BRITANNIA MINE REMEDIATION PROJECT – INTEGRATING ECOLOGICAL MONITORING WITH RECLAMATION ACTIVITIES

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ABSTRACT

The former Britannia Copper Mine operated from the early 1900s to 1974, during which time it generated more than an estimated 40 million tonnes of tailings. A large proportion of the tailings was deposited in Howe Sound and as fill along the Britannia Beach shoreline. The acid-generating tailings and former mine workings had been leaching dissolved copper and zinc into Britannia Creek and Howe Sound. In recent times the provincial Ministry of Agriculture and Lands (MAL) began various ambitious reclamation works intended to intercept, collect and treat metals discharging to the environment. As part of the reclamation works, a monitoring program was initiated to monitor changes in water quality and shoreline ecology as the reclamation program advanced. The monitoring program is structured to measure and report on changes as the reclamation project develops. The data generated will be used to define and support an eventual ecological risk assessment. The monitoring program structure and ongoing implementation is guided by an external Technical Advisory Committee (TAC) comprised of local stakeholders, agency staff, and mining industry technical experts.

INTRODUCTION

Mine History

The former Britannia Mine (45 km north of Vancouver, adjacent to Howe Sound) operated primarily as a copper and zinc mine from the early 1900s to 1974. During its operational life, the mine generated over 40 million tonnes of tailings, largely deposited onto the marine, subtidal slope of Howe Sound within 3 km of Britannia Beach. Mining operations have also led to generation of acid rock drainage (ARD), which was historically released from two point discharges (2200 level and 4100 level portals) into Britannia Creek, as well as the release of other non-point sources of contaminated surface water. Soil contamination, in combination with non-point source ARD, has also resulted in elevated concentrations of metals in groundwater, which in the alluvial fan area of Britannia Creek (Fan Area) subsequently discharge to Howe Sound's intertidal zone. In December 2001, a concrete plug was installed by the University of British Columbia in the 2200 Level adit that prevented discharge of ARD from that location into Britannia Creek, diverting the flow back into the mine such that it reports to the 4100 Level.

The primary contaminants of concern have been identified as copper and zinc, and to a lesser extent, cadmium (Golder 2003). Other metals and metalloids, including antimony, arsenic, barium, chromium, lead, molybdenum, nickel, selenium, silver and tin have also been identified as site contaminants, although the magnitude of contamination from these other substances is considerably less than for copper and zinc. The mine is the single largest source of dissolved metals entering Howe Sound and is subject to the requirements of B.C. Ministry of Environment effluent discharge Permit PE-17469, issued December 17, 2004, as well as requirements existing through the general provisions federal and provincial statute. The Province of British Columbia assumed responsibility for remediation of the Britannia Mine in June 2001. Since then, significant site characterization and remedial activities have occurred or are planned.

Remediation Activities

A program of remedial actions was initiated at the Britannia Mine site in late 2003 through to present day. The most significant remediation activities with the potential to improve water quality in the Britannia Beach area have been the following:

- Construction and operation of a groundwater management (GMS) system to intercept metal-contaminated fresh groundwater within the southern portion of the alluvial fan of Britannia Creek Fan Area (Fan Area) before it discharges into the intertidal zone in the Britannia Beach area. The GMS was completed in late May 2005 and has run continuously since April 2006. Its objective is to reduce the flux of contaminants to the marine environment but not necessarily to reduce the chemical concentration of nearshore groundwater;

- Construction and operation of a water treatment plant (WTP) to treat the metal-contaminated ARD discharge from the mine and the metal contaminated groundwater pumped from the GMS. Previously, the ARD was discharged untreated to Howe Sound through an outfall at a depth of minus 26 m. The WTP commenced 24-hour operation in late October 2005, and initially discharged via the existing outfall adjacent to the mouth of Britannia Creek;

- Installation of a new deep-water outfall for the WTP effluent discharge, located 1 km south of Britannia Beach. The WTP effluent was diverted to this new outfall as of late November 2005.

The environmental monitoring program is an integrated part of the overall reclamation project, which is comprised of a number of inter-related risk management actions designed to bring about improvements in the aquatic habitat quality. The monitoring program was designed at the outset to measure ecological changes as a result of engineered solutions and provide feedback to the risk and site managers on environmental outcomes. Throughout the duration of the monitoring program, ongoing dialogue has been maintained with regulatory agencies and with the reclamation project Technical Advisory Committee (TAC). In this respect it has proven to be a useful tool to assist the owner and regulators in determining relative priorities of site remediation works.

