69	84	1	18	**57**	700	800	H=25 mg/L
Total Molybdenum (Mo)	5	<5	<5	1	3	n/a	1000	2000	
Total Selenium (Se)	30	<30	<30	0.1	0.3	n/a	2	n/a	
Total Silver (Ag)	10	<10	<10	0.02	0.03	n/a	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	10	11	5	7	**9****	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)									
E. coli	1	170	10		4	**19****	385	n/a	geomean,
Fecal coliforms	1	220	11		4	**21****	n/a	n/a	secondary contact

RDL = Reportable Detection Limit
* RDL changed for metals due to lab method changes
** Means based on n=3, while guideline asks for n=5
Pink cells indicate exceedences of guidelines

E267242 FITZSIMMONS CR AT RIVERSIDE CAMPGROUND - OCTOBER 2007 Downstream									BC Water Quality Guideline (Aquatic Life)		
	RDL	Oct 2 Event 1	Oct 10 Event 2	RDL*	Oct 17 Non-storm	Oct 22 Event 3	Nov 1 Non-storm	Mean (n=5)	30-d mean	max	Notes
Field Measurements											
Temperature (deg C)		6	4.98		3.7	4.26	2.56	**4.3**		10.0-18.0	rainbow optimum
pH		7.13	n/a		6.45	5.99	6.99	**6.6**		6.5-9.0	
Dissolved oxygen (DO, mg/L)		12.25	n/a		11.28	10.87	12.73	**11.8**	8.0-11.0	5.0-9.0*	*minimum
Specific conductivity (uS/cm)		113	83		115	138	107.4	**111**			
Organics & Inorganics (mg/L)											
Total Oil and grease	1	<1	<1		n/a	2	n/a	**1**			
Total Organic Carbon	0.5	0.7	2.2		1.3	0.8	1	**1.2**			
Total Hardness (CaCO3)	0.5	57.6	40.7		53.7	56.2	51.5	**51.9**			
Total Suspended Solids	4	108	488		<4	22	<4	**125**	see text	see text	
Turbidity (NTU)	0.1	84.5	154		1	5.2	1.4	**49.2**	see text	see text	
Conductivity (uS/cm)	1	120	62		111	120	110	**105**			
Dissolved Chloride (Cl)	0.5	1.8	1.2		1	1.4	1.4	**1.4**	150	600	
Nutrients (mg/L)											
Total Nitrogen (N)	0.02	0.11	0.23		0.1	0.05	0.06	**0.11**			
Total Kjeldahl Nitrogen (Calc)	0.02	0.08	0.18		0.08	0.03	0.03	**0.08**			
Total Organic Nitrogen (N)	0.02	0.08	0.18		0.08	0.03	0.03	**0.08**			
Nitrate (N)	0.002	0.022	0.027		0.021	0.02	0.037	**0.025**	40	200	
Nitrite (N)	0.002	0.009	0.023		<0.002	0.002	<0.002	**0.008**	0.02	0.06	when Cl < 2mg/L
Ammonia (N)	0.005	<0.005	<0.005		<0.005	<0.005	<0.005	**<0.005**	1.92-1.99	19.9-27.2	pH & T dependent
Total Phosphorus (P)	0.002	n/a	1.26		0.005	0.037	0.008	**0.328**			
Dissolved Phosphorus (P)	0.002	0.017	0.012		n/a	n/a	n/a	**0.015**			
Orthophosphate (P)	0.001	0.017	0.014		0.005	0.006	0.007	**0.010**			
Selected Metals (ug/L)											
Dissolved Aluminum (Al)	20	40	80	1	23	26	23	**38**	50	100	pH ≥ 6.5
Total Cadmium (Cd)	2	<2	<2	0.01	0.02	0.02	0.01	n/a		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	1	<1	<1	<1	n/a		1.0 (Cr(VI))	CCME
Total Cobalt (Co)	5	<5	9	0.5	<0.5	<0.5	<0.5	n/a	4	110	
Total Copper (Cu)	5	18	46	0.2	1.8	3.5	1.6	**14.2**	2	5.8-7.4	H ≤ 50 mg/L
Dissolved Iron (Fe)	5	16	75	5	35	36	27	**38**	n/a	350	
Total Iron (Fe)	5	1320	3680	5	156	575	132	**1173**	n/a	1000	
Total Lead (Pb)	30	<30	<30	0.2	<0.2	0.2	<0.2	n/a	4	18	H=30 mg/L
Total Manganese (Mn)	1	82	210	1	15	30	13	**70**	700	800	H=25 mg/L
Total Molybdenum (Mo)	5	<5	<5	1	3	2	3	n/a	1000	2000	
Total Selenium (Se)	30	<30	<30	0.1	0.2	0.3	0.2	n/a	2	n/a	
Total Silver (Ag)	10	<10	<10	0.02	<0.02	<0.02	<0.02	n/a	0.05	0.1	H ≤ 100 mg/L
Total Zinc (Zn)	5	13	18	5	<5	7	<5	**9.6**	7.5	33	H ≤ 90 mg/L
Bacteriology (Col/100 mL)											
E. coli	1	170	25		5	3	<1	**9**	385	n/a	geomean,
Fecal coliforms	1	180	29		5	13	<1	**13**	n/a	n/a	secondary contact

RDL = Reportable Detection Limit
* RDL changed for metals due to lab method changes
Pink cells indicate exceedences of guidelines

6.0 WATER QUALITY IN ALL CREEKS DURING THE SNOWMELT PERIOD IN MAY 2008

6.1 Study Area

The study areas, including Whistler Creek (and Nita Lake), Crabapple Creek, and Fitzsimmons Creek have been described in previous sections (see Sections 3.1, 4.1 and 5.1).

6.2 Methods & Data Analysis

Site selection and sampling methods
Sampling sites up- and downstream of most winter road maintenance impacts were selected in each creek to assess cumulative impacts of snowmelt runoff (see Appendix 6.1). Grab sampling captured snowmelt in 2008 from Apr 30 to May 27, at a frequency of 5 times in 30 days to satisfy statistical requirements for several B.C. Approved Water Quality Guidelines (AWQGs). This period included a significant warming period from May 15-18 where maximum air temperatures ranged from 23.4 to 29.8ºC (average of 16.4-17.1 ºC). Snowmelt runoff from the large snow pile in Day Lot 5, near Fitzsimmons Creek was also sampled four times, on May 21, May 27, June 3, and June 11. Summer baseflow (Aug 2007) and fall high flow (Oct 2007) grab sample data were also used for comparison with the meltwater flow period, where appropriate.

Water samples were collected and analyzed as described in Section 3.1, although oil and grease were not analyzed.

Analysis of road salt and sand raw material
The RMOW receives annual shipments of road salt from Mexico and sand from north of Mount Currie, B.C. Solid samples of both were collected from the works yard and analyzed for trace metal content using the Toxicity Characteristic Leaching Procedure (TCLP), which simulates the climatic leaching action expected to occur from solids in landfills (Maxxam Analytics, 2008). Extraction fluid (250 mL, pH 4.91) was used to extract metals by tumbling with 12.5 g of road salt or sand in a sealed container for 18±2 hours. The resulting leachate was analyzed accordingly for metal concentrations.

Nita Lake Water Quality Monitoring
Grab samples were collected at the surface, mid-depth, and bottom from Nita Lake, which Whistler Creek flows into, on May 6, June 11, July 10, August 12, Sept 8 and October 14 in 2008. Water samples were analyzed for bacteria (fecal coliforms, *E. coli*), total suspended solids (TSS), turbidity, specific conductivity, chloride, nutrients (nitrogen and phosphorus), and metals (total and dissolved). Only the parameters related to snowmelt, including specific conductivity and chloride will be assessed and discussed in this report.

Automated turbidity monitoring
Three automated monitoring stations, one in Whistler Creek (near mouth) and two in Crabapple Creek (upstream @ Brio and near mouth), collected DO, water temperature, specific conductivity, pH, and turbidity data at 15 min intervals from April to July 2008 (see Photo Series 6.1). Automated monitoring is designed to capture both baseline and high flow (rain event/snowmelt) data, and was used in this study to determine a) peak ion concentrations from dissolving road salt using specific conductivity, and b) magnitude and duration of turbidity events during snowmelt, if detectable.

 Whistler Creek, near mouth	 Crabapple Creek, near mouth

Photo Series 6.1: Automated monitoring stations in Whistler and Crabapple Creeks (Nov 19/08)

i) Relationship between specific conductivity and chloride

Linear relationships between specific conductivity (SC) and each of chloride (Cl^-), sodium (Na^+) and calcium (Ca^{2+}) were first determined from grab samples collected in August 2007, October 2007 and May 2008 at downstream sites in Whistler and Crabapple Creek. Relationships were very good between SC and these ions in Whistler Creek, but only good between SC and Ca^{2+} in Crabapple Creek (see Table 6.1). Thus, Whistler Creek automated data were used to predict peak snowmelt Cl^- and Na^+ concentrations, as Crabapple Creek data could not be used to accurately predict these ion levels, possibly due to strong groundwater influences in downstream portions of the creek.

Table 6.1. Relationships between specific conductivity (SC) and major ions (Cl^-, Na^+, Ca^{2+}) in Whistler and Crabapple Creeks

Whistler Creek (E213692)	Cl^- = 0.1733(SC) - 11.089	R^2=0.92 (n=13)
	Na^+ = 0.0788(SC) - 4.1278	R^2=0.94 (n=13)
	Ca^{2+} = 0.0779(SC) + 6.2555	R^2=0.96 (n=13)
Crabapple Creek (E252029)	Cl^- = 0.035(SC) + 0.2014	R^2=0.36 (n=15)
	Na^+ = 0.0192(SC) + 0.5735	R^2=0.52 (n=15)
	Ca^{2+} = 0.1805(SC) – 2.3056	R^2=0.93 (n=15)

A total of 3981 data points were used for the Whistler Creek analysis, from April 1 to June 2, 2008, although data were not collected from April 17 to May 6 as the YSI needed probe repairs following routine calibration. Thus, analysis of peak chloride concentrations could only be completed for April 1 to 17.

ii) Turbidity

Newcombe (2003) proposed a method to assess potential 'severity of ill effects' (SEV) to clear water fishes using both magnitude and duration of turbidity events, as impacts may be felt both at higher magnitudes over shorter durations, or at lower magnitudes over longer durations. This model, which provides threshold turbidity levels, is useful as a tool to determine the onset of ill effects caused by excessive turbidity to clear water fishes, as well as to determine the rate at which serious ill effects are likely to escalate (Newcombe, 2003). SEV scores can be calculated and used to determine whether water conditions are *ideal* (0≤SEV<0.5), *slightly impaired* (0.5≤SEV<3.5), *significantly impaired* (3.5≤SEV<8.5), or *severely impaired* (SEV ≥8.5) for fish (Table 6.6). An SEV event score of 0 has no effect while an event of 14 would lead to 100% mortality.

A magnitude-duration matrix table adapted from Newcombe (2003), including the appropriate equations for calculating SEV scores, is shown in Master Appendix B. Research has shown that physiological and behavioural effects can occur in salmonids at turbidity levels starting from 10-30 NTU (see Master Appendix C, Bash *et al*., 2001). For the purposes of this study, a turbidity threshold of 20 NTU was chosen to define the start and end of turbidity events at locations where background turbidity could not be monitored concurrently with downstream locations. This value is in the mid-range of initial effects, and events <20 NTU are not generally long lasting in the Whistler area (i.e. <24 h), leading to nil event classifications, which are ideal for fish. According to Newcombe's Table in Master Appendix B, minor effects would not be felt by fish for a 20 NTU turbidity event until 24h (SEV=2). Thus, the 20 NTU threshold allows for characterization of minor to severe events, which are of more concern for fish health and survival. This threshold also allows for 'natural' turbidity increases during periods of high flow from steeper gradient streams in the Whistler area, and particularly where previous land use practices, such as logging, have altered the landscape in background locations.

The B.C. turbidity guideline during turbid flow periods states that 'induced turbidity should not exceed background levels by more than 8 NTU at any time when background turbidity levels are moderate, i.e. 8-80 NTU (see Master Appendix A). This guideline was applied to Crabapple Creek data at the downstream location at times when upstream data were also collected (Apr 30-May 7). Thus, downstream turbidity events of concern were defined as those that exceeded upstream turbidity by >8 NTU. SEV scores were generated using averages and durations for each whole turbidity event, starting and ending at either 20 NTU (upstream sites) or >8 NTU above background (downstream site), and lasting for at least one hour (Newcombe's first time interval). It should be stated that this is an interim approach to characterize the impacts of turbidity to clear water fishes, which can be refined at a later date when natural turbidity patterns in the area are better understood. It is still considered to be a useful tool to describe the overall condition of the water to fish, whether upstream or downstream of impacts. Table 6.2 provides information on the number of turbidity data points used, outliers removed, and gaps in the data.

Table 6.2. Data limitations for the automated turbidity data used for Crabapple and Whistler Creeks, including outliers, gaps, start and end dates.

Automated Site	Data Points Used	Start Date	End Date	Data Gaps	Outliers
Crabapple Creek (U/S @ Brio)	7949	Apr 9	Jul 10	1. May 15 (23:30) to May 27 (7:45) – under sediment 2. May 27 (8:00) to Jun 3 (11:45)	1
Crabapple Creek (D/S @ mouth)	5214	Apr 9	Jul 10	1. Apr 24 (10:15) to Apr 30 (13:45) 2. May 10 (00:15) to Jun 11 (12:45)	0
Whistler Creek (D/S @ mouth)	3981	Apr 1	Jun 2	1. Apr 15 (21:30) to Apr 16 (10:30) 2. Apr 16 (18:30) to Apr 17 (12:00) 3. Apr 17 (17:30) to May 6 (13:00) – calibration & sensor repairs needed	12

6.3 Results & Discussion

6.3.1 Analysis of road salt and sand leachate

Analysis of road salt and sand leaching potential under rainfall (i.e. lower pH) conditions indicated elevated levels of copper in both road salt (0.3 mg/L) and sand (0.1 mg/L) (Table 6.3). This allows for an annual estimation of approximately 1.5 kg copper from ~250 tonnes of road salt, and 6 kg from ~3,000 tonnes of sand, that has the potential to leach into local waterways via ground and surface water flows. Copper is of particular concern to fish and will be discussed further in the Exceedances section.

