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Mr. Bruce Donald
Teck Metals
Bag 2000
Kimberley, BC V1A 3E1

Dear Mr. Donald:

RE: Evaluation of Limnological and Chemical Conditions of Garrow Lake and Chemistry of Garrow Creek, Nunavut 2002 - 2011

Introduction

This letter describes: a) the limnological and chemical conditions of Garrow Lake, Little Cornwallis Island NU from the end of tailings deposition to the lake (2002) through the 2011 field season; and b) chemistry of Garrow Creek and results of toxicity testing during the same time period (2002 – 2011). Since tailings deposition ceased and the mine closed, field studies has documented the vertical physical (temperature, oxygen) and chemical (e.g., conductivity, pH, metals, sulphate) conditions in Garrow Lake and their relationship to chemistry of Garrow Creek, the natural outlet of the lake.

Teck Metals has requested that Azimuth Consulting Group Partnership (Azimuth) review the 2002 – 2011 data to describe the evolution of physical/chemical conditions within the lake post-mining with the objective of determining a future environmental monitoring program and assisting with management decisions at the site.

Background

Garrow Lake is a small (4.2 km^2), permanently chemically and thermally stratified (i.e., meromictic) lake with a maximum depth of 40 m and unique limnological characteristics (BC Research, 1975; Ouellet and Dickman, 1983; Dickman and Ouellet, 1987; Fallis et al., 1987; Azimuth, 2005). The lake is ultra-oligotrophic with very low nutrient concentration and a depauperate biological community that inhabits the upper oxygenated layer, including a marine relict population of fourhorn sculpin, *Myoxocephalus quadricornis* (BC Research, 1978; Fallis et al., 1987; Azimuth, 2005).

Garrow Lake is situated in an area of continuous permafrost and is ice-covered for much of the year. In some years, the ice does not completely melt, leaving a near-complete ice cover. The lake slopes steeply from the narrow littoral zone into the anoxic, hyper-saline profundal zone within tens of meters from shore. The drainage area of Garrow Lake is very small and is only double the surface area of the lake. The small drainage area and low precipitation means that total annual discharge from the lake via Garrow Creek is correspondingly small.

Garrow Lake is one of the few meromictic lakes found in the Arctic and has the highest salinity content of all polar lakes (Ouellet and Dickman, 1983). Strong vertical stratification due to large differences in salinity and temperature between the cold (~0°C), slightly brackish (2 – 7 ppt salinity) mixolimnion (i.e., equivalent to the epilimnion) and the warm (8°C), anoxic, hypersaline (70 – 80 ppt), hydrogen sulphide rich monimolimnion (i.e., equivalent to the hypolimnion) maintains complete separation of these two discrete layers. Isotopic examination of bottom water from Garrow Lake by Page et al. (1984) revealed that exposure of this water to air last took place at least 2,600 years ago. Thus the bottom water of Garrow Lake is discrete and has been isolated from contact with surface waters for 26 centuries.

Discharge to Garrow Bay, 1.4 km south of the lake outlet occurs during the brief open water period from thawing of the creek channel in early July through late-August or early September when the system freezes again. Plume monitoring of Garrow Creek into the marine environment of Garrow Bay indicates that the slightly brackish discharge extends as a thin (2-4 cm) narrow plume offshore of the creek, gradually mixing and dispersing into the surface waters of the nearshore Garrow Bay.

Average ice thickness of Garrow Lake is 2 – 2.5 m depending on snow cover. Vertical sampling of Garrow Lake water column typically occurred through ice during early spring (May) and in open water (August) when ice conditions permitted (e.g., sampling was not possible in summer 2004 due to complete ice cover). Physical/chemical conditions of the water were measured at 1 m intervals near the deep part of the lake to acquire pH, temperature (°C), oxygen (ppm) and conductivity (mS; equivalent to salinity) using a Hydrolab™ meter. Vertical temperature and conductivity profiles have been documented during pre-mining (<1980; BC Research, 1975; Fallis et al., 1987), during-mining (BC Research, 1988) and post-mining (this document). Effects of mine tailings disposal on lake stratification, limnological parameters and water chemistry was described by Azimuth (2005).