OVERVIEW OF THE MARINE ECOLOGICAL MONITORING PROGRAM

A three-year environmental effects monitoring program was initiated in 2005 following a preliminary investigation in 2003 (EVS/Envirowest 2003) to establish baseline conditions in the marine receiving environment. The specific objectives of the marine/intertidal ecological monitoring program are to:

1. Identify and track changes within the ecological structure and overall “health” of the intertidal zone (i.e., conduct an analysis of trends) for the three year duration of the project.

2. Assess the relationships between potential sources of contaminants (e.g., Britannia Creek, groundwater, mine discharges) on observed effects to the intertidal community.

3. Utilize the results and data characteristics to inform the design of a long-term monitoring program to assess the possible benefits of remedial activities to intertidal ecology and the need for and form of additional remediation.

The methods for the monitoring program are summarized below and detailed in Golder (2006, 2007).

Station Locations and Monitoring Frequency

Sampling locations (reaches) were selected based on physical characteristics such as intertidal substrate (to reduce as much variability between sites as possible) and to address multiple discharge points (e.g., groundwater and creek water) along Britannia Beach. The reference stations (Furry and Magnesia creeks) were also selected based on the proximity to a creek estuary for similarity of condition to the Britannia Beach area. Sampling reach locations are shown in Figure 1.

Monitoring Components

Surface Water Chemistry – Surface water samples were collected from near-shore intertidal and subtidal locations during high tide. Two samples were collected at the surface (0.5-1.0 m below the water’s surface) and at depth (0.5 m above the bottom).

Intertidal Porewater Chemistry and Toxicity – Porewater was collected from drive-point piezometers installed in the low intertidal zone, and analyzed for chemistry and toxicity.

Intertidal Community Composition – The community composition component involved an assessment of the diversity and abundance of algae and sessile invertebrates in the intertidal zone, involving three transects oriented perpendicular to the shoreline, each with three 1 x 1 m quadrats (located at low, mid and high intertidal levels). Non-destructive survey methods were used to determine the percent cover of algal taxa and sessile invertebrates in each of the quadrats.

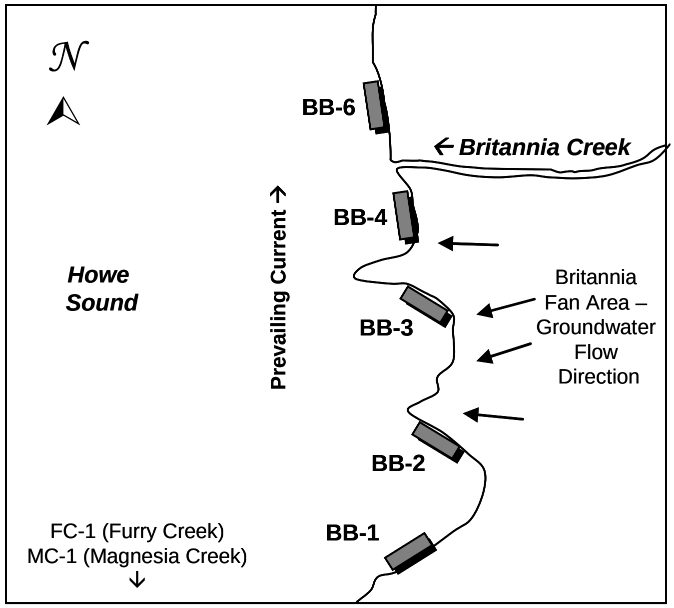

Figure 1: Reach locations for marine water sampling and intertidal community assessment

Caged Bivalve Study – A representative mussel species, *Mytilus edulis*, was used to characterize metals accumulation and survival of resident intertidal organisms. The caged mussels were deployed on the substrate at the intertidal elevation in which native mussels are normally distributed, which was a modification to the methodology for previous studies at the site, in which caged bivalves were suspended in the littoral zone water column (Grout and Levings, 2001). The study was conducted once, in the fall of 2005.