Table 6.3. Metals in leachate from road salt and sand used in RMOW

TCLP Metals (Leachate) Analysis			
	RDL	Road salt	Sand
Metal Leachate above RDL (mg/L)			
Barium (Ba)	0.1	0.1	0.3
Copper (Cu)	0.1	0.3	0.1
kg Cu/kg material		0.000006	0.000002
Winter application (kg)		2.5×10^5	3.0×10^6
Total quantity Cu (kg)		1.5	6

RDL = Reportable Detection Limit

6.3.2 Water quality of runoff from snow storage area in Day Lot 5

Results from the Lot 5 snow storage area runoff sampling in May and June 2008 indicated **elevated levels of TSS, turbidity, and metals (cadmium, copper, iron and zinc)** when compared to the B.C. Approved Water Quality Guidelines (AWQGs) for the protection of aquatic life (Table 6.4). Cadmium, iron, copper, and zinc can be elevated in urban areas, and thus may exist in higher levels in snow removed from urban road surfaces. However, the particularly high levels of copper, TSS and turbidity were also likely due to the use of sand and road salt, both of which contain elevated levels of copper with high leaching potential during snowmelt periods.

Table 6.4. Water chemistry of runoff from snow storage area in Day Lot 5 in May and June 2008, near Fitzsimmons Creek

SNOW PILE - DAY LOT 5 in WHISTLER							BC Water Quality Guidelines		
	RDL	21-May	27-May	03-Jun	11-Jun	Mean	30-day mean	max	Notes
Field Measurements									
Temperature (deg C)		1.71	2.15	0.85	2.53	**1.81**		10.0-18.0	rainbow optimum
Dissolved oxygen (mg/L)		11.87	11.37	11.48	11.7	**11.61**	8.0-11.0	5.0-9.0*	*minimum
pH (pH units)		6.9	7.4	6.8	6.4	**6.9**		6.5-9.0	
Organics & Inorganics (mg/L)									
Total Hardness (CaCO3)	0.5	10.2	13.1	16	13.2	**13.1**			
Total Suspended Solids	4	150	92	150	410	**201**	Mean <5 mg/L above background		
Turbidity (NTU)	0.1	24.4	50.3	79.7	170	**81.1**	Mean <2 NTU above background		
Conductivity (uS/cm)	1	37	49	36	32	**39**			
Dissolved Chloride (Cl)	0.5	3.8	4.5	2.4	2.3	**3.3**	150	600	
Nutrients (mg/L)									
Ammonia (N)	0.005	0.055	0.072	0.145	0.138	**0.103**	1.9-2.0	26.5-27.5	pH & T dependent
Nitrate (N)	0.002	0.021	0.036	0.036	0.073	**0.042**	40	200	
Nitrite (N)	0.002	0.015	0.021	0.033	0.035	**0.026**	0.04	0.12	when Cl 2-4 mg/L
Total Phosphorus (TP)	0.002	0.068	0.069	0.068	0.100	**0.076**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.046	0.002	0.055	0.056	**0.040**			
Selected Metals (ug/L)									
Dissolved Aluminum (Al)	0.2	22.1	63.4	39.1	31.1	**38.9**	50	100	pH > 6.5
Dissolved Iron (Fe)	1	21	54	30	23	**32**		350	
Total Cadmium (Cd)	0.005	0.053	0.037	0.073	0.075	**0.060**		0.017	CCME (interim)
Total Copper (Cu)	0.05	18	14.8	20.1	17.6	**17.63**	2	3-3.5	H < 50 mg/L
Total Iron (Fe)	1	1650	1460	2090	1830	**1758**		1000	
Total Lead (Pb)	0.005	2.44	1.92	3.53	4.35	**3.060**	4	18	H=30 mg/L
Total Manganese (Mn)	0.05	74.9	49.7	79.5	63.6	**66.93**	700	800	H=25 mg/L
Total Zinc (Zn)	0.1	17	13.7	28.2	27.0	**21.5**	7.5	33	H<90 mg/L
Total Calcium (Ca), mg/L	0.05	2.96	4.11	4.77	3.90	**3.94**			
Total Magnesium (Mg), mg/L	0.05	0.67	0.69	1	0.85	**0.80**			
Total Sodium (Na), mg/L	0.05	4.15	5.34	2.2	1.72	**3.35**			

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines
Pink cells indicate exceedences of guidelines

Currently, this discharge appears to drain to nearby ditches and infiltrates the gravel parking lot and does not appear to enter Fitzsimmons Creek via surface flows. However, runoff from this area would be of greater concern if it were to be paved and allowed to flow into the creek. Copper leachate toxicity from the snow storage area runoff would be of particular concern for fish in the creek.

6.3.3 General trends

General trends during the 2008 snowmelt period included **increasing levels of chloride (Figure 6.1), sodium and calcium from upstream to downstream locations, particularly on April 30**. These differences decreased on following sampling dates in May, and were not observable by May 21 in Whistler and Fitzsimmons Creeks. However, downstream chloride levels in Crabapple Creek did not return to upstream background levels, remaining slightly elevated in late May.

Total suspended solids (TSS) and turbidity in grab samples were not significantly higher in downstream sites compared to upstream sites in all three creeks during May 2008 (Appendix 6.2). **Metals, particularly iron (dissolved and total), cadmium, copper, manganese, and zinc were found to be elevated in downstream locations on all occasions in Crabapple Creek**. Only total iron was elevated in Whistler Creek, while total manganese and dissolved iron were elevated in Fitzsimmons Creek until May 21 (Appendix 6.2).

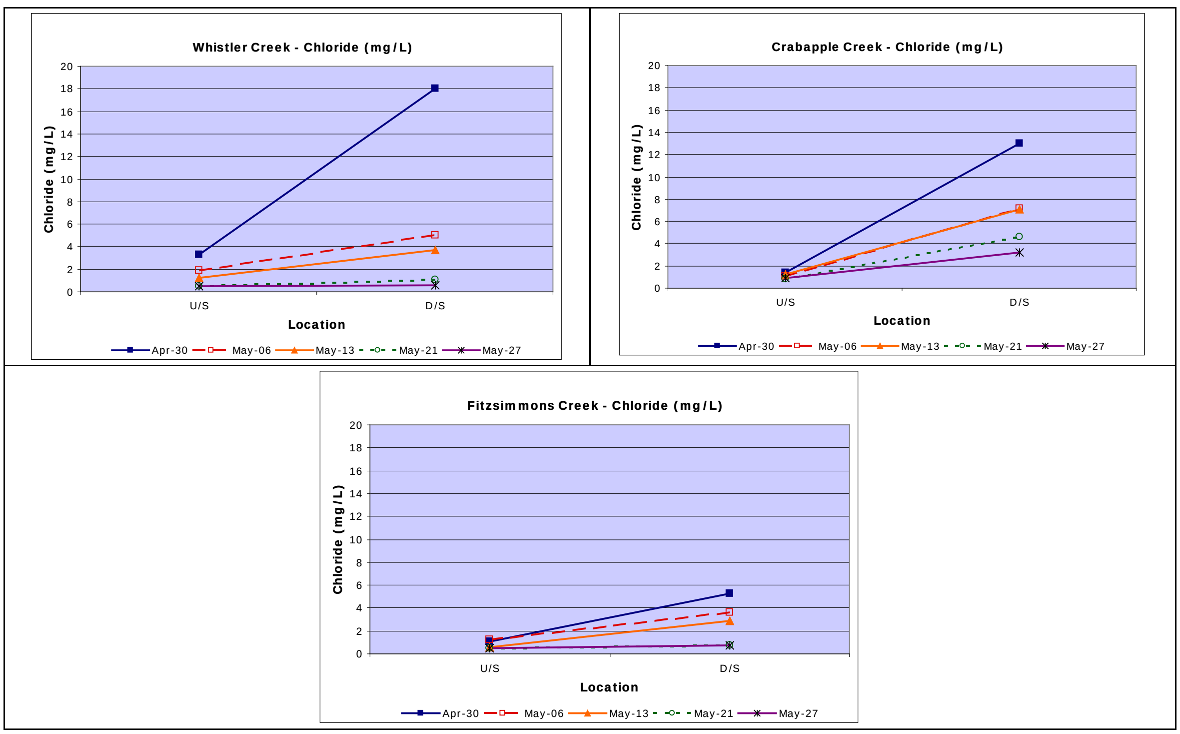


Figure 6.1. Comparison of chloride levels in creeks during snowmelt period sampling, May 2008

6.3.4 Exceedances of B.C. Approved Water Quality Guidelines (AWQGs)

i) Summary

A summary of the exceedances of B.C. AWQGs in the three creeks is provided in Table 6.5. Specific exceedances for aluminum (Al), cadmium (Cd), copper (Cu) and zinc (Zn) will be discussed for the relevant waterbodies in the following sections.

Table 6.5. Summary of exceedances of B.C. Approved Water Quality Guidelines in Whistler, Crabapple and Fitzsimmons Creeks during snowmelt period sampling in May 2008

Creek	Site	Maximum Exceedences					Mean Exceedences
		30-Apr	06-May	13-May	21-May	27-May	
Whistler	U/S		Cd				
	D/S		Cd				
Crabapple	U/S	Al, Cd	Al, Cd	Al, Cd	Al, Cd	Al, Cd	Al, Cu, Zn
	D/S	Cd	Al, Cd	Al, Cd	Al, Cd	Al, Cd	Al, Cu, Zn
Fitzsimmons	U/S		Cd				Cu
	D/S	Cd	Cd	Cd			Cu

ii) Dissolved aluminum (Al)

The **maximum (100 µg/L) and mean (50 µg/L) dissolved aluminum (Al) guidelines were exceeded only in both Crabapple Creek sites** (Table 6.5). Dissolved Al concentrations ranged from 119-254 µg/L at the upstream site, and 72.8-186 µg/L at the downstream site (Appendix 6.2). Mean concentrations were 183.6 and 138.6 µg/L at the up- and downstream sites, respectively. Al appears to be naturally elevated in the creek, as downstream levels ranged from 60-90 µg/L (n=5) during summer base flow conditions in August 2007, and from 80-114 µg/L (n=4) during fall high flow conditions in October 2007. Additional sources of elevated Al during the snowmelt period may be from upstream sediment sources during high flows. The toxicological effects of Al on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Al levels in Crabapple Creek at times in May 2008, the impacts from Al alone were likely short-term and minimal.

iii) Total cadmium (Cd)

In the absence of a B.C. AWQG for total cadmium (Cd), the maximum Canadian Environmental Quality Guideline of 0.017 µg/L (freshwater aquatic life) was used for comparison. This **guideline was exceeded in all three creeks at least once, but was exceeded on all dates and in both up- and downstream sites in Crabapple Creek** (Appendix 6.2). There is some evidence from October 2008 high flow sampling that total Cd can be naturally elevated in Crabapple Creek during high flows, as an upstream sample had a concentration of 0.015 µg/L, which is close to matching the federal guideline. Cd levels subsequently increased 4-fold (0.062 µg/L) further downstream, which was attributed to increased sediment inputs from mountain activities (i.e. bike park and road runoff), and which also served as the upstream site for the snowmelt study. Cd is also likely anthropogenically derived in downstream locations, i.e. from road surfaces.

Cd is a common metal found in urban stormwater runoff, one source coming from tire wear on road surfaces. Additionally, elevated chloride levels during snowmelt periods could increase dissolved Cd levels in sediment pore water through ionic exchange, thereby contributing to increased toxicity for aquatic organisms living in sediment (Marsalek, 2003). Cd is a non-essential metal that is of environmental concern as it readily bioconcentrates in aquatic organisms and biomagnifies in the food chain (see Table 1.1). Effects to aquatic life forms include impairment of macrophyte and fish growth, as well as reduced long-term survival and growth at sublethal exposures (F. Solomon, UBC, October 28, 2008, personal communication).

iv) Total copper (Cu)

While the mean copper guideline is 2 µg/L, maximum total copper (Cu) guidelines for the three creeks, adjusted for hardness, ranged from 3.5-10.9 µg/L. The maximum Cu guidelines were met in all creeks on all dates, and the mean total Cu concentrations in Whistler Creek met the guideline. **However, mean Cu guideline was slightly exceeded in up- and downstream locations of Crabapple and Fitzsimmons Creeks, with the highest mean exceedance (5.13 µg/L) occurring at the downstream Crabapple Creek site** (Appendix 6.2). Cu in both Crabapple and Fitzsimmons Creeks can be elevated during periods of high flow when suspended sediments are also elevated, i.e. total Cu ranged from 4.6-22 µg/L and 1.6-46 µg/L, respectively, during stormwater flows in October 2007. However, additional sources from both the road salt and sand applications, as well as from road surfaces (engine and break wear), may be elevating Cu concentrations to levels that may be of concern for both aquatic life and algae. The toxicological effects of Cu on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Cu levels in Crabapple and Fitzsimmons Creeks at times in May 2008, the impacts from Cu alone were likely short-term and minimal.

v) Total zinc (Zn)

The **mean total zinc (Zn) guideline (7.5 µg/L) was exceeded in Crabapple Creek at both sites in May 2008** (Appendix 6.2). Zn appears to be elevated in lower reaches of Crabapple Creek at times, where downstream levels ranged from 7-9 µg/L (n=5) during summer baseflow conditions in August 2007, and from 20-44 µg/L (n=5) during fall high flow conditions in October 2007. Additional sources of elevated Zn during the snowmelt period may be from road surfaces, i.e. tire wear. The toxicological effects of Zn on aquatic life are described in Master Appendix D. While aquatic life was exposed to elevated Zn levels in Crabapple Creek at times in May 2008, the impacts from Zn alone were likely short-term and minimal.

6.3.5 Evidence of snowmelt runoff in Nita Lake in 2008

The monthly temporal relationships between specific conductivity and chloride in 2008 in both Nita and Alpha Lakes (7m depth) are shown in Figure 6.2. The highest specific conductivity and chloride levels were observed on May 6, 2008, during the snowmelt period. Chloride concentrations were 27 mg/L and 15 mg/L in Alpha and Nita Lakes, respectively, on this date. These elevated levels likely resulted from snowmelt runoff received by both lakes from inflowing creeks that run through urban areas of the Whistler valley, namely Whistler Creek (Nita Lake) and Write-Off/No-name Creek (Alpha Lake). Alpha Lake may also be receiving additional sources of road salt from non-point sources due to its proximity to Hwy 99. While chloride was elevated in both lakes, levels were well below the chloride guidelines and would not be expected to impact significantly on aquatic life.