In summary, tailings deposition between 1981 and 2002 displaced the mixolimnion upwards about 3 m shallower than pre-mining, beginning at 9 m, up from the pre-mine depth of 12.5 m. Salinity of the monimolimnion has diminished from approximately 80 ppt to about 65 ppt owing to the large amount of tailings deposited to the lake over more than 20 years, diluting bottom waters. Similarly, bottom temperature has decreased by about 2°C to range between 6.5° and 7°C. Oxygen was and remains nil and hydrogen sulfide remains very abundant in bottom waters.

To determine the physical stability of the meromictic nature of Garrow Lake and integrity of the pycnocline at end of mine life, Teck Cominco commissioned AXYS (2001) to determine if mixolimnion depth and chemical stability of the pycnocline was sufficient to prevent turnover and mixing of the monimolimnion into the mixolimnion. If this occurred, water chemistry of the entire lake and Garrow Creek would be considerably altered. AXYS (2001) concluded that the density barrier of the pycnocline so strong that no meteorological condition observed (e.g., sustained high winds for a long period over an ice-free lake) could physically overturn the lake.

Garrow Lake Post-Mining Conditions (2002 – 2011)

Temperature/conductivity (**Figures 1** and **2**) and total zinc (**Figure 3**) data are presented for Garrow Lake from 2002, the final year of tailings deposition, through summer 2011. To simplify data presentation only data from the deep (~38 – 40 m) station are depicted as the shallow (20 m) south station show identical data. We also depict open water conditions of Garrow Lake, except for 2002 and 2004 when sampling of the lake during summer was not possible due to ice. Summer data tend to be more variable between years because of the influence of wind mixing.

Temperature/Conductivity

Vertical temperature and conductivity (a measure of salinity) profiles for Garrow Lake between 2002 and 2011 depicted in **Figures 1** and **2** respectively show very repeatable vertical patterns over time. Tailings deposition to the monimolimnion over 20 years of mining caused vertical mixing within this layer, creating fairly uniform temperature and salinity/conductivity profiles in this layer.

- Bottom temperature has gradually diminished from about 8^{o}C in 2002 to 6.5^{o} – 7^{o}C in 2011 and appears to have stabilized at this temperature, with little change from 2008 profiles. These data were field generated using the Hydrolab^{TM} so there is some uncertainty regarding calibration of the meter from year to year that might contribute to temperature variability. Temperature of the monimolimnion remains independent and significantly warmer than surface mixolimnion waters even during summer, as temperature never exceeds 5^{o}C.
- Conductivity of the mixolimnion is fairly consistent and uniform ranging from 10 – 13 mS/cm (millisiemens/cm). This value will vary depending on timing of monitoring and amount of snowmelt and freshwater input to surface water.
- Transition to the hyper saline, dense monimolimnion occurs very rapidly at a depth of 9 – 10 m with an 8x increase in conductivity/salinity. Although conductivity appears to vary over time, the pattern is not consistent with something systematic. Although conductivity in 2003 – 2006 appears to be 10 mS/cm lower than in 2002 (90 mS/cm) data from 2008 – 2011 are only slightly lower than in 2002 and very stable at 88 mS/cm (**Figure 2**). Variation in conductivity between years is likely due to differences in laboratory generated data. However, slightly higher conductivity in 2002 during the final year of tailings deposition may be a reflection of higher metals concentration in the water column (**Figure 3**). Total and dissolved metals concentrations (including zinc) are considerably lower than during the mining period (**Figure 3**).

These data indicate that the monimolimnion is thermally and chemically independent from the mixolimnion with a rapid transition that occurs at 10 m depth in Garrow Lake. Data collected since cessation of mining show stable and uniform patterns of temperature and conductivity that have not changed significantly between 2002 and 2011.