The monitoring program includes three sampling events per year based on seasonal variability in the hydrological regime (e.g., periods of large volumes of runoff) of Britannia Creek and other nearby freshwater sources to Howe Sound. The life histories and biological performance of species and communities measured in the monitoring program are linked to seasonal variations in suspended sediment concentrations and the freshwater influences within nearshore environments. Accordingly, biological sampling has been linked to the major changes in site hydrology, rather than strict adherence to specific sampling dates, as follows:

Summer - the latter stages of the freshets associated with the Squamish and Stawamus Rivers, and the influx of suspended sediments and freshwater within the Britannia Creek and near-field shorelines associated with these freshets.

Fall - a post-freshet period during which time suspended sediment concentrations and freshwater discharge from the Squamish River, Stawamus River and Britannia Creek are typically at seasonal lows.

Spring - a pre-freshet period during which time suspended sediment concentrations and freshwater discharge are intermediate between freshet and post-freshet periods.

Overview of the Results of Years 1 and 2

Surface Water Chemistry - Surface water metal concentrations were generally highest at Britannia Beach reaches BB-2 and BB-3, particularly total copper relative to provincial ambient water quality guidelines (WQG) for the protection of marine aquatic life (BCMWLAP 2006a, 2006). Reach BB-6 also had some of the highest metals concentrations measured (in particular subtidal bottom water) and WQG were exceeded at the reference reaches near Furry and Magnesia creeks. Seasonally, the highest metals concentrations and greatest number of WQG exceedences occurred during the Spring sampling event compared to Summer and Fall. Surface water copper concentrations at the Britannia reaches were generally lower and fewer WQG exceedences occurred in 2006 compared to 2005 (Figure 2). Bottom water copper concentrations in particular appear to have decreased and are now at or lower than WQG.

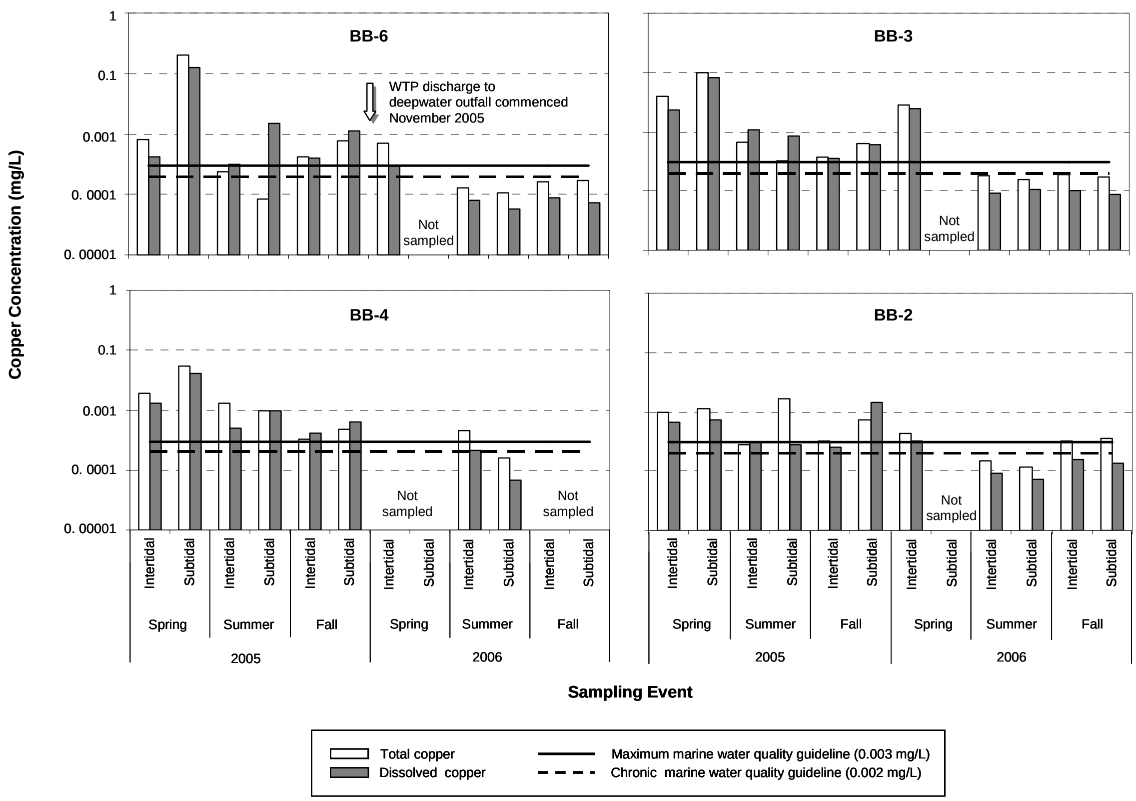

Figure 2: Copper concentrations in intertidal and subtidal bottom waters in the Britannia Fan Area