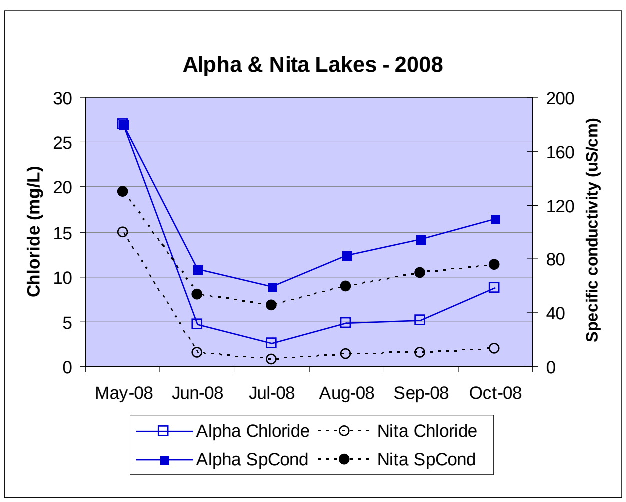


Figure 6.2. Monthly conductivity and chloride levels in Nita and Alpha Lakes (7m depth), 2008

6.3.6 Automated monitoring of specific conductivity and turbidity

i) Determination of peak chloride concentrations in Whistler Creek

The correlation between chloride and specific conductivity grab sample data at the mouth of Whistler Creek was very high (R^2=0.92, n=13, Table 6.1), which allowed for prediction of peak chloride levels in the creek using automated specific conductivity data. The predicted chloride concentrations could then be compared to the mean and maximum B.C. AWQGs for chloride (150 mg/L and 600 mg/L, respectively), for the protection of aquatic life in freshwater.

While the automated station in Whistler Creek was not able to run during the first week of grab sampling (Apr 30 to May 6), peak chloride concentrations were likely the highest in the creek between April 1 and 17, as there appeared to be a downward trend after May 6 (Figure 6.3). The **predicted peak chloride concentration was 33 mg/L on Apr 11, which met B.C. AWQGs**. The predicted levels were also likely short-lived and would not have likely caused harm to aquatic organisms. Predicted chloride concentrations also corresponded reasonably well with grab sample data on May 6 (grab=5 mg/L; predicted=6 mg/L), May 13 (grab=3.7 mg/L; predicted=5.5 mg/L), as well as May 21 and 27 when chloride levels approached detection limits. Chloride levels dropped to low levels (<3 mg/L) by May 16 following re-deployment of the automated station on May 6.

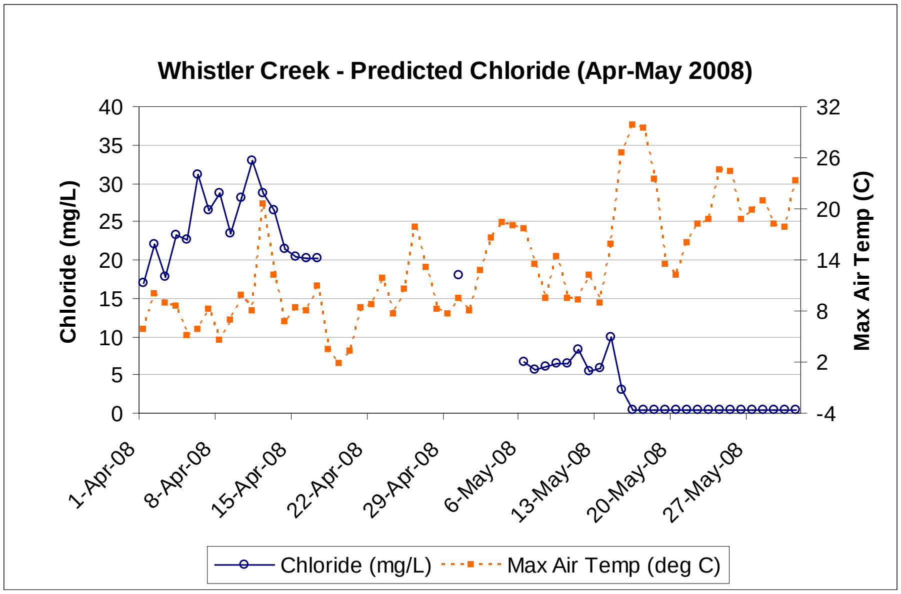


Figure 6.3. Predicted chloride levels in Whistler Creek (at mouth) from April 1 to May 31 (Apr 30 value is grab sample of 18 mg/L chloride)

ii) Turbidity during the snowmelt period in Crabapple and Whistler Creeks

Automated turbidity data were analyzed for both Whistler and Crabapple Creeks to determine whether any periods of rapid melting would lead to turbidity increases and therefore potential impacts to fish. Increased turbidity could be caused by high stream flows and/or rapid release of sediments from snow stored in the stream channel. This may be of particular concern in Crabapple Creek, where snow is stored in the channel in the Brio area, as well as other areas. The 'severity-of-ill-effects' (SEV) scale, water condition and effects of excessive turbidity on clear water fishes proposed by Newcombe (2003) are shown in Table 6.6 (see also Master Appendix B).

Table 6.6: Severity-of-ill-effect (SEV) scale, condition, and potential effects of turbidity on clear water fishes (Newcombe, 2003)

SEV scale	Water condition	Effect on clear water fish
0 ≤ nil < 0.5	Ideal	Best for adult fishes that must live in a clear water environment most of the time
0.5 ≤ minor < 3.5	Slightly impaired	Feeding and other behaviours begin to change: severity of effect increases with duration
3.5 ≤ moderate < 8.5	Significantly impaired	Marked increase in water cloudiness could reduce fish growth rate, habitat size, or both
8.5 ≤ severe < 14.5	Severely impaired	Profound increases in water cloudiness could cause poor 'condition' or habitat alienation

It is also important to consider the **cumulative impacts of excessive turbidity events** over the whole snowmelt period in 2008. Cumulative effects of sediment and turbidity on fish are difficult to capture, but factors that mediate their effect include duration of exposure; frequency of exposure; toxicity; temperature; life stage of fish; angularity, size and type of particle; severity/magnitude of pulse; natural background turbidity (e.g. watershed position and legacy, or historical land use practices); other stressors and general condition of biota; and availability of, and access to, refugia (Bash *et al*., 2001).

The SEV scores for turbidity events that exceeded 20 NTU and 1h in duration at the upstream **Crabapple Creek** site from April 25 to May 15, before the automated station was overcome by sediment and the data became unreliable, are shown in Appendix 6.3. A total of 18 turbidity events were recorded, the majority (12, or 67%) of which were classified as moderate, and six of which were minor. A moderate rating indicates significantly impaired conditions for fish, where growth rate and habitat size can be reduced, while a minor rating indicates slightly impaired conditions where feeding and other behaviours begin to change (Table 6.6). These turbidity events occurred almost daily during the snowmelt period, lasting for 3 to 17 h each time, as air temperatures rose and snowmelt continued, indicating the persistent and cumulative nature of these events (Appendix 6.3). This may have impacts for aquatic life upstream of the golf course, including tailed frogs and fish. A graph showing the cumulative and persistent nature of turbidity events in both locations of the creek is shown in Figure 6.4.

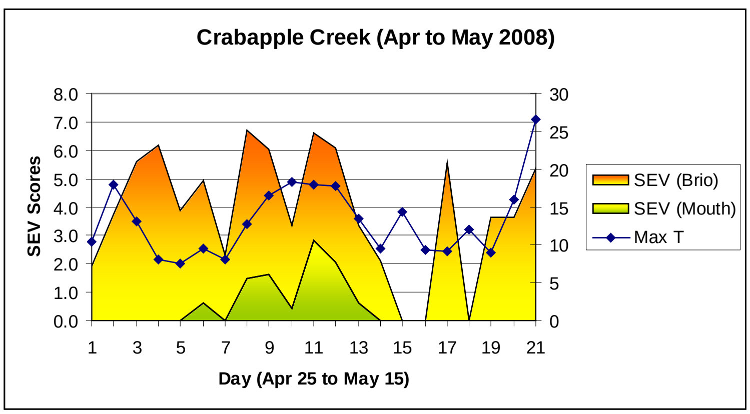


Figure 6.4. SEV scores for turbidity events at upstream (events >20 NTU, at Brio) and downstream (events >8 NTU above upstream turbidity values, at mouth) sites in Crabapple Creek, 2008

At the downstream site, near the mouth, subsequent but less severe turbidity events occurred, which ranged from minor to nil. This was likely due to the fact that the sediment retention ponds in the golf course were effective in capturing sediment from both the melting of gravel-laden snow that was piled in the creek in upstream locations, and from high flow sediment-laden water originating from upstream sources. The downstream events, however, while minor and nil, did exceed the induced turbidity guidelines, as they were >8 NTU above upstream turbidity levels.

The SEV scores for turbidity events in **Whistler Creek**, which exceeded 20 NTU and 1h in duration, from May 6 to June 2, are shown in Appendix 6.3. A total of five turbidity events were recorded, where two were classified as moderate and three were minor. The moderate events that occurred on May 16 and 17 indicate that similar events also likely occurred in Crabapple Creek upstream of the golf course where the automated station was likely buried under sediment caused by high flows in mid-May. Overall, conditions for fish in lower reaches of Whistler Creek from May 6 to June 2 appeared to be reasonable, considering the higher flow regimes typical of snowmelt periods.

6.4 Conclusions

This study was able to show that **snowmelt is likely contributing to elevated levels of chloride, some metals, and turbidity to Whistler area creeks** that receive snowmelt runoff. However, the impacts differed between the three creeks. **Whistler and Fitzsimmons Creeks appeared to be relatively well buffered from snowmelt runoff impacts**, as heavy metal and sediment concentrations increased minimally in downstream locations. This may be due to the fact that little drainage in both watersheds is attributed to stormwater drainage, i.e. 9.2% for Whistler Creek and 4.2% for Fitzsimmons Creek.

Crabapple Creek, however, with nearly 30% of its natural drainage coming from stormwater drainage, appears to be more affected by either the high flows associated with snowmelt or practices such as snow storage within its stream banks along lower reaches. The main impacts to the creek would be the almost daily occurrences of turbidity events >20 NTU upstream of the golf course that may impact aquatic life, although the current status of fish populations in this reach is unknown. These types of events could lead to reduced feeding success and physiological stress for fish in fish-bearing reaches. **Increases in cadmium, copper and zinc were also observed at the downstream site in Crabapple Creek throughout May 2008**, which were likely derived from sediment and road sources, as upstream levels of these metals were also elevated. **B.C. Approved Water Quality Guidelines were exceeded in both up- and downstream sites in Crabapple Creek for dissolved aluminum (mean and max), total cadmium (max), total copper (mean), and total zinc (mean).**

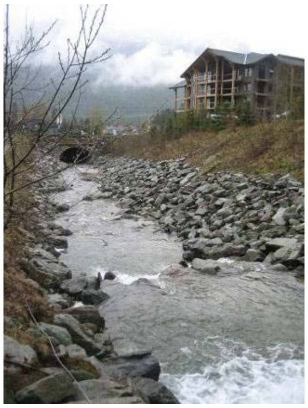
Snowmelt runoff from the snow storage area in Day Lot 5 had particularly high levels of suspended sediments, copper and iron. Copper was also found to be elevated in leaching tests of the raw road salt and sand material used in winter road maintenance, which may be contributing low level, but chronic concentrations to Whistler waterways.

6.5 Recommendations

It is recommended that excess snow not be stored within stream banks, as this melting snow may be contributing significant amounts of sediment and metals from road surfaces to aquatic receiving environments in the Whistler area. **An alternate location for the excess snow in Day Lot 5 should also be considered**, if practicable, because of its proximity to Fitzsimmons Creek and particularly if it is to be paved in the near future. Otherwise **proper management of this snow storage area should be exercised** to minimize runoff to Fitzsimmons Creek.

APPENDIX 6.1 – SITE LOCATIONS

Whistler Creek



Upstream Creekside location
(E268885, upstream Hwy 99, roads & urban development – Apr 9/08)

Downstream and Automated Sampler Location
(E213692, at mouth near Nita Lake – Nov 19/08)

Crabapple Creek

Upstream Brio Location
(E268884, upstream Hwy 99, roads & urban development – Apr 9/08)

Downstream and Automated Sampler Location
(E252029, at mouth – Nov 19/08)

Fitzsimmons Creek

Upstream Fitzsimmons Location
(E268887, upstream Village, roads & urban development – May 13/08)

Downstream Fitzsimmons Location
(E267242, at Riverside Campground – Oct 10/07)

APPENDIX 6.2 – WATER QUALITY RESULTS: MAY 2008

Whistler Creek		30-Apr		06-May		13-May		21-May		27-May		Mean		BC Water Quality Guidelines		
	RDL	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	30-day Mean	Max	Notes
Field Measurements																
Temperature (deg C)		2.11	5.48	3.23	4.96	2.71	3.44	2.94	4.78	4.08	4.3	**3.01**	**4.59**		10.0-18.0	rainbow optimum
Dissolved oxygen (mg/L)		12.71	11.59	12.56		12.74	11.78	13.36	12	12.7	12.28	**12.81**	**11.92**	8.0-11.0	5.0-9.0*	*minimum
pH (pH units)		7.33	6.46	6.48	6.89	6.96	6.44	n/a	n/a	n/a	n/a	**6.92**	**6.60**		6.5-9.0	
Organics & Inorganics (mg/L)																
Total Hardness (CaCO3)	0.5	44.9	52.4	35.1	38.7	36.2	38	20.8	21.2	17.8	18.6	**31.0**	**33.8**			
Total Suspended Solids	4	<4	4	7	6	<4	5	7	5	5	7	**5**	**5**	Mean <5 mg/L above background		
Turbidity (NTU)	0.1	0.5	1.2	0.7	2.2	0.7	0.8	1.9	1.7	1.3	0.7	**1.0**	**1.3**	Mean <2 NTU above background		
Conductivity (lab, uS/cm)	1	100	160	81	100	81	98	50	57	41	43	**71**	**92**			
Dissolved Chloride (Cl)	0.5	3.3	18	1.9	5	1.2	3.7	0.5	1.1	<0.5	0.6	**1.0**	**6.0**	150	600	
Nutrients (mg/L)																
Total Phosphorus (P)	0.002	0.004	0.005	0.007	n/a	0.01	0.006	0.006	0.005	0.004	0.002	**0.006**	**0.005**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.004	0.005	0.007	n/a	0.005	0.005	0.002	0.001	<0.001	0.001	**0.004**	**0.003**			
Selected Metals (ug/L)																
Dissolved Aluminum (Al)	0.2	27.5	15.6	43.6	40.6	32.2	32.7	50	46	47.1	45.7	**40.1**	**36.1**	50	100	pH > 6.5
Dissolved Iron (Fe)	1	25	130	28	42	30	46	25	30	19	21	**25**	**54**		350	
Total Cadmium (Cd)	0.005	0.016	0.013	0.026	0.023	0.009	0.012	<0.005	<0.005	<0.005	<0.005	**0.012**	**0.012**		0.017	CCME (interim)
Total Copper (Cu)	0.05	0.99	0.93	2	1.79	1.04	1.65	1.37	1.28	1.05	1.02	**1.29**	**1.33**	2	3.5-6.9	H < 50 mg/L
Total Iron (Fe)	1	53	328	64	92	43	70	65	81	49	55	**55**	**125**		1000	
Total Lead (Pb)	0.005	0.008	0.04	0.013	0.024	0.007	0.163	0.02	0.026	0.011	0.011	**0.012**	**0.053**	4	18	H=30 mg/L
Total Manganese (Mn)	0.05	33.8	76.4	26.9	27.4	20.1	25.3	11	13.5	6.34	6.91	**19.63**	**29.90**	700	800	H=25 mg/L
Total Zinc (Zn)	0.1	5.5	4.9	5.1	4.8	3.5	3.7	1.5	1.7	1.1	1.2	**3.3**	**3.3**	7.5	33	H<90 mg/L
Total Calcium (Ca), mg/L	0.05	16.3	18.3	12.8	13.9	13.2	13.8	7.68	7.75	6.61	6.91	**11.32**	**12.13**			
Total Magnesium (Mg), mg/L	0.05	1.05	1.6	0.79	0.97	0.78	0.9	0.4	0.43	0.31	0.34	**0.67**	**0.85**			
Total Sodium (Na), mg/L	0.05	2.42	8.94	1.67	3.05	1.59	2.84	0.78	1.08	0.58	0.76	**1.41**	**3.33**			
Bacteriology (Col/100 mL)																
Fecal coliforms	1	<1	2	<1	2	<1	1	<1	1	<1	<1	**<1**	**1.3**	200		geomean, primary contact
E. coli	1	<1	2	<1	<1	<1	<1	<1	<1	<1	<1	**<1**	**1.15**	77		