Zinc

Zinc concentration has been the major focus of water quality monitoring in Garrow Lake as a major component of tailings materials. Tailings discharge to the monimolimnion of Garrow Lake prevented dissolved metals from diffusing upwards through the pycnocline and into the mixolimnion. The high density of the pycnocline presented a physical barrier, while the abundance of sulphides scavenged metals from the water column, acting as a chemical barrier. However, a spill of tailings into surface waters in 1984/85 was responsible for elevating metal concentrations in the mixolimnion. BC Research (1988) estimated that approximately 800 tonnes of zinc was released to the mixolimnion, causing zinc concentrations to rise from 10 µg/L to at least 400 µg/L (4 mg/L) (AXYS, 1991). This spill also influenced zinc concentration in water discharged via Garrow Creek. Concentrations have diminished since this time, but are obviously still higher than pre-mining concentrations.

- Zinc concentrations in the mixolimnion of Garrow Lake have consistently hovered around 0.2 mg/L (200 µg/L). Concentrations between 2006 and 2011 are very similar and suggest that zinc concentrations have stabilized at this concentration, or are declining very slowly. Minor differences in zinc concentration among years are due to differences in timing of collection related to precipitation, snowmelt, ice melt, causing dilution of surface waters.
- Zinc concentration in the mixolimnion has diminished by half since peak concentrations several years after the spill.
- In the monimolimnion, zinc has diminished dramatically since cessation of tailings deposition, with consistent, gradual declines through 2003 – 2005 from the 2002 peak. Total zinc concentration has stabilized at 3 – 4 µg/L with no change between 2006 and 2011. The abundance of sulfides in the water column below the pycnocline have scavenged and precipitated the dissolved and particulate metals where they have fallen to the bottom of the lake to be sequestered there.

Garrow Creek Zinc

Zinc concentrations in Garrow Creek have been measured on a roughly weekly basis (weather and aircraft availability dependent) every year during the brief open water period, between early July and end of August or very early September. The intra-annual profiles of zinc between 2002 and 2011 (**Figure 4**) depict a fairly repeatable pattern with very low concentrations early in the discharge period because of the large influence of snowmelt. Note that discharge rate in the stream is much higher during July of runoff with an exponential decline in runoff volume through August.

Moving through late July and into August, zinc concentrations increase from about 0.05 mg/L to a maximum of 0.15 mg/L in some years. In most years however, zinc concentration of the creek at the end of the open water period is less than 0.10 mg/L. Runoff from Garrow Lake into Garrow Creek consists of the uppermost water of the lake that will have the lowest salinity and metals concentrations because of the lingering influence of ice melting, local precipitation and minor influence of shallow groundwater due to gradual thawing of the upper permafrost layer.

Garrow Creek Toxicity

As per Environment Canada Environmental Effects Regulations (EEM) under the Metal Mining Effluent Regulations (MMER), Teck conducted acute toxicity testing (L50) of Garrow Creek water (i.e., mine effluent) on a monthly basis during the open water period (2003 – 2011) on rainbow trout (*Oncorhynchus mykiss*) and the water flea (*Daphnia magna*). Toxicity testing was initially carried out by EVS Environment Consultants/Golder (to 2006) and then by the same individuals with Nautilus Environmental (>2007) with 2007 monitoring by ALS Environmental.

With the exception of a single event in 2007 (despite a low zinc concentration of 0.05 mg/L), LC50 of the effluent is >100% with no toxicity observed to either species.

Summary Points

In the 10 years since mining and tailings deposition to the monimolimnion of Garrow Lake ceased, physical/chemical conditions of the lake have stabilized, with predictable, repeatable patterns in vertical profiles within the lake and in Garrow Creek. Key points are as follows:

- Despite 20 years of tailings disposal, Garrow Lake is still very strongly vertically stratified. Surface mixolimnion water is characterized as low temperature, low salinity to 9 m depth where there is a rapid and strong transition to a high temperature, high salinity (8x difference) monimolimnion separated by a 2 - 3 m thick pycnocline layer.
- Zinc concentration in the mixolimnion is stable at 0.2 mg/L or slightly declining. Sulfides in the monimolimnion have scavenged zinc from the water column and concentrations are consistently less than 0.02 mg/L below 12 m to depth.
- According to AXYS (2001) the vertical difference in temperature and salinity is still sufficiently strong that wind mixing of the two layers is not physically possible and will ensure that the monimolimnion remains isolated, as it has for at least 2600 years (Page et al., 1984) before present.
- The chemistry of Garrow Creek is a direct reflection of upper surface layer water chemistry of Garrow Lake, with low zinc concentration (<0.1 mg/L) and is not acutely toxicity.