Intertidal Porewater Chemistry and Toxicity - Total copper concentrations in intertidal porewater exceeded the chronic and maximum WQGs at all sampling reaches, including the reference reaches at Furry and Magnesia creeks. However, the highest concentrations were observed at reaches BB-3 and BB-2 and copper was primarily in dissolved form (Figure 3). In the Britannia Beach area porewater quality may be influenced by groundwater from adjacent upland areas and/or leaching from local sources (e.g., mine tailings forming the underlying beach sediments). Temporal trends in intertidal porewater chemistry were not discernable.

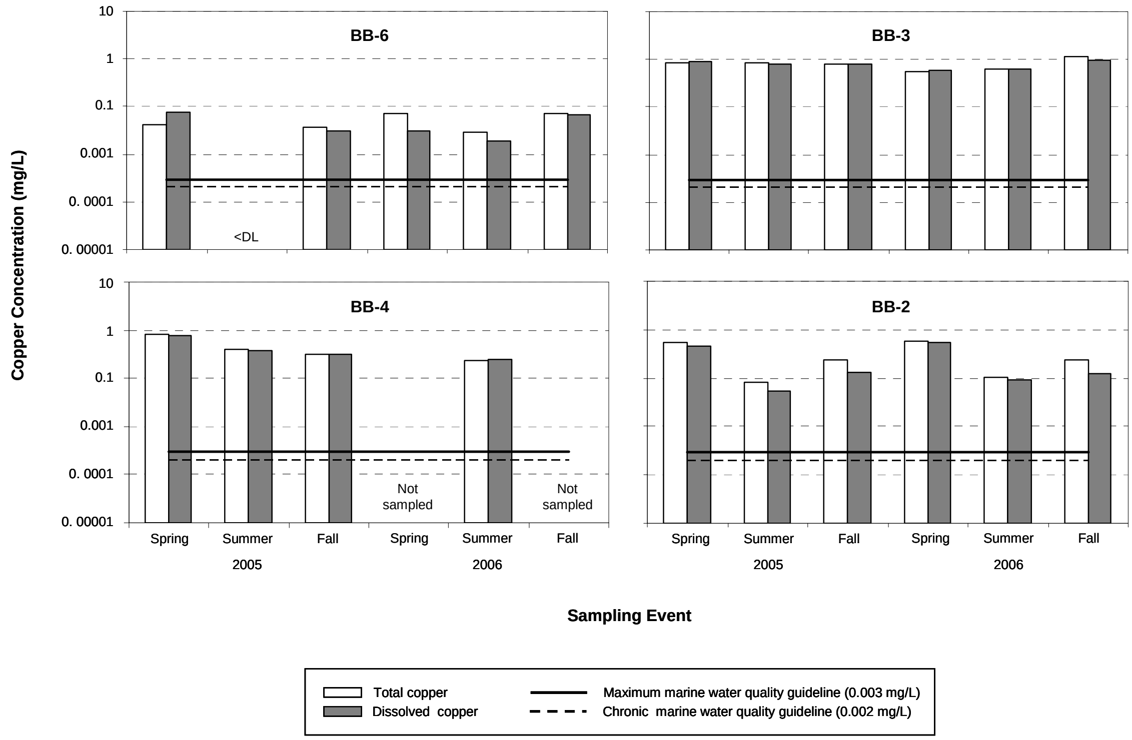

Figure 3: Copper concentrations in porewater of Britannia Fan Area reaches

The porewater from reaches BB-4, BB-3 and BB-2 was found to be toxic to one or more endpoint in a 48-h bivalve (*Mytilus galloprovincialis*) larval development test (USEPA 1995) in both 2005 and 2006. Porewater from BB-3 affected both larval survival and development, whereas only larval development was affected by water from the other two reaches (Figure 4).