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines

Pink cells indicate exceedences of guidelines

Crabapple Creek		29-Apr		06-May		13-May		21-May		27-May		Mean		BC Water Quality Guidelines		
	RDL	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	30-day mean	max	Notes
Field Measurements																
Temperature (deg C)		1.64	5.53	2.45	5.38	2.48	4.21	3.3	5.4	4.39	6.85	**2.9**	**5.5**		10.0-18.0	rainbow optimum
Dissolved oxygen (mg/L)		12.8	11.44	12.3	11.67	11.97	11.64	12.85	11.56	12.01	11.13	**12.4**	**11.5**	8.0-11.0	5.0-9.0*	*minimum
pH (pH units)		6.82	6.9	6.77	6.66	6.83	6.31	n/a	n/a	6.96	n/a	**6.8**	**6.6**		6.5-9.0	
Organics & Inorganics (mg/L)																
Total Hardness (CaCO3)	0.5	53.4	94.5	41.1	63.5	45.4	66.9	36.2	49.4	34	45.5	**42.0**	**64.0**			
Total Suspended Solids	4	4	7	11	9	6	7	11	17	6	8	**8**	**10**	Mean <5 mg/L above background		
Turbidity (NTU)	0.1	1.2	2	6.5	4.2	2.7	2.1	0.6	4.1	0.6	2	**2.3**	**2.9**	Mean <2 NTU above background		
Conductivity (lab, uS/cm)	1	110	220	92	160	97	170	81	120	75	110	**91**	**156**			
Dissolved Chloride (Cl)	0.5	1.4	13	1.1	7.2	1.2	7.1	0.8	4.6	0.9	3.2	**1.1**	**7.0**	150	600	
Nutrients (mg/L)																
Total Phosphorus (P)	0.002	0.005	0.008	0.011	0.01	0.008	0.009	0.006	0.015	<0.002	0.006	**0.006**	**0.010**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.003	0.006	0.005	0.01	0.008	0.009	0.002	0.003	<0.001	0.001	**0.004**	**0.006**			
Selected Metals (ug/L)																
Dissolved Aluminum (Al)	0.2	119	72.8	246	146	254	157	180	186	119	131	**183.6**	**138.6**	50	100	pH > 6.5
Dissolved Iron (Fe)	1	4	41	26	53	22	46	52	102	37	77	**28**	**64**		350	
Total Cadmium (Cd)	0.005	0.105	0.185	0.079	0.12	0.074	0.133	0.034	0.069	0.02	0.05	**0.062**	**0.111**		0.017	CCME (interim)
Total Copper (Cu)	0.05	2.64	6.04	3.69	5.85	3.23	6.17	1.88	4.57	1.36	3.02	**2.56**	**5.13**	2	5.2-10.9	H < 50 mg/L
Total Iron (Fe)	1	56	308	144	270	111	202	91	273	63	180	**93**	**247**		1000	
Total Lead (Pb)	0.005	0.055	0.112	0.189	0.137	0.144	0.081	0.048	0.099	0.024	0.101	**0.092**	**0.106**	4	18	H=30 mg/L
Total Manganese (Mn)	0.05	104	147	82.5	97.5	79.5	108	37.7	63.3	24	42	**65.54**	**91.56**	700	800	H=25 mg/L
Total Zinc (Zn)	0.1	12.7	24.4	11.4	17.6	10	19.9	5.4	10.6	3.5	7.4	**8.6**	**16.0**	7.5	33	H<90 mg/L
Total Calcium (Ca), mg/L	0.05	20.1	35.2	15.3	23.5	17	24.9	13.7	18.5	12.9	17.1	**15.80**	**23.84**			
Total Magnesium (Mg), mg/L	0.05	0.81	1.63	0.68	1.15	0.7	1.18	0.5	0.8	0.45	0.69	**0.63**	**1.09**			
Total Sodium (Na), mg/L	0.05	1.18	6.71	0.96	4.09	1.03	4.34	0.76	2.82	0.71	2.28	**0.93**	**4.05**			
Bacteriology (Col/100 mL)																
Fecal coliforms	1	<1	2	1	1	<1	89	<1	8	<1	15	**<1**	**7**	200		geomean, primary contact
E. coli	1	<1	1	1	1	<1	17	<1	8	<1	15	**<1**	**5**	77		

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines

Pink cells indicate exceedences of guidelines

Fitzsimmons Creek		30-Apr		06-May		13-May		21-May		27-May		Mean		BC Water Quality Guidelines		
	RDL	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	U/S	D/S	30-day Mean	Max	Notes
Field Measurements																
Temperature (deg C)	0	3.64	5.77	5.38	6.76	4.19	4.95	4.23	4.8	5.72	6.21	**4.63**	**5.70**		10.0-18.0	rainbow optimum
Dissolved oxygen (mg/L)	0	11.77	11.74	11.74	11.33	11.64	11.65	12.36	12.05	12.04	11.59	**11.91**	**11.67**	8.0-11.0	5.0-9.0*	*minimum
pH (pH units)	0	6.7	6.74	6.87	6.49	6.54	6.16	n/a	n/a	n/a	n/a	**6.70**	**6.46**		6.5-9.0	
Organics & Inorganics (mg/L)																
Total Hardness (CaCO3)	0.5	85.4	84.6	77.9	68.5	73.9	72	30.5	31.4	30.1	28.4	**59.6**	**57.0**			
Total Suspended Solids	4	8	<4	43	14	14	8	36	31	16	16	**23**	**15**	Mean <5 mg/L above background		
Turbidity (NTU)	0.1	3.1	0.7	6	3.8	3.6	2.1	2.7	3.4	2.2	2.9	**3.5**	**2.6**	Mean <2 NTU above background		
Conductivity (lab, uS/cm)	1	170	180	160	150	160	150	70	70	66	65	**125**	**123**			
Dissolved Chloride (Cl)	0.5	1.1	5.3	1.2	3.6	0.6	2.9	<0.5	0.7	<0.5	0.7	**0.8**	**2.6**	150	600	
Nutrients (mg/L)																
Total Phosphorus (P)	0.002	0.01	0.007	0.96	0.014	0.01	0.007	0.027	0.031	0.004	0.012	**0.202**	**0.014**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.009	0.006	0.009	0.011	0.008	0.005	0.007	0.006	0.002	0.002	**0.007**	**0.006**			
Selected Metals (ug/L)																
Dissolved Aluminum (Al)	0.2	8.6	17.8	15.7	18.2	13.2	17.5	36.7	33.2	27.5	34.9	**20.3**	**24.3**	50	100	pH > 6.5
Dissolved Iron (Fe)	1	4	62	6	39	3	33	16	19	11	18	**8**	**34**		350	
Total Cadmium (Cd)	0.005	0.014	0.023	0.025	0.023	0.013	0.018	0.012	0.012	<0.005	0.012	**0.016**	**0.018**		0.017	CCME (interim)
Total Copper (Cu)	0.05	1.57	1.75	3.18	2.12	1.88	1.68	3.23	3.06	2.16	2.13	**2.40**	**2.15**	2	4.7-10.0	H < 50 mg/L
Total Iron (Fe)	1	64	123	136	128	63	101	191	189	106	137	**112**	**136**		1000	
Total Lead (Pb)	0.005	0.048	0.019	0.144	0.073	0.039	0.031	0.056	0.065	0.033	0.04	**0.064**	**0.046**	4	18	H=30 mg/L
Total Manganese (Mn)	0.05	9.02	25.9	13	21.2	7.06	17	8.52	10.8	4.82	7.11	**8.48**	**16.40**	700	800	H=25 mg/L
Total Zinc (Zn)	0.1	1.5	2.9	2	2.9	1.2	2.5	1.1	1.5	0.8	1	**1.3**	**2.2**	7.5	33	H<90 mg/L
Total Calcium (Ca), mg/L	0.05	32.9	32.4	29.9	26.2	28.4	27.6	11.6	11.9	11.5	10.8	**22.86**	**21.8**			
Total Magnesium (Mg), mg/L	0.05	0.81	0.89	0.79	0.76	0.73	0.75	0.39	0.4	0.34	0.35	**0.61**	**0.63**			
Total Sodium (Na), mg/L	0.05	1.55	3.38	1.42	2.46	1.36	2.28	0.69	0.91	0.63	0.8	**1.13**	**1.97**			
Bacteriology (Col/100 mL)																
Fecal coliforms	1	<1	<1	1	1	2	1	<1	4	<1	2	**1**	**2**	200		geomean,
E. coli	1	<1	<1	1	1	1	<1	<1	4	<1	2	**1**	**2**	77		primary contact

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines

Pink cells indicate exceedences of guidelines

APPENDIX 6.3 – SEVERITY-OF-ILL-EFFECT (SEV) SCORES for turbidity events in both upstream (events >20 NTU) and downstream (>8 NTU above upstream) locations in Crabapple Creek in April and May 2008, including average turbidity (NTU) and duration (h) of whole events (see methods). Events are colour-coded green (nil, or ideal), yellow (minor, or slightly impaired), and orange (moderate, or significantly impaired) to indicate potential impairment of each turbidity event on clear water fishes (Newcombe, 2003).

7.0 WATER QUALITY IN THE STORMWATER BIOFILTRATION POND IN 2007 & 2008

7.1 Site Description & Historical Water Quality

The biofiltration pond is a 100 m long stormwater retention pond along Blackcomb Way (Photo Series 7.1), between Lorimer Road and Settebello Drive, constructed in the fall of 2004 from a natural wetland area. The pond receives runoff from the Village area, although there is a bypass built in to carry excess flows directly to Fitzsimmons Creek. Water discharges from the pond to mix with the Village 'amenities' stream (taken from Fitzsimmons Creek) before re-entering Fitzsimmons Creek near Nancy Greene Drive.

Limited sampling of the wetland in August 1998 indicated 'marginal' water quality, with low dissolved oxygen (2.2 mg/L) and a pH of 6.3 (B. Rebellato, RMOW, July 19, 2007, personal communication). Following construction, water quality sampling in 2005 showed elevated levels of aluminum, copper, iron and zinc at both the pond inlet and outlet, which exceeded B.C. Approved Water Quality Guidelines for the protection of aquatic life (Table 7.1). Due to the limited sampling, it was not previously clear whether the biofiltration pond is effective in removing pollutants during rain events and snowmelt runoff periods.

Table 7.1. Water quality in the biofiltration pond in June and October, 2005

Biofiltration Pond - 2005	June		October		BC Water Quality Guidelines		
	Inlet	Outlet	Inlet	Outlet	30-day Mean	Max	Notes
Field Measurements							
Temperature (deg C)	9.6	10.6	10.9	9.4		10.0-18.0	rainbow optimum
Dissolved oxygen (mg/L)	11	8	n/a	n/a	8.0-11.0	5.0-9.0*	*minimum
pH (pH units)	6.5-7	7	6.78	7.12		6.5-9.0	
Organics & Inorganics (mg/L)							
Total Suspended Solids	4	9	5	<4			
Turbidity (NTU)	10	10	10	10			
Chloride (Cl)	29.4	28.5	22.8	27.6	150	600	
Oil & grease	1.5	<1	<1	<1		1	
Selected Metals (ug/L)							
Aluminum (Al)	1130	580	180	180	50	100	pH > 6.5
Copper (Cu)	18	14	14	8	2	H dependent	H < 50 mg/L
Iron (Fe)	1580	892	583	757		1000	
Lead (Pb)	2.4	4.1	n/a	n/a	4	18	H=30 mg/L
Zinc (Zn)	36	37	n/a	n/a	7.5	33	H<90 mg/L

Pink cells indicate exceedences of guidelines

Sep 6/07

Sediment build-up area at pond inlet where sediment collected

Note visible turbidity at inlet headwall – May 13/08

May 13/08

Photo Series 7.1. Biofiltration Pond along Blackcomb Way in Whistler, B.C. on September 6, 2007 and May 13, 2008

7.2 Methods & Data Analysis

Site locations and sampling dates

Site locations were chosen at the pond's inlet (E268229) and outlet (E268230) to assess the pond's effectiveness in removing pollutants from the rain- and meltwater runoff it receives at various times of the year (see Photo Series 7.1). In October 2007, grab sampling captured rain events on October 2, 10 and 22. These events occurred during a compressed but intense rainy period, where 97.1 mm of rain fell between September 30 and October 10 (64% of the month's precipitation of 150.7 mm). In May 2008, the snowmelt period was sampled from April 30 to May 27 at a frequency of 5 times in 30 days to satisfy statistical requirements for several B.C. Approved Water Quality Guidelines (AWQGs).

Analysis of road salt and sand raw material

Road salt and sand used by RMOW were analyzed for leaching potential of metals as described in Section 6.2.