Sincerely,
Azimuth Consulting Group Inc.

Randy Baker, M.Sc., R.P.Bio. Principal

References

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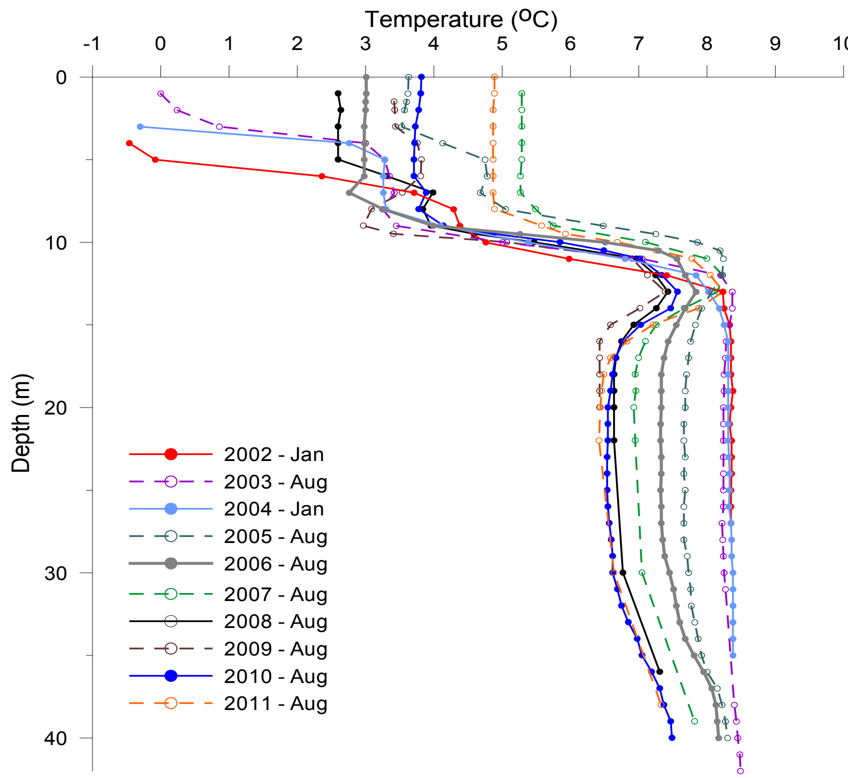
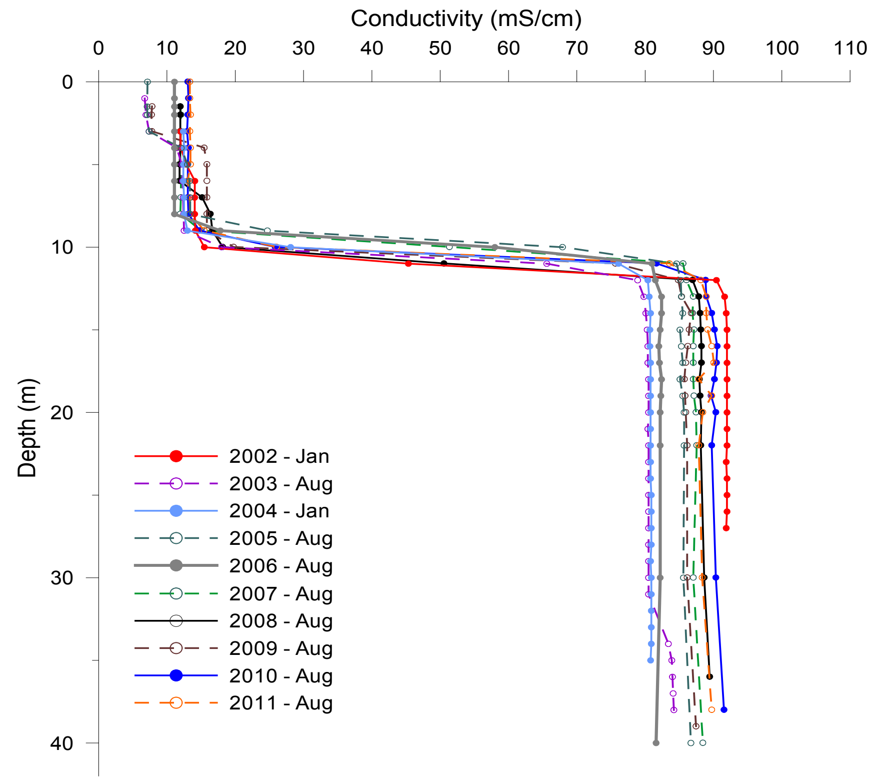
Page, P., M. Ouellet and M. Dickman. 1984. Isotopic analysis (^{18}O, ^{13}C, ^{14}C) of two meromictic lakes in the Canadian Arctic Archipelago. Limnol. Oceanogr. 29(3): 564 – 573.