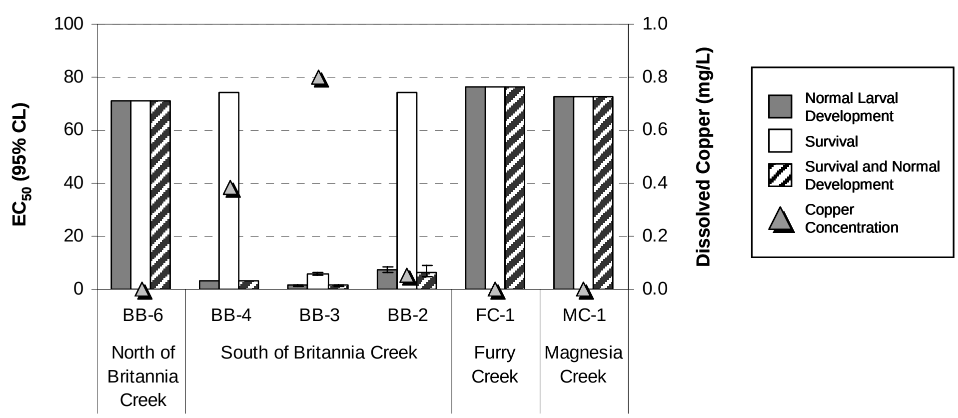

Figure 4: Summary of EC_{50} values for *Mytilus galloprovincialis* larval development in intertidal porewater and synoptic dissolved copper concentrations for July 2005

Intertidal Community Structure - The intertidal macrophyte and sessile invertebrate community of the Britannia Beach foreshore has lower diversity and cover by various organisms than the reference sampling locations in Howe Sound at Furry Creek and Magnesia Creek. An absence of or poor representation by various species was noted at reaches BB-2, BB-3 and BB-4, where elevated porewater metals concentrations were recorded. Reach BB-3 tended to have the lowest species richness, and macrophyte (i.e., algae) coverage was dominated by *Cladophora* sp. compared to the other reaches assessed during this study (Figure 5). This reach also showed the greatest toxicity (*M. galloprovincialis*) and porewater copper concentrations of all the reaches.

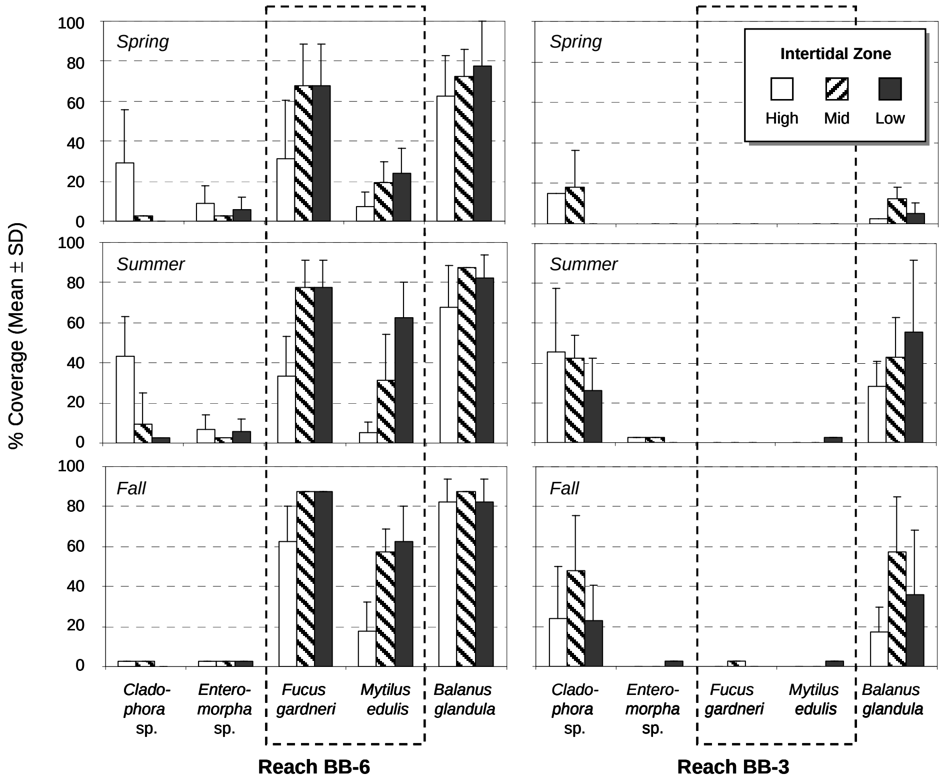

Figure 5: Comparison of Intertidal Community Structure Between Britannia Beach Reaches BB-6 and BB-3 (2006).