Grab sampling and analysis
Water samples were collected and analyzed at both the inlet and outlet as described in Section 3.2. A Student's t-test was used (JMP 7.0 software) to compare parameter means between the inlet and outlet during each runoff period and determine whether they were significantly different from each other (α=0.05).

Sediment sampling
A sediment sample was collected from the sediment deposition area at the pond inlet (see Photo Series 1) on Sept 6, 2007. This sample was likely not representative of the sediment composition throughout the pond, but rather sediments deposited over that small area from urban and road stormwater runoff sources since 2004. The sediment sample was analyzed for total metals, total organic carbon, and particle size, and metal concentrations were compared to applicable B.C. Working Guidelines for Sediment.

7.3 Results & Discussion

7.3.1 Analysis of road salt and sand leachate

Elevated levels of copper were found in both road salt (0.3 mg/L) and sand (0.1 mg/L). This allows for an annual estimation of approximately 1.5 kg copper from ~250 tonnes of road salt, and 6 kg from ~3,000 tonnes of sand, which has the potential to leach into local waterways via ground and surface water flows [see Section 6.3, part a)]. Copper is of particular concern to fish and will be discussed in the **Exceedances** section.

7.3.2 General trends & exceedances of B.C. Approved Water Quality Guidelines (AWQGs)

i) Summary of Exceedances
A summary of the exceedances of B.C. Approved Water Quality Guidelines (AWQGs) in the biofiltration pond (for the protection of aquatic life) is provided in Table 7.2. Specific exceedances and biological impacts of cadmium (Cd), copper (Cu), iron (Fe) and zinc (Zn) will be discussed in the following sections, along with general water quality trends observed in the pond. For parameters of concern, including bacteria, TSS, turbidity, and metals, comparisons of results for each sampling date were provided for both runoff periods to examine differences in runoff quality.

Table 7.2. Summary of exceedances of B.C. AWQGs in the biofiltration pond during high precipitation (October 2007) and snowmelt runoff periods (May 2008)

Biofiltration Pond	Maximum Guideline Exceedences					Mean Guideline Exceedences
Rain events - 2007	**02-Oct**	**10-Oct**	**22-Oct**			**Mean**
Inlet	Cu, Fe, Zn	Cu, Zn	Cd, Zn			Cu, Zn
Outlet	Cu, Zn	Cu, Zn	Cd, Cu, Zn			Cu, Zn
Snowmelt - 2008	**30-Apr**	**06-May**	**13-May**	**21-May**	**27-May**	**Mean**
Inlet	Cd, Cu	Cd, Cu	Cd, Cu, Zn	Cd	Cd	Cu, Zn
Outlet	Cd, Zn	Cd	Cd	Cd	Cd	Cu, Zn

ii) Bacteria
E. coli levels were elevated (>2000 colonies/100 mL) at the pond inlet during the initial rain events in October 2007 (Oct 2 & 10) and during the last date of snowmelt sampling in 2008 (May 27; Figure 7.1 and Appendix 7.1). However, the B.C. AWQG of 385 colonies/100 mL (geometric mean) for secondary-contact recreation was not exceeded during the 2008 snowmelt period and could not be applied during the fall sampling period as statistical requirements of 5 samples in 30 days were not met. The **general**

trend was for decreasing *E. coli* levels at the outlet of the pond except during the first flush event on October 2/07 when *E. coli* levels were higher at the outlet (Figure 7.1).

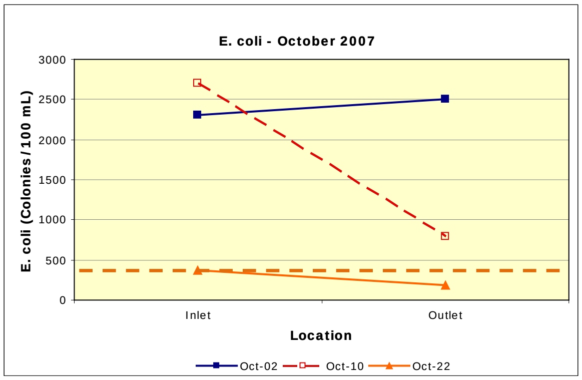
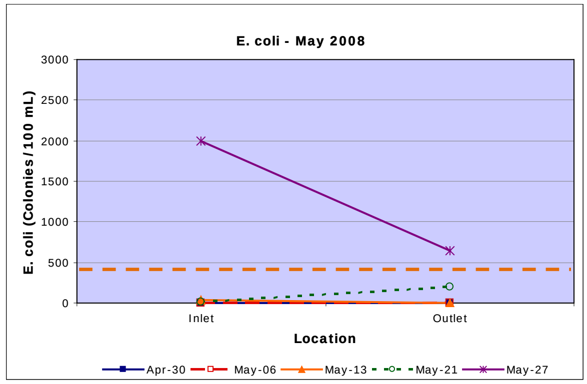
High precipitation – October 2007	Snowmelt - May 2008
	

Figure 7.1: ***E. coli*** results during 2007 high precipitation and 2008 snowmelt periods at the inlet and outlet of the biofiltration pond, showing B.C. AWQG for secondary recreation (385 colonies/100 mL)

iii) Sediment and turbidity

Total suspended solids (TSS) in the biofiltration pond reached relatively high levels (85 mg/L, Oct 2/07; 81 mg/L, Apr 30/08) at the pond inlet during both the fall and spring runoff periods. TSS levels were then considerably lower (12-15 mg/L) during subsequent rain events in October 2007, and during subsequent warming events in May 2008 (<4 mg/L; Figure 7.2 and Appendix 7.1). B.C. AWQGs were not applied to TSS and turbidity in the pond as the requirement of a 'background' sample for guideline comparison was not met. At higher TSS levels, a moderate reduction (25%) occurred at the outlet during the October 2 first flush event in 2007, while more significant reductions occurred during the snowmelt runoff on April 30 (95%) and May 13 (91%) in 2008. Furthermore, no significant removal of TSS occurred when TSS at the inlet was <15 mg/L (Figure 7.2).

Turbidity levels at the pond inlet reached elevated levels of 70.4 NTU on October 2/07, and 34.3 NTU on May 13/08, during the fall high precipitation and snowmelt periods, respectively. Similar to TSS trends, turbidity levels were lower during subsequent rain events in October 2007, and during subsequent warming events in May 2008 (Figure 7.2 and Appendix 7.1). At higher turbidity levels, a moderate reduction (18%) occurred at the outlet during the October 2 first flush event in 2007, while a more significant reduction (89%) occurred on May 13 in 2008. Similar to TSS, no significant improvement occurred when turbidity at the inlet was <20 NTU (Figure 7.2).

While the pond is not considered to provide fish habitat, it does provide habitat for other aquatic life and wildlife. This is a concern as suspended sediments are often associated with other pollutants, particularly metals, which can exert toxic effects at high levels and bioaccumulate within biota in the pond. Suspended sediments can also settle and smother benthic invertebrate habitat within the pond (see Table 1.1).

High precipitation – October 2007	Snowmelt - May 2008

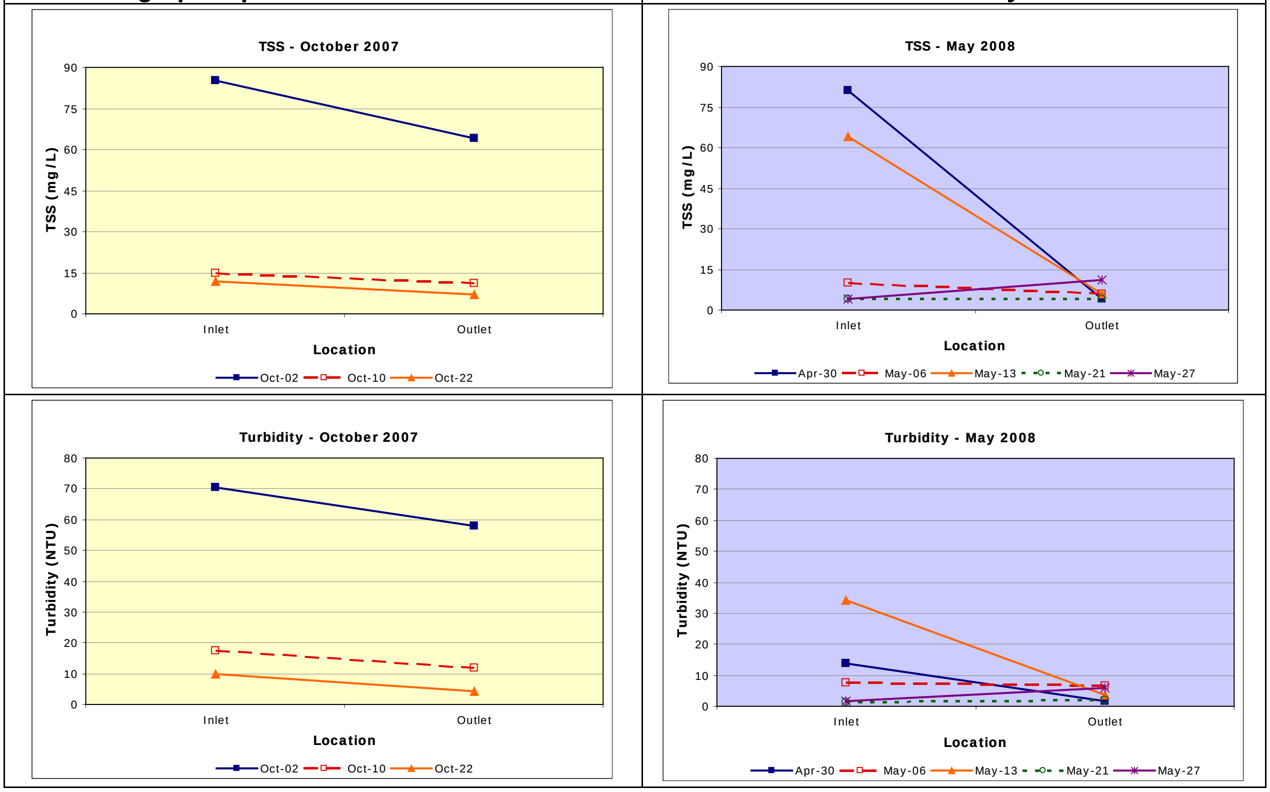


Figure 7.2: Total suspended solids (TSS) and turbidity results during 2007 high precipitation and 2008 snowmelt periods at the inlet and outlet of the biofiltration pond (note use of same scales on graphs)

iv) Chloride

Elevated chloride levels (56-110 mg/L), due to use of road salt, **were detected in the biofiltration pond throughout the May 2008 snowmelt season** (Appendix 7.1). There appeared to be little difference between the inlet and outlet, indicating limited removal of chloride within the pond. Removal of chloride would not be expected as the ion is extremely mobile and does not readily react with other chemicals or adsorb to mineral surfaces (Marsalek, 2003). However, these levels did not exceed the B.C. AWQGs for chloride (mean 150 mg/L and max 600 mg/L). Chloride levels were significantly lower (8.3-39.1 mg/L) during rain events in October 2007, as expected, and showed the same limited removal between the inlet and outlet.

v) Ammonia

Ammonia levels appeared to be more highly elevated during the snowmelt runoff period, presumably due to the use of urea in the road salt mixture, although the data were highly variable and thus were not analyzed further due to reliability concerns. Ammonia concentrations ranged similarly at both sites in May 2008, from 0.08-0.38 mg/L at the inlet and from 0.06-0.36 mg/L at the outlet (Appendix 7.1). While the mean (1.9-2.0 mg/L) and maximum (26.5-27.5 mg/L) B.C. AWQGs for ammonia toxicity were not exceeded during the snowmelt period, increased sources of inorganic nitrogen can lead to eutrophication, or excessive algal and plant growth, which can degrade water quality over time (i.e. decreased dissolved oxygen levels).

vi) Trace Metals

Total cadmium (Cd) levels were elevated during both runoff periods, although improvements in low level detection did not allow for accurate low level analysis needed for guideline comparison. Nonetheless, Cd concentrations were particularly high on October 22/07 and during early May 2008, ranging from 0.225-0.28 µg/L at the inlet (Figure 7.3 and Appendix 7.1). A significant reduction in Cd (48%) was observed at the outlet on October 22, while only moderate reductions (13-24%) occurred at the outlet on May 6, 13, and 27 during the 2008 snowmelt season (Figure 7.3 and Appendix 7.1). In the absence of a B.C. AWQG for total Cd, the maximum Canadian Environmental Quality Guideline of 0.017 µg/L for freshwater aquatic life was used for comparison. This guideline **was exceeded on all dates and at both pond sites, with levels 4 to 16 times higher than the guideline** (Figure 7.3 and Appendix 7.1). The toxicological effects of Cd on aquatic life are described in Master Appendix D.

Total lead (Pb) levels were the highest at the inlet during the May 2008 snowmelt period, on April 30 (1.4 µg/L) and May 13 (1.2 µg/L), although the mean (4 µg/L) and maximum (18 µg/L) B.C. AWQGs for Pb were not exceeded at any time in the pond (Figure 7.3 and Appendix 7.1). It should also be noted that low Pb levels could not be detected in early October 2007 due to higher laboratory detection methods, so higher levels may have also occurred at this time. Significant reductions in Pb (50%) were observed at the outlet during the October 22 rain event in 2007, and on April 30 (79%) and May 13 (73.5%) during the 2008 snowmelt period (Figure 7.3 and Appendix 7.1). However, Pb concentrations were actually higher at the outlet on May 6, 21 and 27 in 2008, indicating limited effectiveness in Pb removal at lower concentrations.