Figure 1. Temperature in Garrow Lake Center 2002 - 2011.



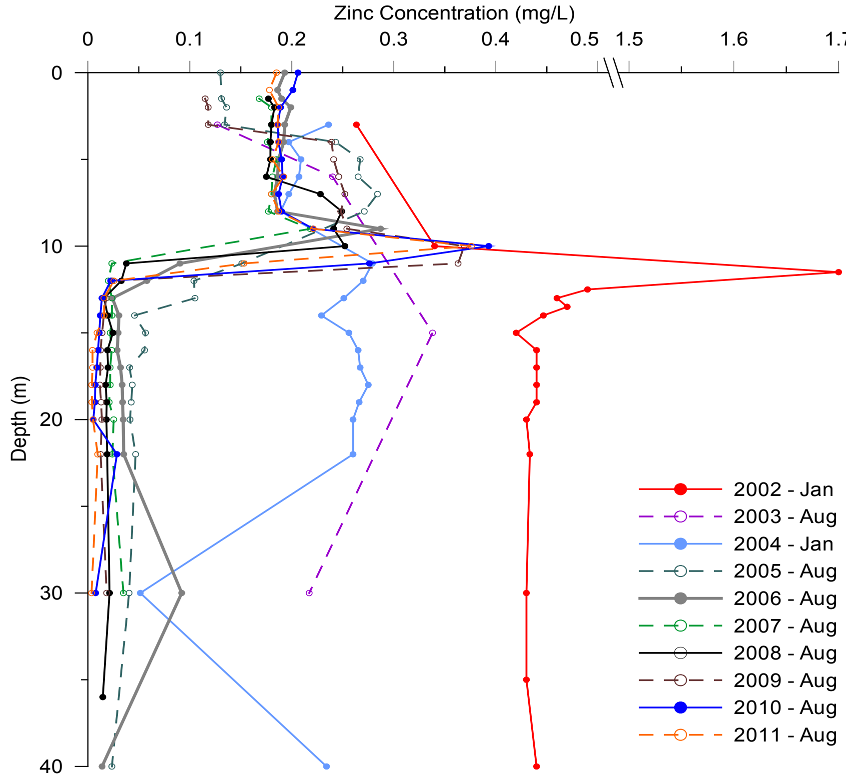
**Garrow Lake South station data are shown for January 2004 due to a sampling error at the center station.

Figure 2. Conductivity in Garrow Lake Center 2002 - 2011.