Between 2004 and 2006, there did not appear to be any considerable change in the mean percent cover of select macrophytes and sessile invertebrates at Britannia Beach reach BB-2, Furry Creek reach FC-1, or Magnesia Creek reach MC-1, except for the appearance of *Cladophora* sp. at reach MC-1 in 2006. There may have been a slight improvement at Britannia Beach reach BB-3, with the appearance of rockweed (*F. gardneri*) and *M. edulis*, albeit in lower abundance than seen at reference stations, in 2006 (neither were observed at reach BB-3 in 2004 or 2005). As well, mean percent cover of barnacles at BB-3 and BB-4 increased between 2005 and 2006, and mean percent cover of *F. gardneri* and *M. edulis* increased at BB-6 between 2005 and 2006. The period of observation is limited, however, and caution should be exercised in making inferences about the direction of change.

Caged Bivalve Survival/Growth and Metals Accumulation – Survival of the caged mussels was not significantly different between reference and exposed sampling reaches, while growth was affected at Britannia Beach reaches BB-4 (relatively small increase in weight) and BB-3 (decrease in weight) (Figure 6). Mussels from BB-6 contained relatively low concentrations of copper despite their proximity to the outlet of Britannia Creek. In comparison, mussels from BB-3 and BB-4, south of Britannia Creek, had relatively high copper concentrations. The spatial patterns in growth and metals accumulation in the caged mussels was consistent with the degree of colonization by *M. edulis* in the intertidal zone, and with the observed laboratory toxicity of porewater to *M. galloprovincialis*, a related species.

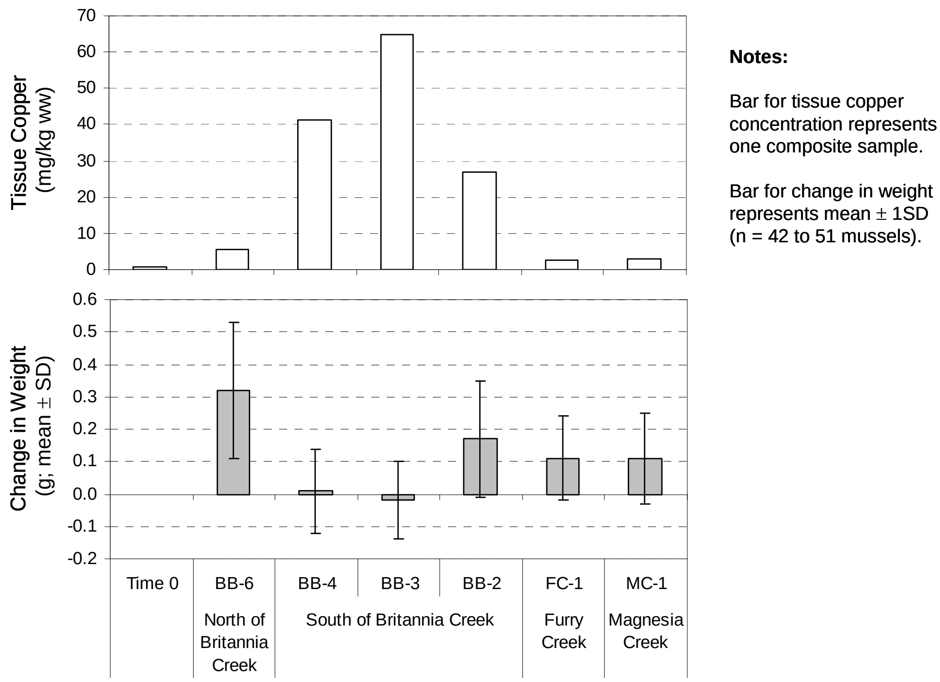

Figure 6: Comparison of mussel growth (as weight) and copper accumulation between sampling reaches (Fall 2005)