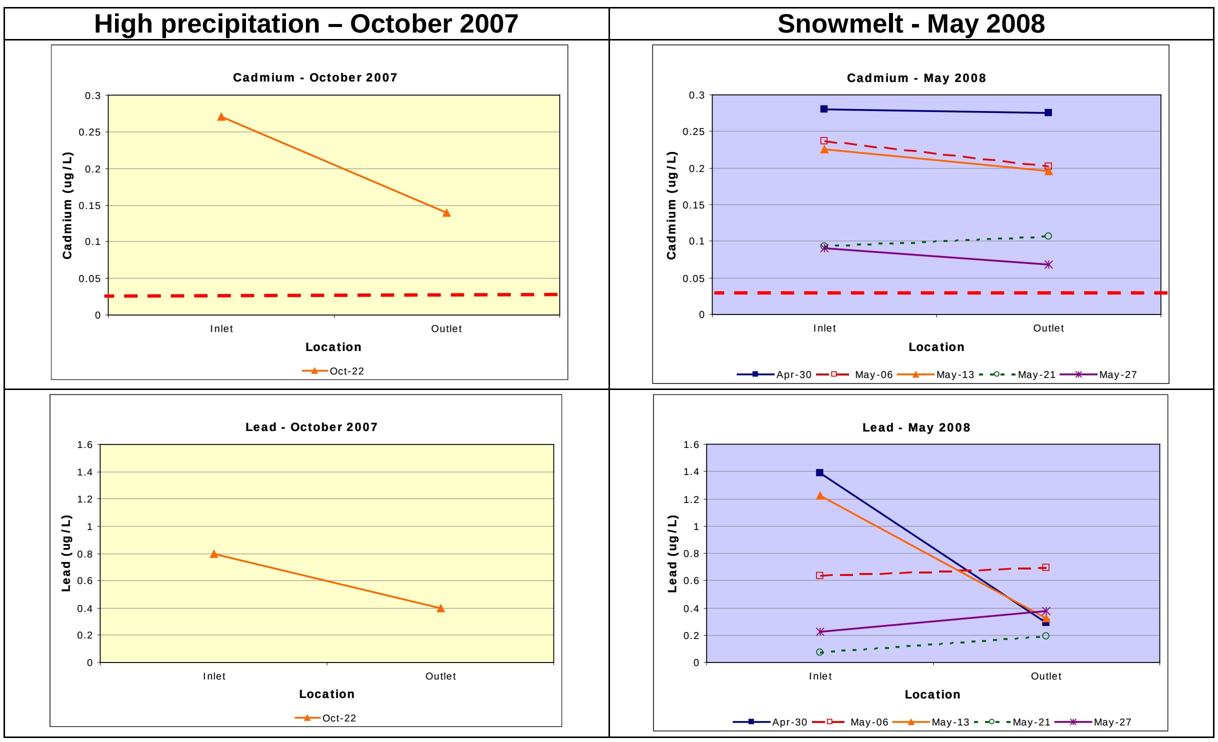


Figure 7.3. Total cadmium (Cd) and lead (Pb) results during high precipitation and snowmelt periods at the inlet and outlet of the biofiltration pond. A line showing the maximum CCME guideline for Cd (red-dashed) is provided. Values for both metals on October 2 & 10 are not included as lab detection limits for cadmium and lead were above biologically relevant levels.

Maximum **total copper (Cu)** guidelines for the protection of aquatic life, adjusted for hardness, ranged from 5.8-17.1 µg/L for the pond, while the mean copper guideline is 2 µg/L. Mean total Cu concentrations in the pond did not meet the mean guideline at either site, ranging from 11-16 µg/L during both runoff periods. The maximum guideline was exceeded at both sites in October 2007, but only at the inlet in early May 2008. The highest levels were found at the inlet following the first flush event in 2007 (Oct 2, 25 µg/L), and on April 30 (22 µg/L) during the 2008 snowmelt period (Figure 7.4 and Appendix 7.1). Moderate reductions in Cu occurred at the outlet during the first flush event in 2007 (Oct 2, 28%), and on April 30 (40%), May 6 (31%), and May 13 (30%) during the 2008 snowmelt period. Only minor reductions in Cu occurred at the outlet on subsequent dates in both October 2007 and in May 2008, indicating limited effectiveness in Cu removal at lower concentrations.

Sources of Cu are likely from road surfaces (e.g. engine and break wear), and from both road salt and sand applications in the winter (see previous **Analysis of metals in road salt and sand raw material** section). These sources may be elevating Cu levels to chronic levels that may be of concern for both aquatic life and algae in the pond, as well as for fish in Fitzsimmons Creek. The toxicological effects of Cu on aquatic life are described in Master Appendix D.

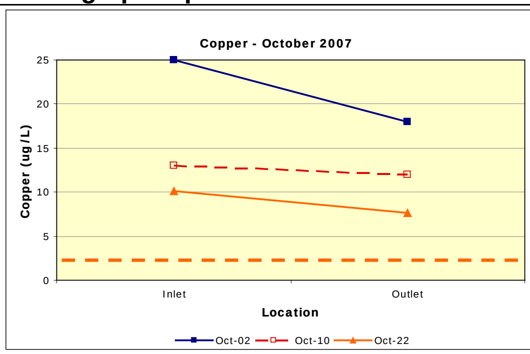
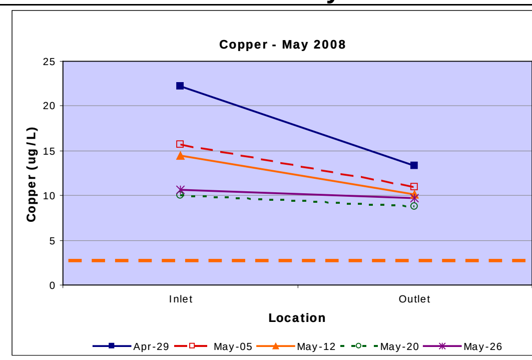
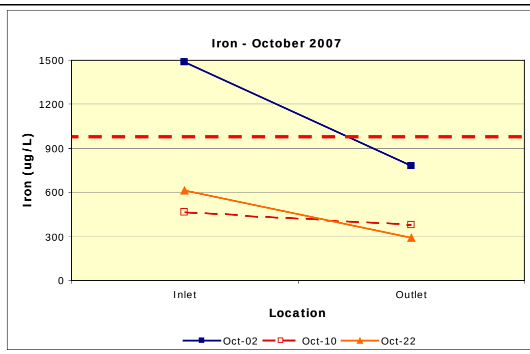
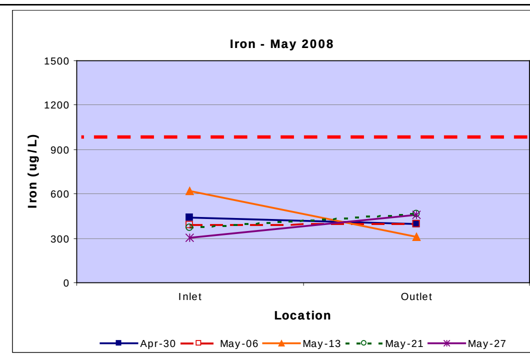
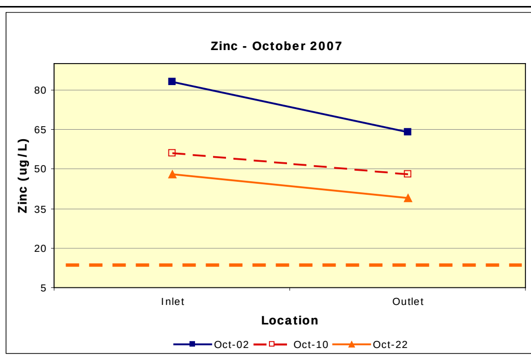
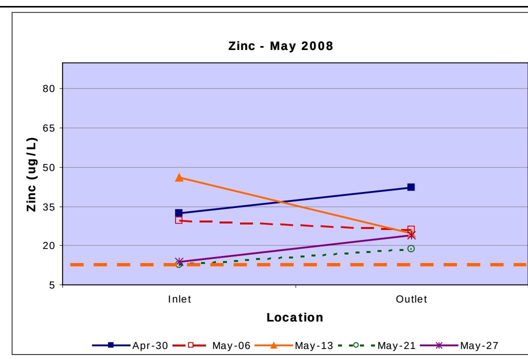
High precipitation – October 2007	Snowmelt - May 2008
	
	
	

Figure 7.4. Total copper (Cu), iron (Fe) and zinc (Zn) results during high precipitation and snowmelt periods at the inlet and outlet of the biofiltration pond. Lines showing the B.C. AWQGs for each metal are provided on the graphs.

Total iron (Fe) levels exceeded the maximum B.C. AWQG (1000 µg/L) only once, at the pond inlet, during the first flush rain event in 2007 (Oct 2, 1,490 µg/L) (Figure 7.4 and Appendix 7.1). Sources of Fe are likely natural (groundwater) and anthropogenic (from urban runoff), as Fe is correlated well with suspended sediments (Phippen *et al*., 2008). Moderate reductions in total Fe (48-53%) were observed at the outlet on October 2 and 22 in 2007, and on May 13 during the 2008 snowmelt season (Figure 7.4). Removal of Fe appeared to be limited when concentrations <600 µg/L. The toxicological effects of Fe on aquatic life are described in Master Appendix D.

Total zinc (Zn) levels exceeded the mean (7.5 µg/L) and maximum (33 µg/L) BC AWQGs during both runoff periods, but were the highest in the pond inlet during October 2007, with concentrations ranging from 48 to 83 µg/L (Figure 7.4 and Appendix 7.1). Sources of Zn are likely from road surfaces, i.e. tire wear. Moderate reductions in total Zn (14-23%) occurred at the outlet in October 2007, and on May 13 (47%) during the 2008 snowmelt period (Figure 7.4 and Appendix 7.1). Removal of Zn appeared to be limited at concentrations <35 µg/L. The toxicological effects of Zn on aquatic life are described in Master Appendix D. It is not known whether elevated levels of Zn at times in the pond can contribute to a deleterious effect on aquatic life, as other metals (i.e. Cd and Cu) are also elevated and some of the metals can have synergistic or antagonistic effects on each other.

vii) Oil and grease

Total oil and grease reached maxima of 2 mg/L at both sites in the pond during the first flush event in 2007 (Oct 2), and at the inlet on October 22, where levels did not differ significantly between the inlet and outlet on each date. Additionally, since the laboratory detection limit is relatively high (1 mg/L), levels in the pond did not appear to be significantly elevated in comparison. For this reason, water samples were not analyzed for oil and grease in May 2008.

7.3.3 Effectiveness of the biofiltration pond in removing contaminants

An evaluation of the effectiveness of the pond in removing contaminants of concern showed that the **pond was more effective in removing some contaminants [i.e. TSS, turbidity, total phosphorus (TP), and some metals (Cu, Fe and Zn)]** than others (*E. coli*, chloride, and total Cd and Pb) (Figure 7.5 and Table 7.3). It should also be noted that **removal of metals (i.e. Cu, Pb & Zn) was closely linked to the successful removal of TSS on dates when TSS was elevated (Oct 22, Apr 30, May 6 & May 13)**, indicating that these metals were likely associated with sediments (Figure 7.5).

There were also differences in effectiveness of pollutant removal during each runoff period. In the rainy October 2007 period, for instance, the pond was least effective in removing contaminants during the first flush event on October 2, likely due to higher contaminant loadings and higher flows through the pond which prevented settling of sediment and pollutants (Figure 7.5, left graph). The pond was more effective during subsequent rain events, presumably due to lower runoff flows. During the snowmelt period in May 2008, the pond was more effective in removing pollutants when concentrations were above certain thresholds (i.e. on Apr 30, May 6, May 13), as discussed in previous sections. Additionally, total Fe and total Zn were not as effectively removed during the whole snowmelt period, which may have been due to the fact that concentrations were lower compared to the stormwater period of October 2007. The pond's efficacy in removing contaminants also appeared to drop significantly near the end of May, when concentrations of most parameters decreased to low levels (Figure 7.5, right graph).

Statistical analysis of contaminant arithmetic means between the inlet and outlet showed **significantly lower ($\rho<0.05$) levels of TSS and total Zn at the pond outlet during the fall rainy period in October 2007**. There was also some evidence that total Cu ($\rho=0.1$), total Fe ($\rho=0.09$), and turbidity ($\rho=0.13$) were significantly lower at the outlet in October 2007, although the relationship was not as strong due to the small sample size (i.e. limited rain events) (Table 7.3). **During the snowmelt period in 2008, only total Cu was significantly lower ($\rho<0.05$) at the pond outlet**, indicating the complex nature of contaminant removal when initial inlet concentrations range widely with runoff volumes, and when the pond is more effective in removing contaminants at higher concentrations (Figures 7.1-7.5, Table 7.3).

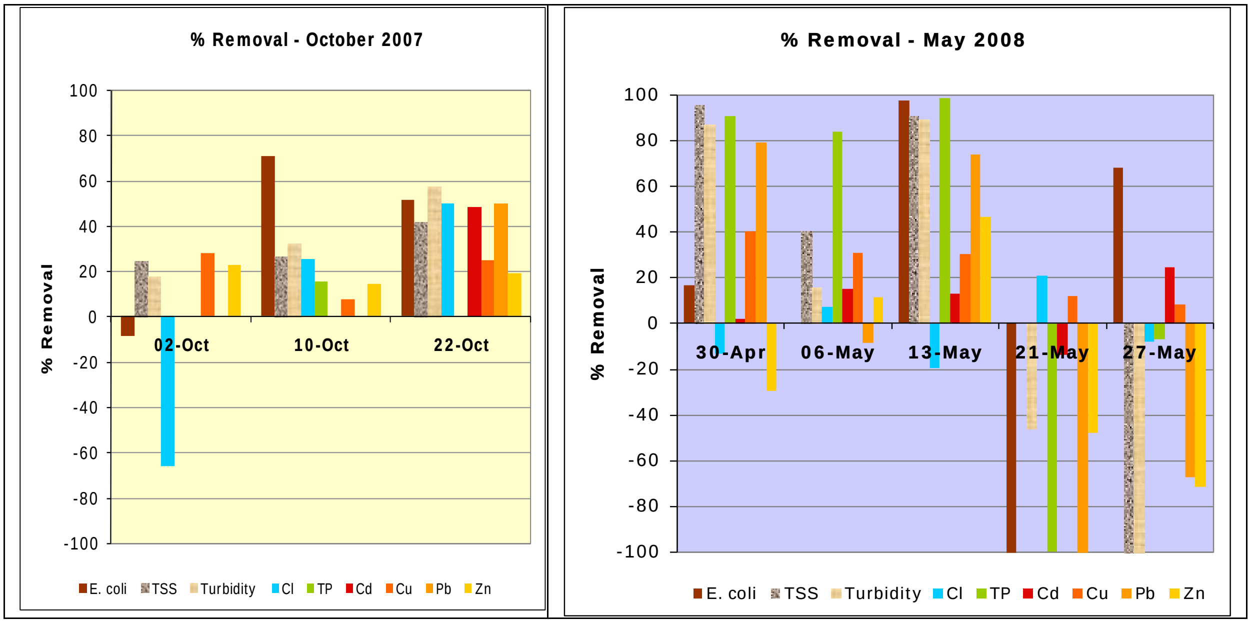


Figure 7.5. Biofiltration pond effectiveness (% removal) in removing *E. coli*, TSS, turbidity, chloride, total phosphorus (TP), and metals (Cd, Cu, Pb and Zn) during rain and snowmelt events

Table 7.3. Significance of mean differences between the biofiltration pond inlet and outlet (Student's t-test, ρ=0.05)

Parameter	Rain Events (Oct 2007, n=6)		Snowmelt (May 08, n=10)		Combined (n=16)	
	ρ-value	Conclusion	ρ-value	Conclusion	ρ-value	Conclusion
TSS	**0.04***	**TSS significantly lower at outlet**	0.26	No significant difference	0.16	Some evidence of effective removal
Turbidity	0.13	Some evidence of effective removal	0.46		0.11	
E. coli	0.25	No significant difference	0.68		0.55	No significant difference
Chloride	0.7		0.85		0.67	
Nitrate	0.25		0.52		0.11	Some evidence of effective removal
TP	n/a (n=4)	Not enough data	0.16	Some evidence of effective removal	0.16 (n=14)	
Total Cd	n/a (n=2)		0.25	No significant difference	0.27 (n=12)	No significant difference
Total Cu	0.1	Some evidence of effective removal	**0.02***	**Cu significantly lower at outlet**	**0.002***	**Cu significantly lower at outlet**
Total Fe	0.09		0.89	No significant difference	0.12	Some evidence of effective removal
Total Pb	n/a (n=2)	Not enough data	0.63		0.41 (n=12)	No significant difference
Total Zn	**0.02***	**Zn significantly lower at outlet**	0.69		0.53	

* Denotes significant difference at ρ<0.05 level

There was also some evidence, although weak (ρ=0.16), that total phosphorus (TP) was significantly lower at the outlet in May 2008, although only when initial concentrations at the inlet were elevated (i.e. 0.1-0.7 mg/L) on April 29, May 5 and May 12 (Appendix 7.1 and Figure 7.4). As with the other parameters, there was no net removal of TP at lower concentrations, i.e. ≤0.03 mg/L.