**Garrow Lake South station data are shown for January 2004 due to a sampling error at the center station.

Figure 3. Zinc in Garrow Lake Center 2002 - 2011



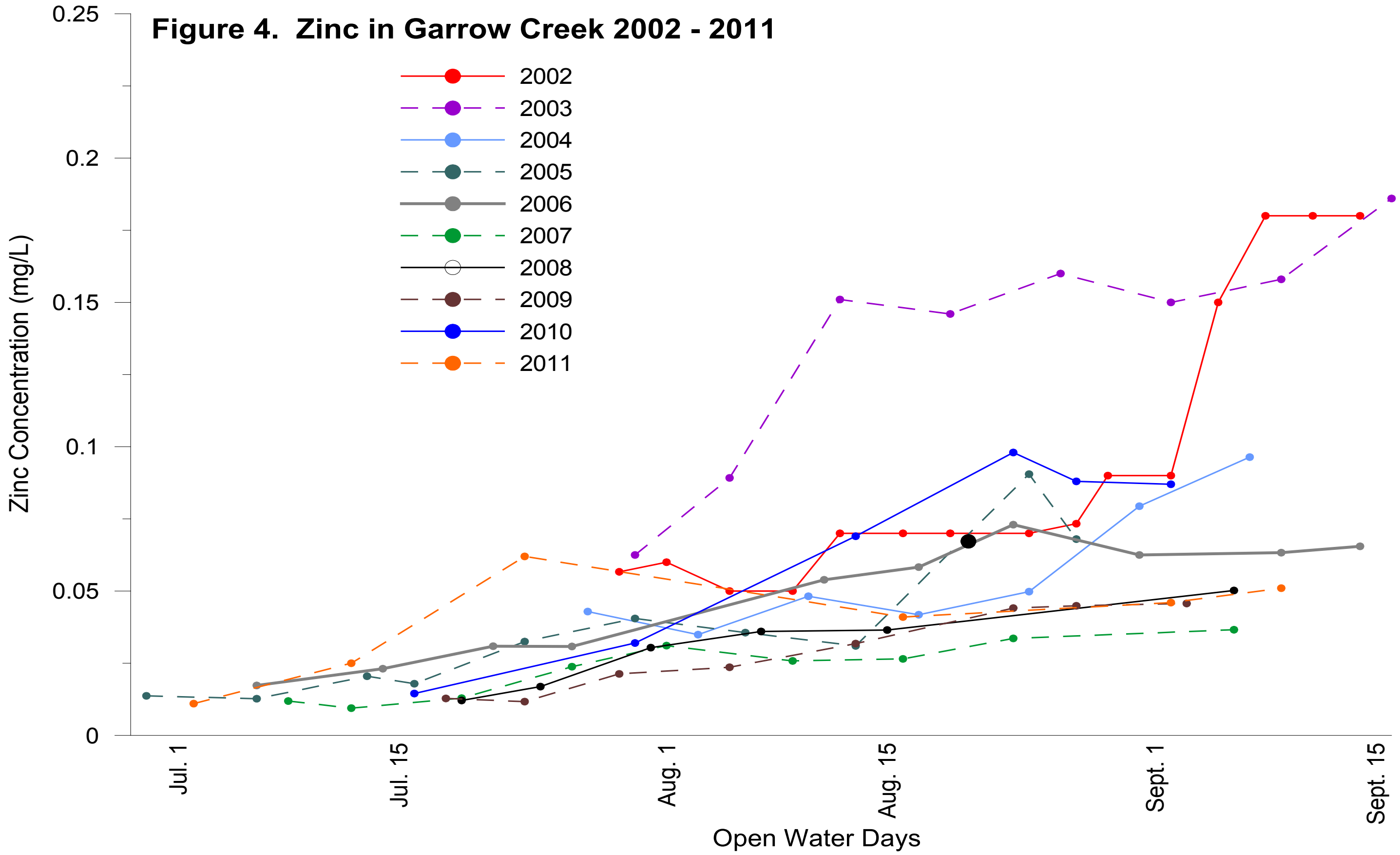


Figure 4. Zinc in Garrow Creek 2002 - 2011
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Zinc Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Jul. 1
Jul. 15
Aug. 1
Aug. 15
Sept. 1
Sept. 15
Open Water Days

Table 1. Summary of Polaris Mine acute toxicity tests, 2003 - 2011.