INTEGRATING THE RESULTS WITH RECLAMATION ACTIVITIES

The data collected to date suggest that near-bottom water quality near Britannia Beach, in particular at reach BB-6, may be improving (Figure 2). These observations, while preliminary as they are based on the short term, coincide with the construction and commissioning of the WTP and the associated interception and removal of dissolved metals from the effluent, most notably copper and zinc. Prior to 2005, untreated mine water discharged to Howe Sound via an outfall at 26 m depth at the mouth of Britannia Creek. Given the prevailing water currents along Britannia Beach from south to north, it is possible that the effluent plume was dispersing in the vicinity of BB-6 and resulting in the measured elevated copper concentrations. Since the commissioning of the WTP both intertidal and subtidal bottom water copper concentrations have decreased and remained at or below WQG throughout the summer and fall of 2006. Another possible explanation for the observed decrease at other reaches such as BB-2 and BB-3 could be a reduction in groundwater movement and discharge at the shoreline which would decrease if groundwater movement was retarded further by the GMS. However, the encouraging results at depth would suggest that larger scale loadings reductions may be a more plausible explanation. Additionally, notable improvements to the shoreline community, which would be expected with decreased groundwater movement have not been observed. These observations should not be viewed as conclusions because the data set is currently limited. In order to provide further insight into the reason for the continued high concentrations of copper in the intertidal zone, a specific study of the effluent plume (e.g., conducting a tracer test) and/or a specific study of the potential contaminant release from the local sub-shore sediments may be considered.

In comparison, intertidal porewater concentrations remained elevated through 2006 relative to WQG (Figure 3) and reference areas despite the commissioning of the GMS, suggesting that reactive waste at the shoreline may be contributing to the lower diversity and coverage in the local marine community than at the reference locations. This concept is further supported by changes in groundwater chemistry at a monitoring well in the upland adjacent to reach BB-2 (Figure 7) and the lack of improvement in porewater chemistry (Figure 3). After the GMS became fully operational in August 2005, dissolved copper concentrations increased and continued to remain elevated relative to levels measured in 2005 before installation of the GMS was completed. The findings of the monitoring program suggest that the hydrogeological and hydrogeochemical conditions of materials underlying the nearshore and intertidal area around BB-2 need to be evaluated further to determine potential additional remediation activities at the site.

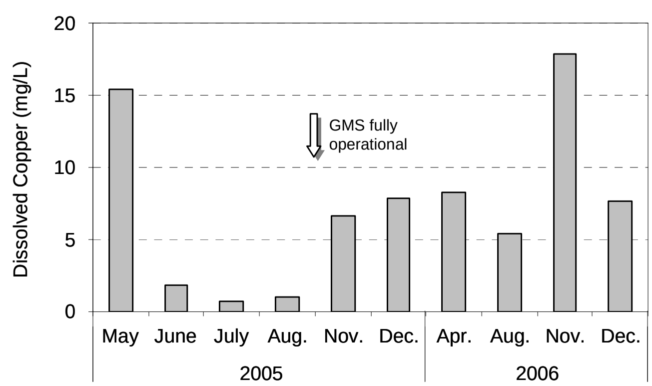

Figure 7: Temporal variation in groundwater copper concentrations at a monitoring well near reach BB-2

Finally, the results of Years 1 and 2 of the environmental monitoring program suggest that ecological risk assessment, another remediation activity planned for the site, is premature as some contaminant sources/release mechanisms, as discussed above, are presently unclear. The monitoring program is being modified for Year 3 to accommodate the additional information needs for the reclamation project.

SUMMARY

Monitoring of water quality and associated experimental (i.e., laboratory toxicity testing) and field (i.e., *in situ* caged bivalve study and intertidal community structure) effects along Britannia Beach during 2005 and 2006 have provided preliminary information regarding the relationship between remediation activities at the Britannia Mine and changes in the receiving environment. The short term data suggest that the commissioning of the WTP and discharge through a new outfall to the south may be resulting in improvements in intertidal and subtidal water quality. In comparison, intertidal porewater quality and community structure have not yet improved in relation to the commissioning of the GMS. Rather, the results suggest that additional investigation into local sources of reactive material underlying nearshore and intertidal areas is warranted. These findings are presently being considered by MAL as part of refinements and investigations related to the GMS.

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