7.3.4 Sediment metal concentrations

Analysis of a **sediment** sample taken **from the pond forebay area**, where sediment deposition occurs near the pond inlet, **showed elevated levels of arsenic, chromium, copper, iron, nickel and zinc** compared to the relevant B.C. Sediment Quality Guidelines (Table 7.4). These levels were similar to metal levels found in stormwater ponds influenced by residential and road land uses (see Table 7.4), although Cu was significantly higher in the Blackcomb Way biofiltration pond than in the study ponds. This may be due to the elevated Cu levels in road salt and sand used in winter road maintenance.

The metal levels found are likely representative of the accumulation of larger sediment particles and associated metals in the inlet area entering from Whistler Village runoff, and may not represent levels in the rest of the pond. There may be some chronic toxicity concerns for aquatic organisms inhabiting the inlet area, particularly those inhabiting the sediment layer of the pond or those sensitive to certain metals.

Table 7.4. Metal concentrations in sediment from the biofiltration pond inlet (Sept 6, 2007)

Biofiltration Pond - 2007 Sediment Sample	RDL	Biofiltration pond inlet (Sep-6-07)	Relevant BC Sediment Quality Guidelines					Metal levels in the stormwater pond muck layers, by land use (TRS, 1994)	
			TEL[1]	PEL[1]	ISQG[2]	LEL[3]	SEL[3]	Residential	Road
Selected Metals (ug/g)		n=1						n=18	n=13
Total Arsenic (As)	0.2	9.8		17	5.9				
Total Cadmium (Cd)	0.05	0.61	0.60	3.50				2	11
Total Chromium (Cr)	1	46		90	37				51
Total Copper (Cu)	0.5	200		197	36			9.4	30
Total Iron (Fe)	100	26,500				21,200	43,766		
Total Lead (Pb)	0.1	29		91	35			44	330
Total Manganese (Mn)	0.2	423				460	1,100		
Total Nickel (Ni)	0.8	32.2				16	75	831	52
Total Zinc (Zn)	1	227		315	123			35	163
Organics (ug/g)									
Total Organic Carbon (TOC)	2	54							
Particle Size (%)									
Clay (<4 um)		12.2							
Silt (<63 um)		24.8							
Sand (<2 mm)		63.0							

[1] **TEL** = interim threshold effect level, **PEL** = probable effect level
[2] **ISQG** = interim sediment quality guideline
[3] **LEL** = lowest effect level, based on SLC, SEL = severe effect level, based on SLC (SLC is Screening Level Concentration)

RDL = Reportable Detection Limit
Pink cells indicate exceedences of guidelines

7.4 Conclusions

Results from grab sampling during both rain and snowmelt periods show that the biofiltration pond is at times receiving pollutants from urban stormwater runoff that are exceeding B.C. AWQGs for the protection of aquatic life. In particular, **elevated levels of TSS, turbidity, *E. coli*, and metals (cadmium, copper and zinc) were observed during periods of high runoff, i.e. first flush fall events and active snowmelt periods.** Ammonia was also elevated during the snowmelt period, likely due to the use of urea in the road salt mixture. Levels of these contaminants dropped significantly in the pond on subsequent rain events in October 2007 and after snowmelt had ended in late May 2008.

Statistical analysis showed that during the high precipitation period in October 2007, the biofiltration pond was particularly effective in reducing suspended solids and associated metals (total copper, iron and zinc) at higher concentrations. During the snowmelt period in May 2008, the pond was particularly effective at removing total copper, which was also elevated during this time. There was also some evidence that total iron, nitrate and total phosphorus were effectively removed during the snowmelt period, while turbidity was somewhat effectively removed during both runoff periods. Cadmium and lead did not appear to be effectively removed by the pond in May 2008, and there were inadequate data during October 2007 to make conclusions. Thus **the pond appears to be relatively effective in removing sediments and associated metals at higher concentrations, although this may pose problems for the long-term health of the wetland, as contaminants can accumulate to harmful levels.**

Analysis of a sediment sample from the pond inlet area, where runoff sediments have been accumulating since 2004, showed elevated levels of total arsenic, chromium, copper and zinc. These levels exceeded B.C. Interim Sediment Quality Guidelines and may be impacting aquatic life inhabiting sediments in that area, although not necessarily in the rest of the pond. Copper was also found to be elevated in leaching tests of the raw road salt and sand material used in winter road maintenance, which may be contributing low level, but chronic concentrations to some Whistler waterways, including the biofiltration pond.

7.5 Recommendations

It is recommended that:

- **Optimization of source controls be implemented in Whistler Village**, so that the effectiveness of the biofiltration pond as a ‘polishing’ treatment system can be maximized, and impacts to the wetland can be minimized. Examples of source control can include low-impact development (LID), increased infiltration, and use of appropriate amounts of road salt and sand so that excessive sediment, chloride, ammonia and copper levels are not impacting water quality in the pond.
- **Limited quantities of snow be stored near the banks of the biofiltration pond**, to reduce the impact of snowmelt that is contaminated with pollutants from road surfaces, as well as sediment, ammonia, and copper from application of salt and sand.
- **The pond be upgraded, if necessary**, to higher engineering standards, to improve its effectiveness in removing contaminants during high flow periods, particularly during first flush events in the summer and fall. For example, a dam structure near the inlet could further encourage sediment deposition in the initial discharge area.
- **Accumulated sediment be removed from the sediment deposition area** at the inlet of the pond periodically to prevent re-suspension in the pond during high flow periods and to prevent toxic effects to aquatic organisms inhabiting this area.

APPENDIX 7.1 – WATER QUALITY RESULTS: OCTOBER 2007 & MAY 2008

Biofiltration Pond - Stormwater Sampling	RDL	02-Oct		10-Oct		RDL*	22-Oct		Arithmetic Mean		BC Water Quality Guidelines		
		Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	Inlet	Outlet	30-day Mean	Max	Notes
Field Measurements													
Temperature (deg C)		9.26	9.55	10.09	9.48		9.17	7.52	**9.51**	**8.85**		10.0-18.0	rainbow trout optimum
Dissolved oxygen (mg/L)		9.86	9.66	8.29	7.62		8.05	8.86	**8.73**	**8.71**	8.0-11.0	5.0-9.0*	*minimum
pH (pH units)		6.73	6.5	n/a	n/a		n/a	n/a	**n/a**	**n/a**		6.5-9.0	
Organics & Inorganics (mg/L)													
Total Hardness (CaCO3)	0.5	40.8	47.8	68.5	56.2		94.8	54.2	**68.0**	**52.7**			
Total Suspended Solids	4	85	64	15	11		12	7	**37**	**27**			
Turbidity (NTU)	0.1	70.4	57.9	17.4	11.8		9.8	4.2	**32.5**	**24.6**			
Conductivity (lab, uS/cm)	1	112	146	239	188		341	190	**231**	**175**			
Dissolved Chloride (Cl)	0.5	8.3	13.8	25.9	19.4		39.1	19.5	**24.4**	**17.6**	150	600	
Total Oil and Grease	1	2	2	1	<1		2	1	**1.7**	**1.3**	Surface water should be virtually free of oils		
Nutrients (mg/L)													
Ammonia (N)	0.005	0.065	0.087	0.088	0.037		0.009	0.006	**0.054**	**0.043**	1.9-2.0	26.5-27.5	pH & T dependent
Nitrate (N)	0.002	0.266	0.246	0.377	0.319		0.36	0.175	**0.334**	**0.247**	40	200	
Total Phosphorus (P)	0.002	n/a	n/a	0.066	0.056		0.063	0.063	**0.065**	**0.060**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.033	0.031	0.041	0.033		0.029	0.03	**0.034**	**0.031**			
Selected Metals (ug/L)													
Dissolved Aluminum (Al)	20	40	30	30	40	1	34	36	**35**	**35**	50	100	pH > 6.5
Dissolved Iron (Fe)	5	32	43	65	69	5	108	84	**68**	**65**		350	
Total Cadmium (Cd)	2	<2	<2	<2	<2	0.01	0.27	0.14	**n/a**	**n/a**		0.017	CCME (interim)
Total Chromium (Cr)	5	<5	<5	<5	<5	1	<1	<1	**n/a**	**n/a**			
Total Copper (Cu)	5	25	18	13	12	0.2	10.1	7.6	**16.0**	**12.5**	2	5.8-10.9	H < 50 mg/L
Total Iron (Fe)	5	1490	781	464	378	5	614	290	**856**	**483**		1000	
Total Lead (Pb)	30	<30	<30	<30	<30	0.2	0.8	0.4	**n/a**	**n/a**	4	18	H=30 mg/L
Total Manganese (Mn)	1	226	137	132	108	1	129	60	**162**	**102**	700	800	H=25 mg/L
Total Zinc (Zn)	5	83	64	56	48	5	48	39	**62.3**	**50.3**	7.5	33	H<90 mg/L
Total Calcium (Ca), mg/L	50	14.3	17.1	24.7	20.2	0.05	34.3	19.6	**24.4**	**19.0**			
Total Sodium (Na), mg/L	50	6.58	9.83	17.1	13.6	0.05	27.3	13.1	**17.0**	**12.2**			
Bacteriology (Col/100 mL)													
Fecal coliforms	1	2700	5200	3900	960		540	450	**1785****	**1310****			geometric mean (n=5),
E. coli	1	2300	2500	2700	790		370	180	**1320****	**708****	385		secondary contact

RDL = Reportable Detection Limit (* improvement in laboratory RDLs for metals in mid-Oct 2007), CCME are Canadian Water Quality Guidelines

** Bacterial means based on n=3, while guideline asks for n=5

Pink cells indicate exceedences of guidelines

Biofiltration Pond - Meltwater Sampling		30-Apr		06-May		13-May		21-May		27-May		Arithmetic Mean		BC Water Quality Guidelines		
	RDL	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	30-day Mean	Max	Notes
Field Measurements																
Temperature (deg C)	0	6.99	6.16	6.81	6.29	7.19	7.25	8.44	9.12	9.14	10.71	**7.71**	**7.91**		10.0-18.0	rainbow trout optimum
Dissolved oxygen (mg/L)	0	9.72	9.37	10.18	9.81	9.37	9.87	8.81	8.28	9.17	7.88	**9.45**	**9.04**	8.0-11.0	5.0-9.0*	*minimum
pH (pH units)	0	5.78	6.14	6.23	6.31	5.35	5.72	n/a	n/a	n/a	n/a	**6**	**6**		6.5-9.0	
Organics & Inorganics (mg/L)																
Total Hardness (CaCO3)	0.5	157	161	127	126	131	143	146	156	111	104	**134.4**	**138.0**			
Total Suspended Solids	4	81	4	10	6	64	6	<4	<4	<4	11	**33**	**6**			
Turbidity (NTU)	0.1	13.9	1.8	7.7	6.5	34.3	3.7	1.3	1.9	1.7	5.9	**11.8**	**4.0**			
Conductivity (lab, uS/cm)	1	560	630	490	440	420	470	640	570	410	440	**504**	**510**			
Dissolved Chloride (Cl)	0.5	97	110	71	66	56	67	110	87	60	65	**78.8**	**79.0**	150	600	
Nutrients (mg/L)																
Ammonia (N)	0.005	0.139	0.356	0.159	0.119	0.382	0.06	0.075	0.223	0.274	0.203	**0.206**	**0.192**	1.9-2.0	26.5-27.5	pH & T dependent
Nitrate (N)	0.002	0.413	0.428	0.261	0.225	0.331	0.184	0.351	0.354	0.306	0.38	**0.332**	**0.314**	40	200	
Total Phosphorus (P)	0.002	0.209	0.02	0.14	0.023	0.73	0.012	0.019	0.038	0.029	0.031	**0.225**	**0.025**		0.005-0.015	lake guideline
Orthophosphate (P)	0.001	0.023	0.016	0.082	0.02	0.66	0.01	0.02	0.024	0.012	0.018	**0.159**	**0.018**			
Selected Metals (ug/L)																
Dissolved Aluminum (Al)	0.2	27.1	18.4	16.8	19.3	10.5	25.8	20.7	16.8	25.9	17.9	**20.2**	**19.6**	50	100	pH > 6.5
Dissolved Iron (Fe)	1	56	12	9	15	16	29	50	19	86	73	**43**	**30**		350	
Total Cadmium (Cd)	0.005	0.28	0.275	0.237	0.202	0.225	0.196	0.093	0.106	0.09	0.068	**0.185**	**0.169**		0.017	CCME (interim)
Total Copper (Cu)	0.05	22.2	13.3	15.7	10.9	14.5	10.1	9.98	8.8	10.6	9.75	**14.60**	**10.57**	2	11.8-17.1	H < 50 mg/L
Total Iron (Fe)	1	439	399	388	394	622	307	370	465	303	461	**424**	**405**		1000	
Total Lead (Pb)	0.005	1.39	0.292	0.638	0.693	1.22	0.323	0.072	0.189	0.226	0.378	**0.709**	**0.375**	4	18	H=30 mg/L
Total Manganese (Mn)	0.05	142	189	133	130	209	171	121	178	82.9	111	**137.58**	**155.80**	700	800	H=25 mg/L
Total Zinc (Zn)	0.1	32.4	42.1	29.5	26.1	46.1	24.6	12.7	18.8	13.9	23.9	**26.9**	**27.1**	7.5	33	H<90 mg/L
Total Calcium (Ca), mg/L	0.05	55.8	57.7	45.8	45.6	47.2	52.3	52.6	56.6	40.3	37.5	**48.34**	**49.94**			
Total Magnesium (Mg), mg/L	0.05	4.27	4.12	3.01	2.9	3.15	3.14	3.46	3.48	2.48	2.54	**3.27**	**3.24**			
Total Sodium (Na), mg/L	0.05	56.7	60.5	39.7	33.6	32	35.4	64.7	49.5	35	38.5	**45.62**	**43.50**			
Bacteriology (Col/100 mL)																
Fecal coliforms	1	9	8	2	<1	100	630	28	290	2300	1100	**41**	**69**			geometric mean,
E. coli	1	6	5	1	<1	37	<1	14	200	2000	640	**23**	**14**	385		secondary contact