Test Date	Species Tested	Test Type	Sample Method	Consultant Laboratory	LC50 (% effluent)	LC50 Lower Confidence Limit (% effluent)	LC50 Upper Confidence Limit (% effluent)
Rainbow Trout 96-hr LC50							
29-Jul-03	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants, North Vancouver, BC	> 100	-	-
19-Aug-03	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants, North Vancouver, BC	> 100	-	-
16-Sep-03	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants, North Vancouver, BC	> 100	-	-
7-Jul-04	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants, North Vancouver, BC	> 100	-	-
27-Jul-04	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants, North Vancouver, BC	> 100	-	-
24-Aug-04	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
16-Jul-05	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
6-Aug-05	*Oncorhynchus mykiss*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
15-Jul-06	*Oncorhynchus mykiss*	Survival	Grab	Golder Associates, North Vancouver, BC	> 100	-	-
23-Aug-06	*Oncorhynchus mykiss*	Survival	Grab	Golder Associates, North Vancouver, BC	> 100	-	-
9-Sep-06	Sample lost due to laboratory error						
26-Jul-07	*Oncorhynchus mykiss*	Survival	Grab	ALS Environmental, Winnipeg, MB	PASS	-	-
23-Aug-07	*Oncorhynchus mykiss*	Survival	Grab	ALS Environmental, Winnipeg, MB	> 100	-	-
6-Sep-07	*Oncorhynchus mykiss*	Survival	Grab	ALS Environmental, Winnipeg, MB	> 100	-	-
30-Aug-08	*Oncorhynchus mykiss*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
9-Sep-08	*Oncorhynchus mykiss*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
18-Jul-09	*Oncorhynchus mykiss*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
16-Jul-10	*Oncorhynchus mykiss*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
23-Aug-10	*Oncorhynchus mykiss*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
23-Jul-11	*Oncorhynchus mykiss*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
7-Sep-11	*Oncorhynchus mykiss*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
Daphnia magna **48-hr LC50**							
29-Jul-03	*Daphnia magna*	Survival	Grab	EVS Consultants, North Vancouver, BC	> 100	-	-
19-Aug-03	*Daphnia magna*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
16-Sep-03	*Daphnia magna*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
7-Jul-04	*Daphnia magna*	Survival	Grab	EVS Consultants, North Vancouver, BC	> 100	-	-
27-Jul-04	*Daphnia magna*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
24-Aug-04	*Daphnia magna*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
16-Jul-05	*Daphnia magna*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
6-Aug-05	*Daphnia magna*	Survival	Grab	EVS Consultants North Vancouver, BC	> 100	-	-
15-Jul-06	*Daphnia magna*	Survival	Grab	Golder Associates, North Vancouver, BC	> 100	-	-
23-Aug-06	*Daphnia magna*	Survival	Grab	Golder Associates, North Vancouver, BC	> 100	-	-
9-Sep-06	*Daphnia magna*	Survival	Grab	Golder Associates, North Vancouver, BC	> 100	-	-
26-Jul-07	*Daphnia magna*	Survival	Grab	ALS Environmental, Winnipeg, MB	PASS	-	-
23-Aug-07	*Daphnia magna*	Survival	Grab	ALS Environmental, Winnipeg, MB	67.4	59.7	76.1
6-Sep-07	*Daphnia magna*	Survival	Grab	ALS Environmental, Winnipeg, MB	86.6	-	-
30-Aug-08	*Daphnia magna*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
9-Sep-08	*Daphnia magna*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
18-Jul-09	*Daphnia magna*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
16-Jul-10	*Daphnia magna*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
23-Aug-10	*Daphnia magna*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
23-Jul-11	*Daphnia magna*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-
7-Sep-11	*Daphnia magna*	Survival	Grab	Nautilus Environmental, Burnaby, BC	> 100	-	-