RDL = Reportable Detection Limit, CCME are Canadian Water Quality Guidelines

Pink cells indicate exceedences of guidelines

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MASTER APPENDIX A – B.C. AWQGS FOR SUSPENDED SEDIMENTS AND TURBIDITY

B.C. Water Quality Guidelines for **suspended sediments and turbidity** during clear and turbid flow periods

BC Water Quality Guidelines - Turbidity & Suspended Sediments			
	Conditions	**Suspended Sediments (SS)**	**Turbidity**
Clear Flow Periods	During any 24-h period (hourly sampling preferred)	Induced SS concentrations should not exceed background levels by >25 mg/L	Induced turbidity should not exceed background levels by more than 8 NTU
	For sediment inputs that last between 24-h & 30 days (daily sampling preferred)	Mean SS concentration should not exceed background by >5mg/L	Mean turbidity should not exceed background by more than 2 NTU
Turbid Flow Periods	Moderate background levels	Induced SS concentrations should not exceed background levels by more than 25 mg/L at any time when background levels are 25-250 mg/L	Induced turbidity should not exceed background levels by more than 8 NTU at any time when background turbidity is 8-80 NTU
	High background levels	When background >250 mg/L, SS should not be increased by >10% of measured background level at any one time	When background >80 NTU, turbidity should not be increased by >10% of measured background level at any one time

Note: Statistical reliability of data set is improved with increased monitoring frequency. Ideally, 24 samples in 24 h and/or 30 samples in 30 days are preferred.

MASTER APPENDIX B – IMPACT ASSESSMENT MODEL FOR CLEAR WATER FISHES

Visual clarity of water (turbidity)		Impact Assessment Model for Clear Water Fishes Exposed to Conditions of Reduced Water Clarity (adapted from Newcombe, 2001, 2003)										
		Severity-of-ill-effect Scores (SEV) - Potential										
Secchi depth (m)	Turbidity (NTU)	**SEV = -4.49 + 0.92[ln(h)] - 2.59[ln(yBD)]**										
0.01	1100	7	8	9	10	11	12	13	14			
0.03	400	${}_{P}6^{\pi}$	7	7	8	9	10	11	12	13	14	
0.07	150	3	${}_{P}4^{\pi}$	${}_{P}5^{\pi}$	6	7	8	9	10	11	12	13
0.15	55	${}_{P}\underline{1}^{\pi}$	2	3	4	5	6	7	8	9	10	10
0.34	20	$\underline{0}$	${}_{P}\underline{0}^{\pi}$	${}_{P}\underline{1}^{\pi}$	2	3	4	5	6	7	$\underline{8}$	8
0.77	7	$\underline{0}$	${}_{P}\underline{0}^{\pi}$	$\underline{0}$	$\underline{0}$	$\underline{1}$	2	3	4	4	5	6
1.53	3	$\underline{0}$	${}_{P}\underline{0}^{\pi}$	$\underline{0}$	$\underline{0}$	$\underline{0}$	$\underline{0}$	1	2	3	4	5
3.68	1	${}^{P}\underline{0}_{\pi}$	${}^{P}\underline{0}_{\pi}$	${}^{P}\underline{0}_{\pi}$	0	0	0	0	0	0	1	2
		1	**3**	**7**	**1**	**2**	**6**	**2**	**7**	**4**	**11**	**30**
		Hours			**Days**			**Weeks**		**Months**		

NTU (nephelometric turbidity units): measure of light scattering by suspended clay particles (0.2 to 5µm diameter)
yBD (black disk sighting range (m): horizontal measurement in water of any depth (reciprocal of beam attenuation).
SEV scale: 0 ≤ nil < 0.5; 0.5 ≤ minor < 3.5; 3.5 ≤ moderate < 8.5; 8.5 ≤ severe < 14.5
Impact assessment is based on *net* duration (less clear-water intervals) and weighted-average visual clarity data.

Equation for converting NTU to yBD: **ln(yBD) = 5.572012 - 0.80137ln(NTU), yBD in cm**

(green)	***Ideal (0)*.** Best for adult fishes that must live in a clear water environment most of the time.
(light yellow)	***Slightly impaired (1-3)*.** Feeding and other behaviours begin to change: severity of effect increases with duration.
(orange)	***Significantly impaired (4-8)*.** Marked increase in water cloudiness could reduce fish growth rate, habitat size, or bot
(pink)	***Severely impaired (9-14)*.** Profound increases in water cloudiness could cause poor 'condition' or habitat alienation.
(grey)	Areas with least supporting data (1 day to 11 months), or least likelihood of problems (30 months), or both.
${}^{P}\underline{0}_{\pi}$	Some predatory fish (P) catch more prey fish (π) in clear water (${}^{P}{}_{\pi}$) than they do in cloudy water.
${}_{P}\underline{1}^{\pi}$	Survival of some fishes (e.g. young juvenile Pacific salmon) is enhanced (${}^{P}{}_{\pi}$) by natural, seasonal, cloudiness.
${}_{P}5^{\pi}$	Data sources: predatory-prey dynamics, see Newcombe, 2000.
$\underline{8}$	Data sources: severity of hill effects (any SEV with underscore), see Newcombe, 2000.

MASTER APPENDIX C – EFFECTS OF TURBIDITY ON FISH PHYSIOLOGY AND BEHAVIOUR

Effect	Sub-effect	Lowest turbidity level causing the effect
Physiological	Gill flaring	20 NTU
	Reduction in growth	25 NTU
Behavioural	Emigration of young coho salmon & steelhead from laboratory streams (& reduction in growth)	25-50 NTU
	Breakdown of territory structure	30-60 NTU
	Reestablishment of territory (after short-term sediment pulse)	20 NTU
	Mis-striking of prey items frequently	10 NTU
	Significant delay in response & reduction in reaction distance to introduced prey	20-60 NTU

Note: Individual lab studies referenced in Bash et al., 2001

MASTER APPENDIX D – TOXICOLOGICAL IMPACTS OF SELECTED METALS

Aluminum (Al)

Al is ubiquitous in rock and soils and can be mobilized in aquatic environments from these sources, as well as from lake and stream sediments, where natural levels of dissolved Al in B.C. rivers and streams have been reported to range from <5 to 900 µg/L, with a median of 30 µg/L (n=1308) (Butcher, 1988). Freshwater invertebrates appear to be relatively tolerant to short-term Al exposure, where chironomid larvae appeared to be unaffected by a 96-h exposure to 6.7-78 mg/L at pH 6.9-7.7 (Butcher, 1988). However, benthic invertebrate downstream drift density was found to triple in a B.C. coastal stream after dissolved Al levels increased from ambient levels (50-75 µg/L) to >225 µg/L, where some invertebrates (Ephemeroptera, or mayflies) responded within 1 h (Butcher, 1988).

Acute toxicities of total Al (≤4 d) to rainbow trout (*Salmo gairdneri*) have been reported to be 3.2 mg/L (96-h LC50) and 7.6 mg/L (48-h LC50) for waters with pH 7.0, while no effect levels have been reported to be 1 mg/L (pH 6.5-7.2) (Butcher, 1988). It has also been reported, however, that 0.1 mg/L is the threshold Al level for increased cough frequency in rainbow trout (Butcher, 1998).

Cadmium (Cd)

Cd is a common metal found in urban stormwater runoff, one source coming from tire wear on road surfaces. Additionally, elevated chloride levels during snowmelt periods could increase dissolved Cd levels in sediment pore water through ionic exchange, thereby contributing to increased toxicity for aquatic organisms living in sediment (Marsalek, 2003). Cd is a non-essential metal that is of environmental concern as it readily bioconcentrates in aquatic organisms and biomagnifies in the food chain. Effects to aquatic life forms include impairment of macrophyte and fish growth, as well as reduced long-term survival and growth at sublethal exposures (F. Solomon, UBC, October 28, 2008, personal communication).

Copper (Cu)

Cu is generally present in trace amounts in natural surface waters up to concentrations of 5 µg/L, where higher levels are usually associated with anthropogenic sources, such as road building, which can accelerate the release of Cu to the aquatic environment (Singleton, 1987). It has also been reported that adsorption of Cu to silt particle surfaces may account for 20-80% of total Cu transported in rivers (Singleton, 1987). Cu in the aquatic environment is of concern as it is toxic to aquatic organisms at low levels and can bioaccumulate in algae, macrophytes, invertebrates and fish.

Incipient lethal Cu levels, or concentrations beyond which organisms can no longer live for an indefinite period of time, for several freshwater invertebrate species in soft water (<50 mg/L CaCO3) range from 7-14 µg/L Cu (Singleton, 1987). Sublethal effects of Cu on invertebrates and fish include behavioural, reproductive, and growth effects; growth of rainbow trout can be inhibited by Cu concentrations as low as 10 µg/L in soft water (H=20 mg/L) at pH 6 (Singleton, 1987). A recent study also found that dissolved Cu was neurotoxic to juvenile coho salmon (*Oncorhynchus kisutch*) where a 30-min exposure to 20 µg/L reduced the olfactory response to a natural odorant by 82% (McIntyre et al., 2008).

Iron (Fe)

Fe is ubiquitous in the environment and necessary for all life forms, but can also be potentially toxic at high concentrations, leading to both reduced abundance and reduced species diversity of periphyton, benthic invertebrates and fish. This occurs mainly from precipitation of ferric hydroxide ($Fe(OH)_3$) on stream and lake bottoms, which can cover spawning grounds and reduce light penetration, thereby decreasing productivity and food sources for invertebrates and fish (Phippen *et al*., 2008). Acute toxicities (96-h LC50s) of dissolved Fe for some freshwater invertebrates have been reported to be 3.5 mg/L for the amphipod, *Hyalella* (soft water), and 11.8 mg/L for the water flea, *Daphnia magna* (pH 6.5); while the 96-h LC50 for total Fe for brown trout (*Salmo trutta*) has been reported to be 28 mg/L (Phippen *et al*., 2008). It should be noted that the dissolved Fe guideline of 0.35 mg/L was derived by building in a safety factor of 10 for the most sensitive organism, *Hyalella*.

Zinc (Zn)

While zinc (Zn) is ubiquitous in the environment and a necessary element for aquatic and terrestrial biota, higher concentrations can be toxic to aquatic life (Nagpal, 1997). Acute toxicities for the freshwater invertebrate Daphnia magna (water flea) have been reported to be 68 µg Zn/L (96-h LC50, hardness 130 mg/L), while 96-h LC50s of 90-169 µg Zn/L have been reported for rainbow trout (*Oncorhynchus mykiss*), although no hardness was given (Nagpal, 1997).

MASTER APPENDIX E – ENVIRONMENTAL MANAGEMENT ACT

Environmental Management Act
[SBC 2003] CHAPTER 53

Definition of **"pollution"** means the presence in the environment of substances or contaminants that substantially alter or impair the usefulness of the environment.

Waste disposal

6 (4) Subject to subsection (5), a person must not introduce waste into the environment in such a manner or quantity as to cause pollution.

MASTER APPENDIX F – FISHERIES ACT

Fisheries Act (R.S., 1985, c. F-14)

FISH HABITAT PROTECTION AND POLLUTION PREVENTION

Definitions

34. (1) For the purposes of sections 35 to 43,

"deleterious substance" means

(*a*) any substance that, if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water, or

(*b*) any water that contains a substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water,

and without limiting the generality of the foregoing includes

(*c*) any substance or class of substances prescribed pursuant to paragraph (2)(*a*),

(*d*) any water that contains any substance or class of substances in a quantity or concentration that is equal to or in excess of a quantity or concentration prescribed in respect of that substance or class of substances pursuant to paragraph (2)(*b*), and

(*e*) any water that has been subjected to a treatment, process or change prescribed pursuant to paragraph (2)(*c*);

"deposit" means any discharging, spraying, releasing, spilling, leaking, seeping, pouring, emitting, emptying, throwing, dumping or placing;

"fish habitat" means spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes;

"water frequented by fish" means Canadian fisheries waters.

Regulations for purpose of definition "deleterious substance"

(2) The Governor in Council may make regulations prescribing

(*a*) substances and classes of substances,

(*b*) quantities or concentrations of substances and classes of substances in water, and

(*c*) treatments, processes and changes of water

for the purpose of paragraphs (*c*) to (*e*) of the definition "deleterious substance" in subsection (1).

R.S., c. F-14, s. 31; R.S., c. 17(1st Supp.), ss. 2, 3; 1976-77, c. 35, ss. 5, 7.

Harmful alteration, etc., of fish habitat

35. (1) No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat.

Alteration, etc., authorized

(2) No person contravenes subsection (1) by causing the alteration, disruption or destruction of fish habitat by any means or under any conditions authorized by the Minister or under regulations made by the Governor in Council under this Act.

R.S., c. F-14, s. 31; R.S., c. 17(1st Supp.), s. 2; 1976-77, c. 35, s. 5.

Throwing overboard of certain substances prohibited

36. (1) No one shall

(*a*) throw overboard ballast, coal ashes, stones or other prejudicial or deleterious substances in any river, harbour or roadstead, or in any water where fishing is carried on;

(*b*) leave or deposit or cause to be thrown, left or deposited, on the shore, beach or bank of any water or on the beach between high and low water mark, remains or offal of fish or of marine animals; or

(*c*) leave decayed or decaying fish in any net or other fishing apparatus.

Disposal of remains, etc.

(2) Remains or offal described in subsection (1) may be buried ashore, above high water mark.

Deposit of deleterious substance prohibited

(3) Subject to subsection (4), no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.